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]

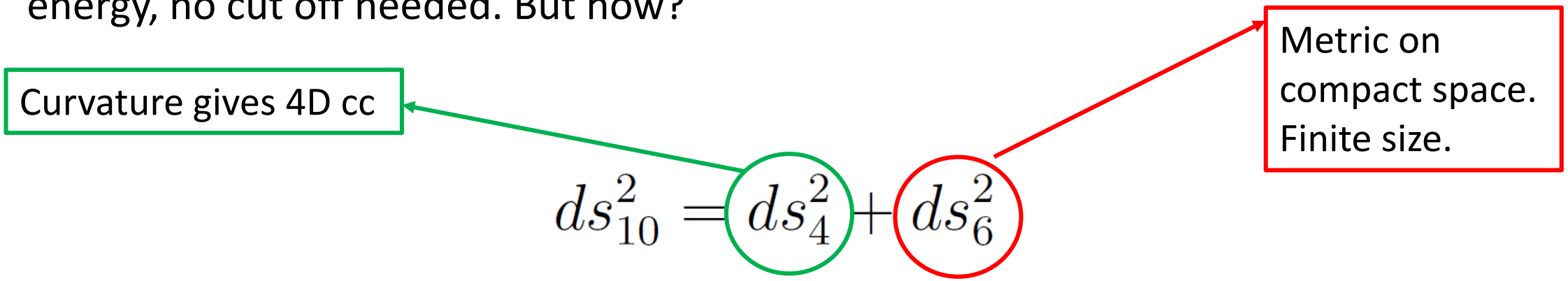
- *Supersymmetric dS/CFT,* with T. Hertog, G. T.-Mazzucchelli, G. Venken [1709.06024]

- *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?



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Curvature gives 4D cc

Metric on compact space. Finite size.

$$ds_{10}^2 = ds_4^2 + ds_6^2$$

String theory reduces to classical 10D SUGRA if

1) g_s is small ($g_s << 1$):

2) All field gradients are small with respect to $1/l_s$ to control higher derivative expansion. OK, if "curvature is small enough → 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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- 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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- Standard Model loop corrections get 'geometrized'. Example: add standard model from intersecting branes.

∧ from strings: results thus far

How to classify?

References: half of this audience.
See my review with Danielsson.

