Is dS space in the Swampland?

Thomas Van Riet -- KULeuven

String Pheno, Warsaw, Poland 2018.
Mainly based on

• *What if string theory has no dS vacua?* with Ulf Danielsson [1804.01120]

• *Racing through the swampland: de Sitter uplift vs Weak Gravity* with Jakob Moritz, [1805.00944]

• *Supersymmetric dS/CFT*, with T. Hertog, G. T.-Mazzucchelli, G. Venken [1709.06024]

• *Observations on fluxes near antibranes*, with C.-Maldonado, Diaz, Vercnocke [1507.01022]
∧ from strings: general ideas
De Sitter from string theory?

- UV completeness of string theory implies we know in principle how to compute vacuum energy, no cut off needed. But how?

Curvature gives 4D cc

\[ ds_{10}^2 = ds_4^2 + ds_6^2 \]

Metric on compact space. Finite size.
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Metric on compact space. Finite size.

String theory reduces to classical 10D SUGRA if

1) \( g_s \) is small (\( g_s \ll 1 \)):

2) All field gradients are small with respect to \( 1/l_s \) to control higher derivative expansion. OK, if “curvature is small enough \( \rightarrow \) volumes are large enough”.
Then the computed result is the full result (up to small corrections.) Nice virtue of string theory. We can compute vacuum energies in certain corners of the theory!
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What happened to the QFT lore?

- Naturalness? The expectation that the “typical” cc is of order cut-off was perhaps correct. The “typical” flux solution obeys:

\[
\frac{m_\Lambda}{m_{KK}} = \mathcal{O}(1)
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So the failure of the solution to look genuinely 4D is the same as not having a cc hierarchy.
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- Standard Model loop corrections get ‘geometrized’. Example: add standard model from intersecting branes.
∧ from strings: results thus far
How to classify?

STRINGY de Sitter

Non-critical

critical

Non-geometric

Geometric

10D-tree level

With quantum corrections

SUSY-breaking below KK scale (4D SUGRA!)

SUSY-breaking above KK scale (?)

References: half of this audience. See my review with Danielsson.
First ideas for this in [Hertzberg, Kachru, Taylor, Tegmark, 0711.2512, Silverstein 0712. 1196]
• In fact moduli-stabilization at tree-level works the best of all (in AdS vacua)!

→ Ingredients: 4 intersecting O6 planes in massive IIA on SU3 structure

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• Are these counterexamples to the Swampland constraint of [arXiv:1806.08362, Obied, Ooguri, Spodyneiko, Vafa] ? (see talks David Andriot and Timm Wrase)

\[
|\nabla V| \geq c \cdot V
\]
90% of all papers on dS "corrections to GKP" [Most people in the audience and their friends]


Not many papers? Is there more than [Acharya, Kane et al.]? Stable dS seems ok, but unclear how top down the results are. Is there more? Heterotic M-theory? [Lukas, Gray, Ovrut 2007]

Not a single stable dS? [Parameswaran, Ramos-Sanchez, Zavalla (2010)] However see, [de Alwis, Cicoli, Westphal, 2013].
Let us take the prime example: KKLT

90% of all papers on dS "corrections to GKP" [Most people in the audience and their friends]
Problem 1: The approach to moduli stabilisation. [S. Sethi arXiv:1709.03554]

SUSY-breaking GKP fluxes have higher derivative forces which cannot be ignored and lead to runaway instead.

Figure 1: A good starting point. Figure 2: A not so good starting point.
Problem 2: 6D backreaction of antibranes

(Bena, Blaback, Grana, Giecold, Puhm, Orsi, Massai, Kuperstein, Zagermann, Junghans, Wrase, Danielsson, Gautason, Vercnocke, Diaz, Truijen, Cohen-Maldonado, Hashimoto, Cottrell, VR, Vargas, Halmagyi, Kutasov, Wisanji, McGuirk, Massai, Shiu, Sumitomo, Galante, Buchel, Hartnett, Dymarsky, Polchinski, Saad, Mintun, Michel)

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• So it could have been a red herring. However, brane repelling tachyons [Bena, Grana, Kuperstein, Massai 1402.2294, 1410.7776, Bena, Kuperstein 1504.00656, Bena, Blaback, Turton 1602.05959]. See also [Danielsson, 1502.01234]

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Problem 3: 4D backreaction of antibranes  [Moritz, Retolaza, Westphal 1707.08678]

When KKLT uplifting is studied from a 10D point of view, we find AdS at best!
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When KKLT uplifting is studied from a 10D point of view, we find AdS at best!

\[ S_{D7} \supset \int_{\mathcal{M}_{10}} \delta_D^{(0)} e^{\phi/2} e^{-4A} \frac{\bar{\lambda} \lambda}{16\pi^2} G_3 \wedge *_{10} \Omega + c.c. , \]

• Before uplift:

\[ \nabla^2 \Phi^- = R_4 + e^{-6A} |d\Phi^-|^2 + \frac{e^{2A}}{\text{Im}(\tau)} |G_3^-|^2 + \Delta_{\text{gaugino}} \]

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- After uplift: extra term on RHS

\[ e^{4A} \left( T^{\mu}_\mu - T^m_m \right) \]
Same sign as other terms!


\[ W = W_0 + A \exp(iaT) + B \exp(ibT) \]


\[ W = W_0 + A \exp(i\alpha T) + B \exp(i\beta T) \]

Reason is that racetrack finetuning, brings SUSY vacuum very close to Minkowski while maintaining finite Kahler masses.