STRINGY de Sitter

Non-critical

critical

Non-geometric

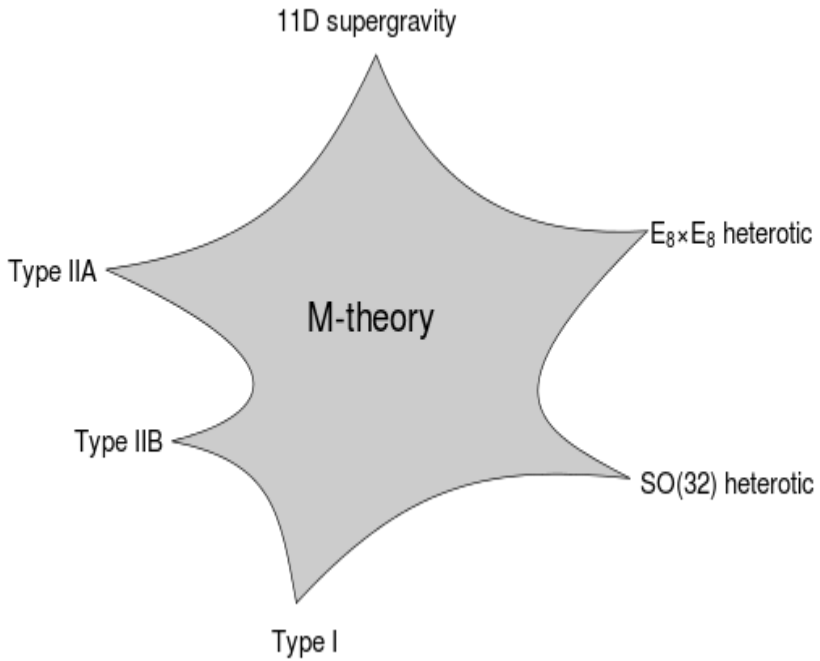
Geometric

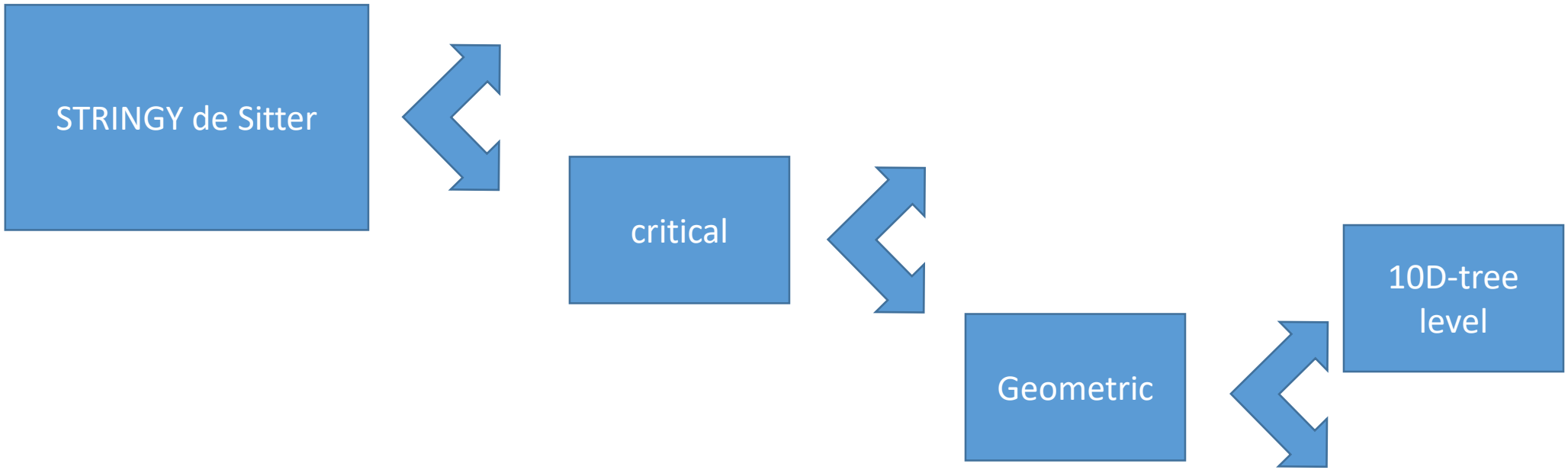
10D-tree level

With quantum corrections

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

SUSY-breaking above KK scale (?)





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

e^1	e^2	e^3	e^4	e^5	e^6
⊗	⊗	⊗	–	–	–
–	–	⊗	⊗	–	⊗
–	⊗	–	–	⊗	⊗
⊗	–	–	⊗	⊗	–

[deWolfe, Giryavets, Kachru, Taylor 2005].

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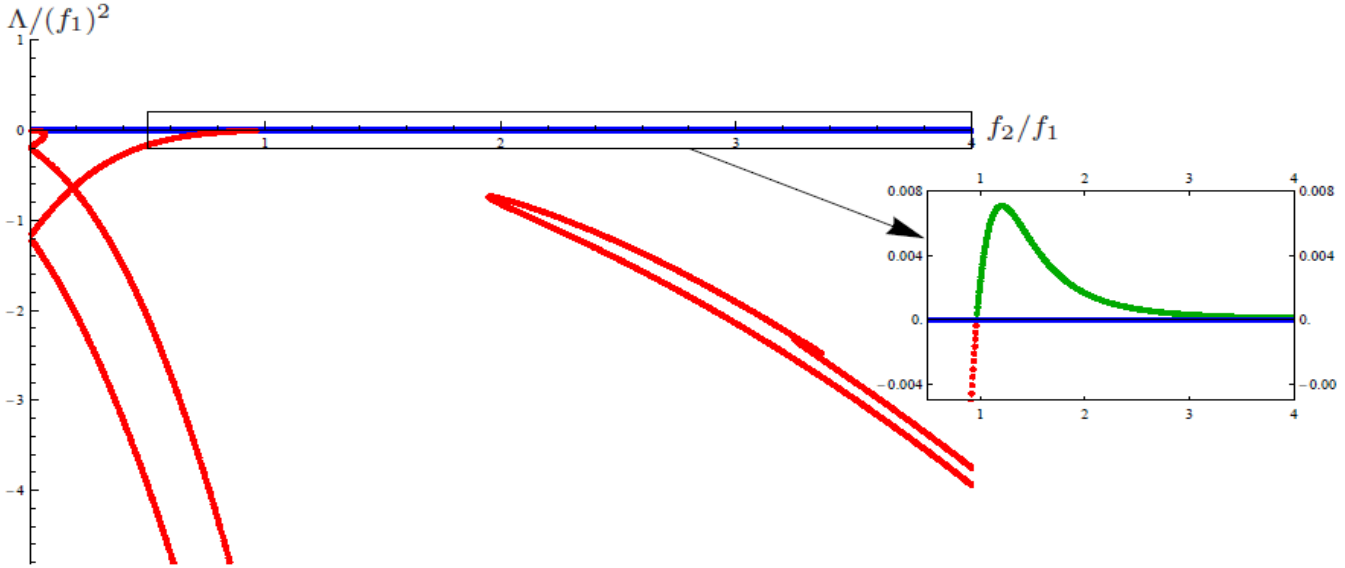
→ All **unstable**. Recent works: [Andriot, Blaback 2016 & Andriot, 2017 & Junghans 2016 & Junghans, Zagermann 2016] try to close the gap.

- Later from 10D perspective: [Danielsson, Haque, Shiu, VR, 0907.2041 Danielsson, Koerber, VR 1003.3590], again all **unstable AND rare**.



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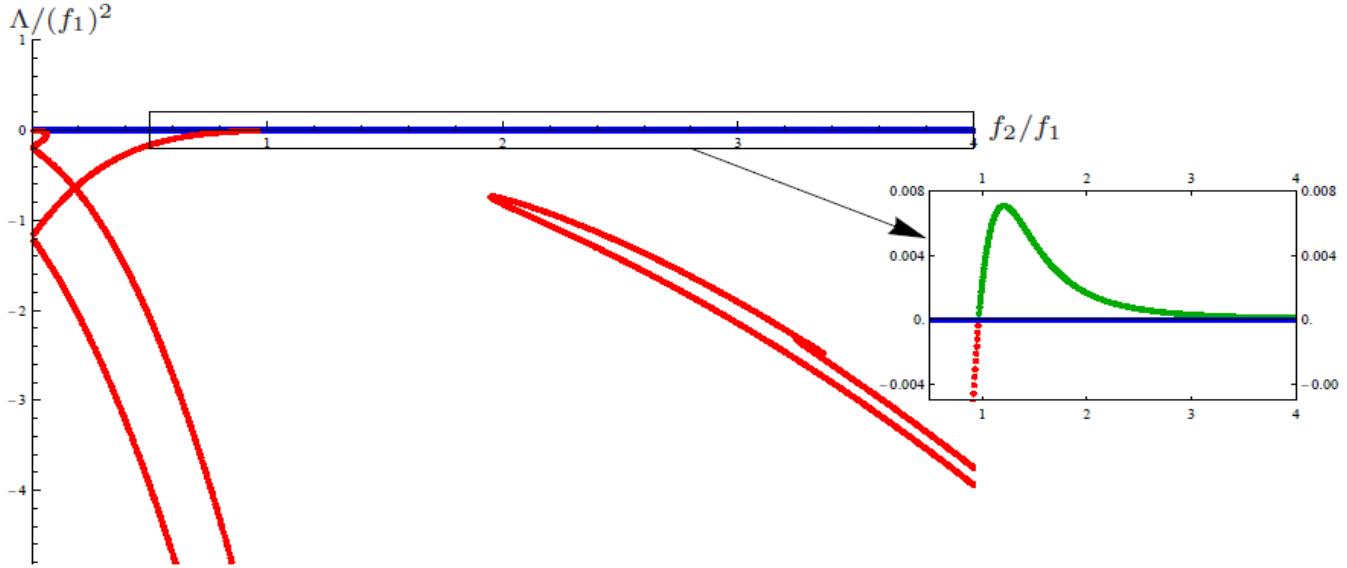

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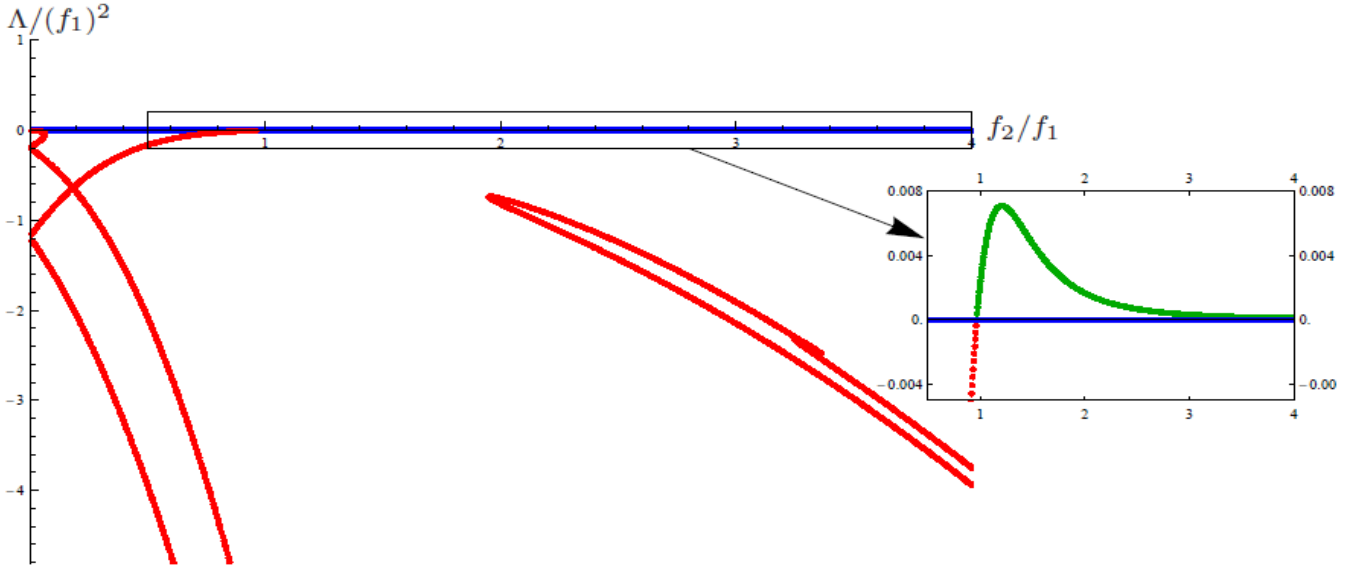