\[
\begin{align*}
a &= \frac{2\pi}{N_1}, & b &= \frac{2\pi}{N_2} \\
N_1 &= N_2 + 1 \sim N \gg 1
\end{align*}
\]
But exactly that limit makes the axionic partner of the volume modulus have parametrically large decay constant! [Moritz, VR, 1805.0944]

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If you ask me, string theory is trying to tell us something simple
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If you ask me, string theory is trying to tell us something simple.
• For more reasons and an overview see:

“What if string theory has no dS vacua?” with Ulf Danielsson 1804.01120

• For similar lines of thought see [Obied, Ooguri, Spodyneiko, Vafa, 1806.09621]
dS / CFT ?
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→ Ooguri-Vafa: non-SUSY AdS/non-SUSY CFT duality cannot be. dS cannot be SUSY. So no dS/CFT.
**Why not supersymmetric (and hence stable?) dS?**

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• Examples exist! 10d IIA*/B* theories [Hull hep-th/9806146]. But always with ghosts (flipped sign of RR kinetic terms).

• SUSY can never be global for normal susy algebras [Witten hep-th/0106109]: dS space has no globally conserved charge that is positive everywhere. Assume a conserved Q exists:

\[ i(Q - Q^\dagger) \quad \text{or} \quad Q + Q^\dagger \]

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• However, maybe makes sense in some unconventional way [Hull 1998, Dijkgraaf, Heidenreich, Jefferson, Vafa, 1603.05665]
Other reasons dS/CFT is tough:

• Wickrotating AdS→dS typically inconsistent.

• No simple string theory background. (Not any?)

• Complex operator dimensions: \[ \Delta_{\pm} = \frac{3}{2} \pm \sqrt{\frac{9}{4} - m^2 R^2} \]

• dS is at best meta-stable in string theory → decaying geometry has no CFT dual
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Vasiliev AdS / free O(N) model  \[\leftrightarrow\]  Vasiliev dS / free Sp(N) model

\[
I_{Sp(N)}^{free} = \frac{1}{8\pi} \int d^3 x \Omega_{ab} \delta^{ij} \partial_i X^a \partial_j X^b, \quad \Omega_{ab} = \begin{pmatrix} 0 & 1_N \times N_2 \\ -1_{N_2} \times N_2 & 0 \end{pmatrix}
\]
How does the correspondence work? [Maldacena, 2003]

\[
\Psi_{HH}[h_{ij}, A_s] = Z_{QFT}[\tilde{h}_{ij}, J_s] \exp(iS_{st}[h_{ij}, A_s]/\hbar)
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Spatial 3 metric  
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Sources conformally related to boundary metric and matter fields
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Spatial 3 metric  \quad Matter fields  \quad Sources conformally related to boundary metric and matter fields

If dS/CFT works in Vasiliev gravity then maybe dS is fully stable in Vasiliev gravity?

→ Indeed Swampland ideas typically do not apply to models with infinite amount of light fields.
Go to your room!

STRING THEORY

De Sitter

Vasilievs universe
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In fact it can be consistently supersymmetrised by adding spinor fields! [Hertog, M.-Tartaglino, Venken, VR 1709.06024]

SUSY Vasiliev AdS / free O(N) model \hspace{1cm} SUSY Vasiliev dS / free Sp(N) model

SUSY DE SITTER SOFAR STABLE!
• Higher spin theory (Vasiliev)? Supersymmetrisation done in [Sezgin, Sundell 1208.6019].

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No-boundary probability

Deformation by bulk field
How?

From Hull’s original paper in 98’:

However, the situation for the type $\text{II}^*$ theories might be similar. If the type $\text{II}^*$ string theories are truncated down to their supergravity limits, the supergravity theories have ghosts. However, in the full string theories, it is possible that the string gauge symmetries can be used to eliminate the ghosts. Indeed, the type $\text{II}^*$ theories are linked by T-duality to the type II theories which are ghost-free, at least perturbatively.
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→ The tensionless limit is exactly the trick to “integrate in “ all the string modes and be able to compute. We find no instabilities. Hull’s intuition was correct!?
Conclusions
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• Unconventional string theory (II*) has SUSY dS! We have given firm evidence for no ghosts in tensionless limit using a new dS/CFT dual. Good for pheno? Not sure. But why would we insist?
EXTRA SLIDES
Interesting paper [Dong, Horn, Silverstein, Torroba 1005.5403]. Example of classical stable dS in D=3??

Our construction requires ingredients which are collected in the following table:

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Just because I am strong enough to handle pain doesn't mean I deserve it.

Lessons Learned In Life
Worried?

From [Hertzberg, Kachru, Taylor, Tegmark, 0711.2512]

general NS-NS fluxes cannot in general be taken to the large volume limit. For example, fluxes of the $Q$ type involve a T-duality inverting the radius of a circle in a fiber when a circle in the base is traversed. Thus, somewhere the size of the fiber must be sub-string scale. This makes solutions of the naive 4-dimensional supergravity theory associated with flux compactifications such as those found in [60] subject to corrections from winding modes and also to uncontrolled string theoretic corrections if curvatures become large.

Important lesson:

• We can have lower-dimensional supergravities “derived” from string theory, where we know they are NOT the low-energy EFT.

• Maybe these SUGRAS are good to capture non-geometric BPS objects?  But existence of these $dS$ vacua is far from clear.

\[ M_{\text{ADM}} = \text{Vol}_4 \left( \alpha_H Q_3 + b_H Q_5 \text{Vol}_2 \right) \]

WITH NS5 BOUNDARY CONDITION CAN SINGULARITY BE AVOIDED!

→ Indeed impossible for smeared branes (that’s what caused the singularity).