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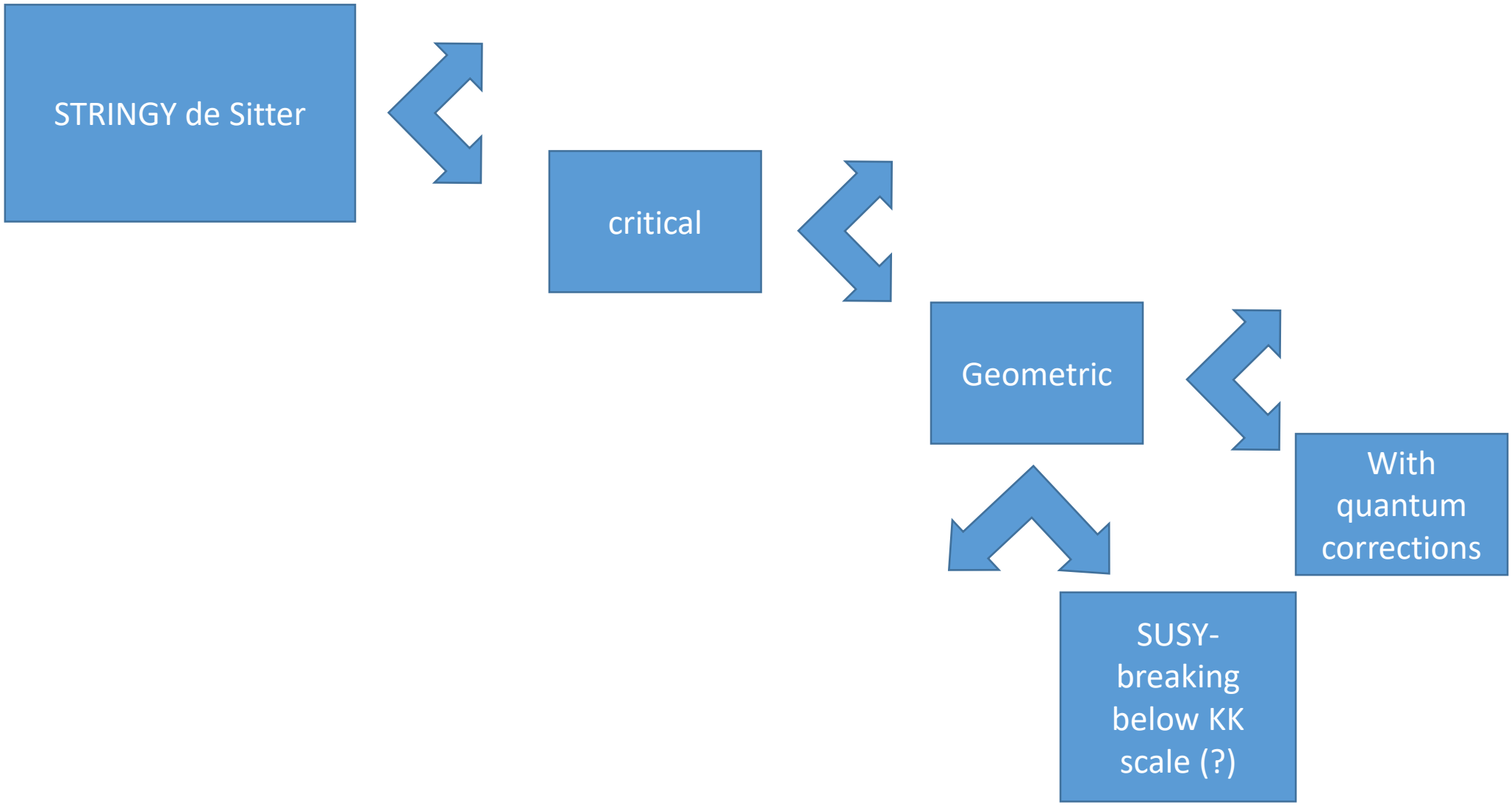
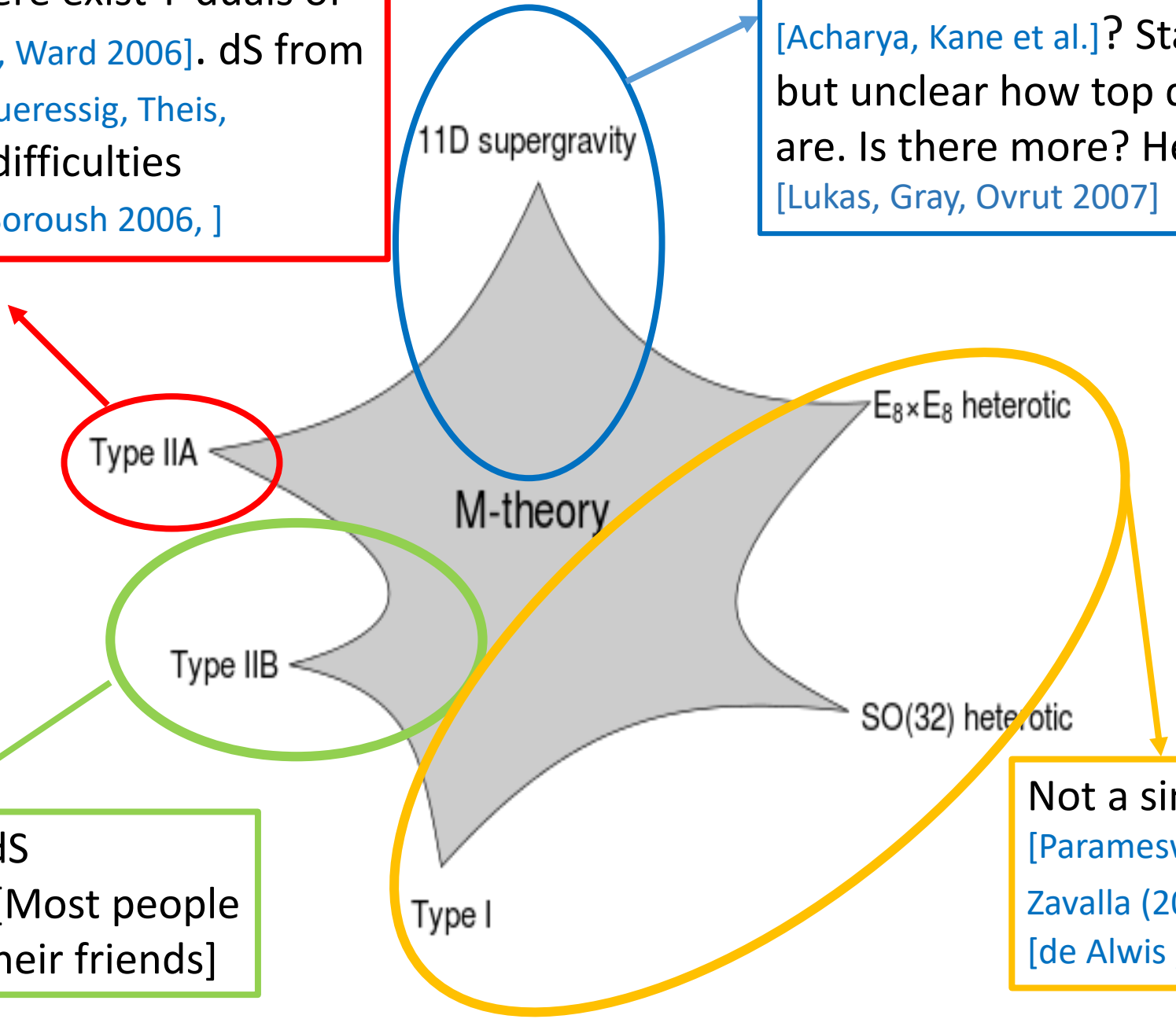
- *Are these counterexamples to the Swampland constraint of* [arXiv:1806.08362 ,Obied, Ooguri, Spodyneiko, Vafa] ? (see talks David Andriot and Timm Wrase)

$$|\nabla V| \geq c \cdot V$$


STRINGY de Sitter
critical
Geometric
With quantum corrections
SUSY-breaking below KK scale (?)

Not many papers? There exist T-duals of LVS-type: [Palti, Tasinato, Ward 2006]. dS from instantons: [Davidse, Saueressig, Theis, Vandoren, 2005] . Some difficulties addressed in [Kallosh&Soroush 2006,]

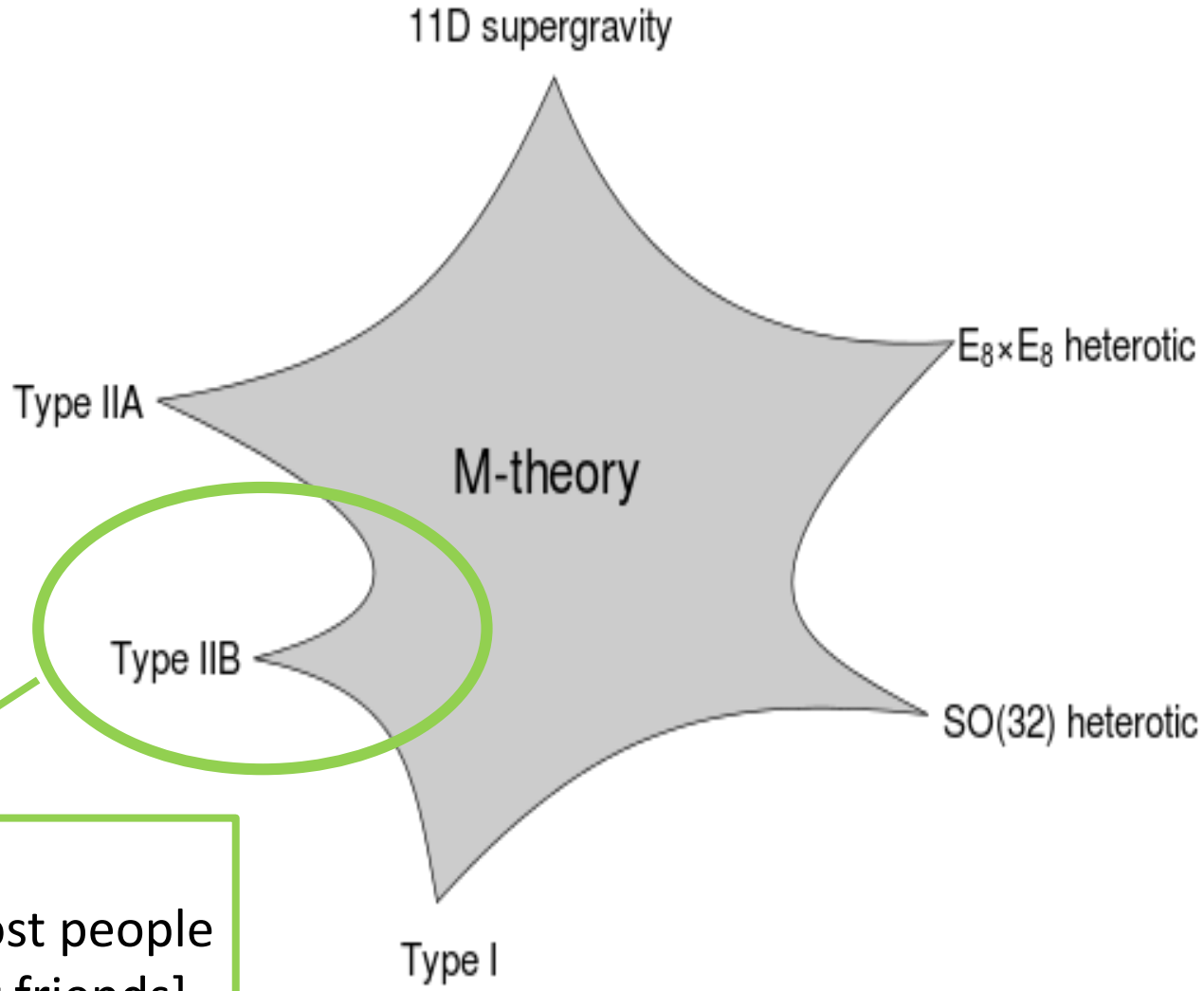
Not many papers? Is there more than [Acharya, Kane et al.]? Stable dS seems ok, but unclear how top down the results are. Is there more? Heterotic M-theory? [Lukas, Gray, Ovrut 2007]



90% of all papers on dS "corrections to GKP" [Most people in the audience and their friends]

Not a single stable dS? [Parameswaran, Ramos-Sanchez, Zavalla (2010)]However see, [de Alwis , Cicoli, Westphal, 2013].

Let us take the prime example: KKLT



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Problem 1: The approach to moduli stabilisation.

[S. Sethi arXiv:1709.03554]

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

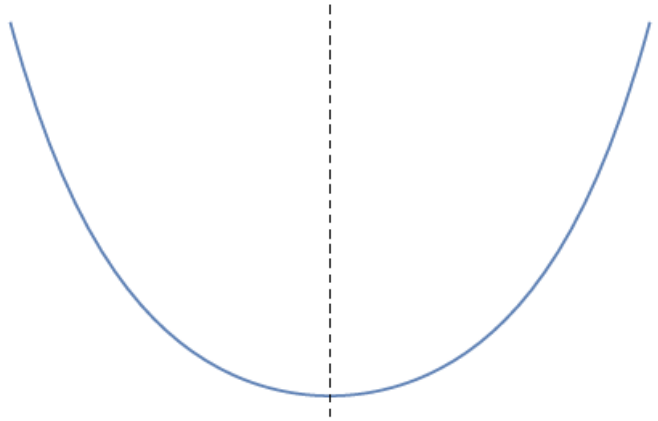

Figure 1: A good starting point.

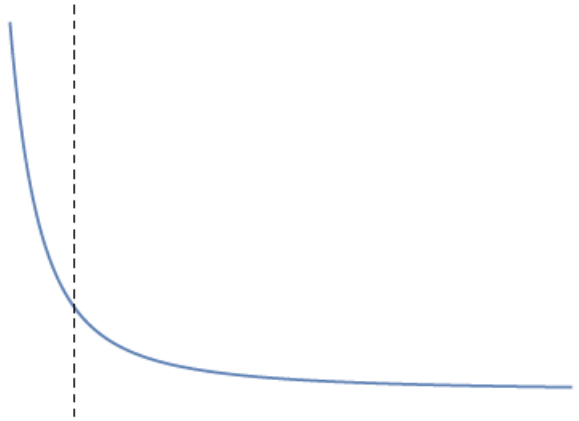

Figure 2: A not so good starting point.

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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$$e^{-\phi} H^2 \to \infty$$

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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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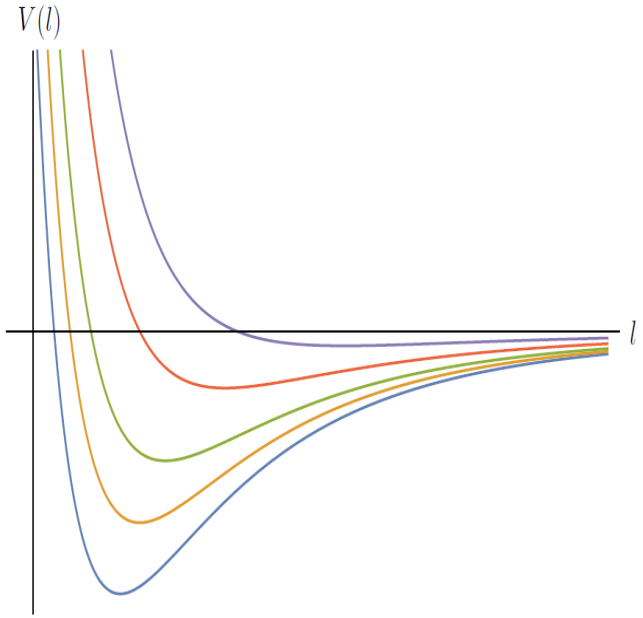

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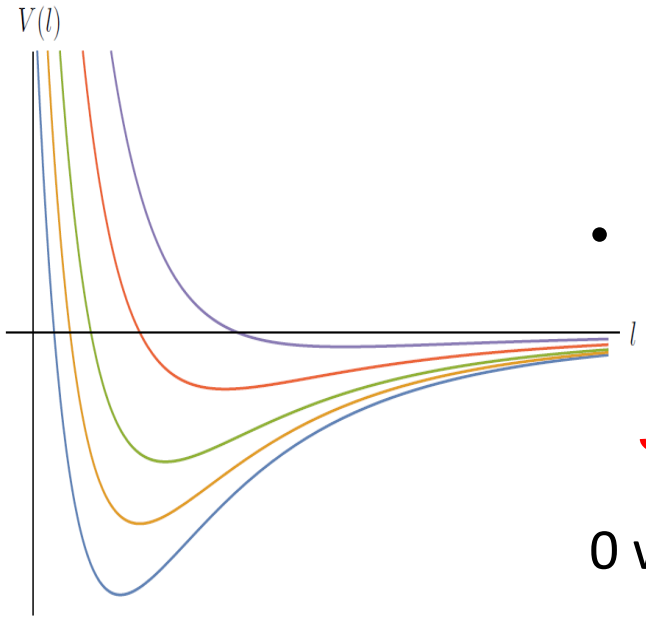

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[Baumann, Dymarsky, Kachru, Klebanov, McAllister, 2010]

- Before uplift:

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

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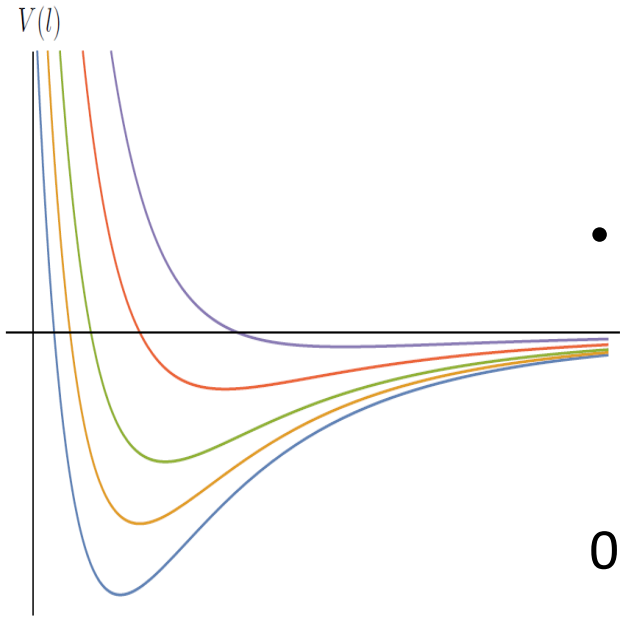

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- After uplift: extra term on RHS

$$e^{4A}(T_\mu^\mu - T_m^m)$$

Same sign as other terms !

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

$$a = \frac{2\pi}{N_1}\,, \quad b = \frac{2\pi}{N_2} \qquad \boxed{N_1 = N_2 + 1 \sim N >> 1}$$

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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The room

- 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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- 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: $\Delta_{\pm} = \frac{3}{2} \pm \sqrt{\frac{9}{4} - m^2 R^2}$
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[Anninos,Hartman, Strominger 2011]

Vasiliev AdS / free O(N) model ⟺ Vasiliev dS / free Sp(N) model

$$I^{free}_{Sp(N)} = \frac{1}{8\pi} \int d^3x \, \Omega_{ab} \delta^{ij} \partial_i \chi^a \partial_j \chi^b \, , \qquad \Omega_{ab} = \begin{pmatrix} 0 & 1_{\frac{N}{2} \times \frac{N}{2}} \\ -1_{\frac{N}{2} \times \frac{N}{2}} & 0 \end{pmatrix}$$

How does the correspondence work? [Maldacena, 2003]

$$\Psi_{HH}[h_{ij}, A_s] = Z_{QFT}[\tilde{h}_{ij}, J_s] \exp(\mathrm{i}S_{st}[h_{ij}, A_s]/\hbar)$$

Spatial 3 metric

Matter fields

Sources conformally related to boundary metric and matter fields

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

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 ⟺ 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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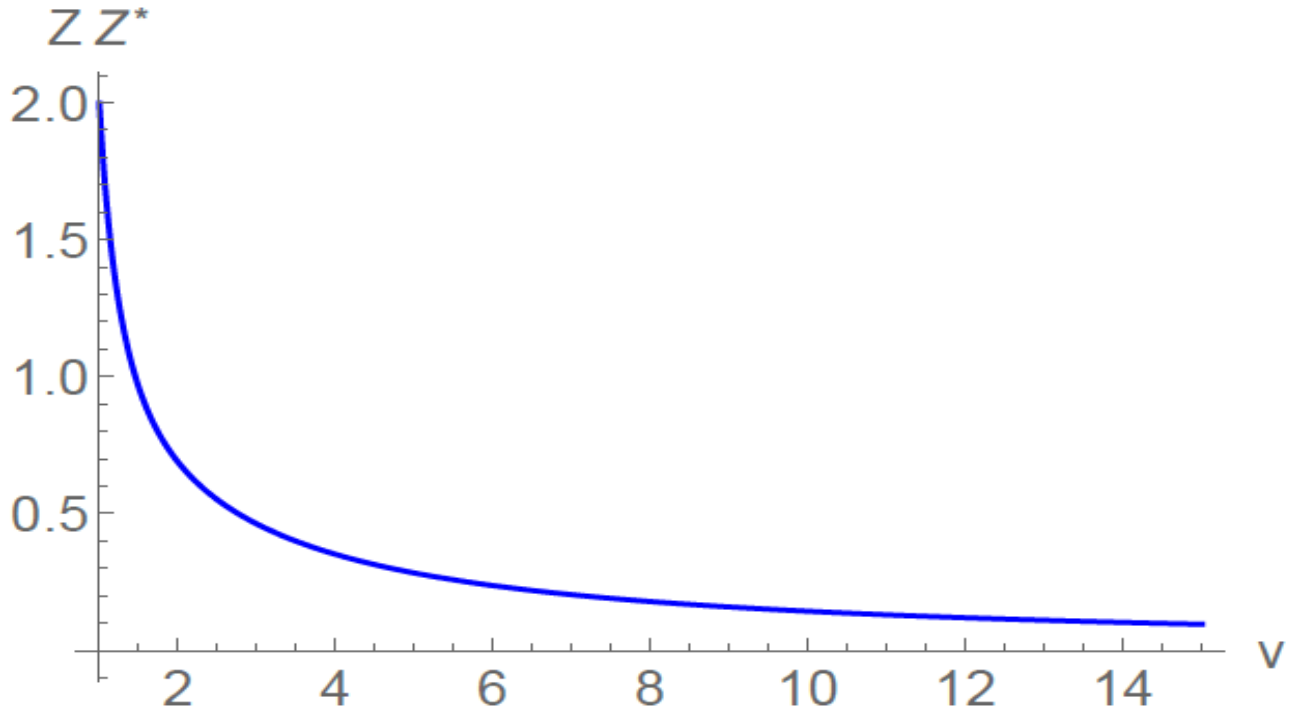
- Wickrotated holographic dual [Anninos, Hartman, Strominger 2011] seems fine, no signs of instability, ghosts [Hertog, Tartaglino-Mazzucchelli, VR, Venken, 2017]

No-boundary probability



Deformation by bulk field

How?

From Hull's original paper in 98':

> However, the situation for the type II^* theories might be similar. If the type 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 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:

	0	1	2	3	4	5	6	7	8	9
$D1$	x	x								
$D5$	x	x					x	x	x	x
$O5$	x	x		x	x				x	x
$O5'$	x	x	x			x	x	x		
$\rho 5$	x	x	x	x					x	x
$\rho 5'$	x	x			x	x	x	x		
NS5	x	x		x	x		x		x	
NS5′	x	x	x			x		x		x
$D7$, $\overline{D7}$	x	x	x	x	x	x		x	x	
$D7'$, $\overline{D7'}$	x	x	x	x	x	x	x			x

Worried?

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

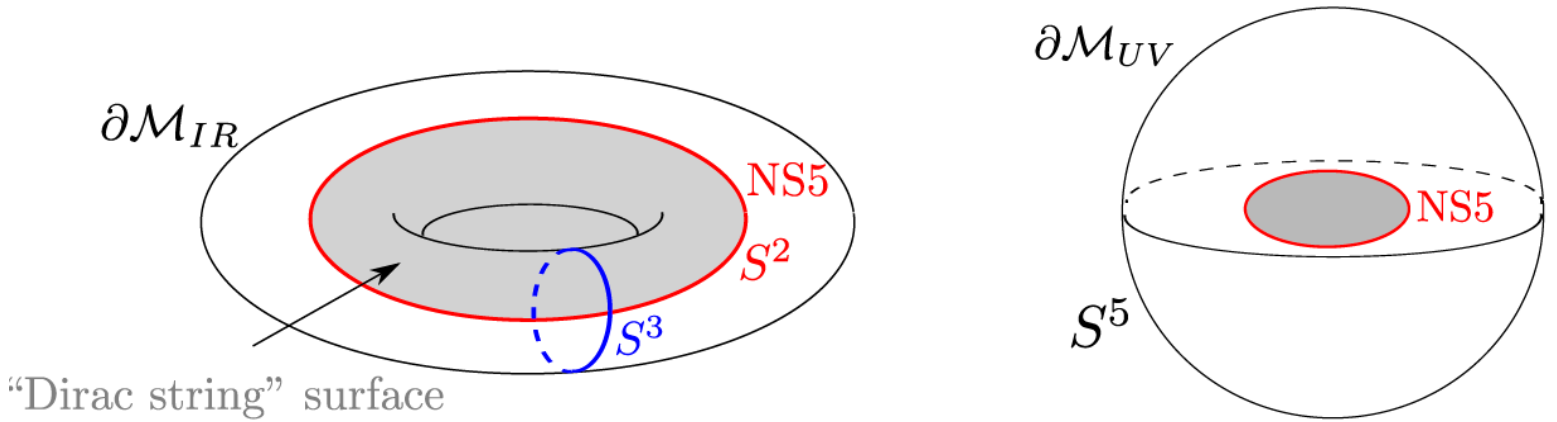
general NS-NS fluxes cannot in general be taken to the large volume limit. For example, fluxes of the Q type involve a T-duality inverting the radius of a circle in a fiber when a circle in the base is traversed. Thus, somewhere the size of the fiber must be sub-string scale. This makes solutions of 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.*

Smarr-like formula links UV to IR [Gautason, et al 2013; Blaback et al 2014; **C-Maldonado et al (2015, 2016)**]

$$M_{ADM} = \mathrm{Vol}_4\left(\alpha_H Q_3 + b_H Q_5 \mathrm{Vol}_2\right)$$



WITH NS5 BOUNDARY CONDITION CAN SINGULARITY BE AVOIDED!

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