Classical de Sitter string backgrounds and the swampland

David ANDRIOT

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Based on arXiv:1902.10093
arXiv:2004.00030 (with N. Cribiori, D. Erkinger)
arXiv:2005.12930, 2006.01848 (with P. Marconnet, T. Wrase)

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Introduction

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Various approaches, perturbative or not

S. Kachru, R. Kallosh, A. D. Linde, S. P. Trivedi [hep-th/0301240],

V. Balasubramanian, P. Berglund, J. P. Conlon, F. Quevedo [hep-th/0502058]

Here: focus on classical regime,
i.e. **classical de Sitter string backgrounds**.

D. A. [arXiv:1902.10093]

Classical de Sitter string backgrounds

Motivation: "simple" well-defined framework, good chances to control approximations.

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$$10\text{d} = \textbf{4d de Sitter} \times 6\text{d compact space } \mathcal{M}$$

+ fluxes + D_p-branes, orientifold O_p-planes
Equivalent 4d effective description with a scalar potential V
$\Rightarrow$ (classical) de Sitter solutions? **Well-posed question**.

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Cost to simplicity: not many ingredients at hand,
very constrained framework, many no-go theorems.
$\rightarrow$ very difficult to find such solutions, none is known up-to-date, but not excluded

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Conjectured answer: **no**, in asymptotic regime, e.g. classical...

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$\neq$ models that cannot be coupled consistenly to quantum gravity: part of the **swampland**
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Can one trust these swampland criteria/conjectures?
$\rightarrow$ Discuss, test, refine, prove them...
De Sitter: **test them** very accurately! Comparison to no-go theorems

Incomplete list of more recent references

F. Marchesano, D. Prieto, J. Quirant, P. Shukla [arXiv:2007.00672],

S. Brahma, K. Dasgupta, R. Tatar [arXiv:2007.00786],

M. Cicoli, G. Dibitetto, F. G. Pedro [arXiv:2007.11011],

S. Brahma, K. Dasgupta, R. Tatar [arXiv:2007.11611],

F. Farakos, G. Tringas, T. Van Riet [arXiv:2007.12084],

I. Basile, S. Lanza [arXiv:2007.13757],

V. Basiouris, G. K. Leontaris [arXiv:2007.15423],

M. Gunaydin, R. Kallosh, A. Linde, Y. Yamada [arXiv:2008.01494],

A. Bedroya, M. Montero, C. Vafa, I. Valenzuela [arXiv:2008.07555],

M. Dine, J. A. P. Law-Smith, S. Sun, D. Wood, Y. Yu [arXiv:2008.12399],

S. Banerjee, U. Danielsson, S. Giri [arXiv:2009.01597],

F. Farakos, A. Kehagias, N. Liatsos [arXiv:2009.03335],

H. Bernardo, S. Brahma, K. Dasgupta, R. Tatar [arXiv:2009.04504],

P. Agrawal, S. Gukov, G. Obied, C. Vafa [arXiv:2009.10077],

I. Bena, G. Bruno De Luca, M. Grana, G. Lo Monaco [arXiv:2010.05936],

A. Bedroya [arXiv:2010.09760],

S. Bansal, S. Nagy, A. Padilla, I. Zavala [arXiv:2010.13758],

C. Crinò, F. Quevedo, R. Valandro [arXiv:2010.15903],

V. Aragam, S. Paban, R. Rosati [arXiv:2010.15933],

C. P. Burgess, S. P. de Alwis, F. Quevedo [arXiv:2011.03069],

...

Classical de Sitter solutions

Two steps:

1.

2.

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1. find 10d (type II) supergravity de Sitter solution
Very constrained, no-go theorems
Find some:

C. Caviezel, P. Koerber, S. Kors, D. Lüst, T. Wrase, M. Zagermann [arXiv:0812.3551],
R. Flauger, S. Paban, D. Robbins, T. Wrase [arXiv:0812.3886],
C. Caviezel, T. Wrase, M. Zagermann [arXiv:0912.3287],
U. H. Danielsson, P. Koerber, T. Van Riet [arXiv:1003.3590],
U. H. Danielsson, S. S. Haque, P. Koerber, G. Shiu, T. Van Riet, T. Wrase [arXiv:1103.4858],
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C. Roupec, T. Wrase [arXiv:1807.09538],
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2. verify that in classical string regime: small g_s, large volume...

C. Roupec, T. Wrase [arXiv:1807.09538],
D. Junghans [arXiv:1811.06990],
A. Banlaki, A. Chowdhury, C. Roupec, T. Wrase [arXiv:1811.07880],
D. A. [arXiv:1902.10093],
T. W. Grimm, C. Li, I. Valenzuela [arXiv:1910.09549],
D. A., P. Marconnet, T. Wrase [arXiv:2006.01848]

$\hookrightarrow$ **no solution left!**

No-go theorems, parameter space, and new solutions

Existence of de Sitter solutions

5 supergravity equations (e.o.m., BI) → constraints:

T. Wrase, M. Zagermann [arXiv:1003.0029], G. Shiu, Y. Sumitomo [arXiv:1107.2925]

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D. A. [arXiv:1807.09698], [arXiv:1902.10093]

p	A de Sitter solution requires $T_{10} > 0$ and $\mathcal{R}_6 \geqslant 0$	$\mathcal{R}_6 < 0$
3	×	×
4	×	??
5	×	??
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8	×	×
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Excluded in many cases. Small corner of parameter space left: O_p ($T_{10} > 0$), $\mathcal{R}_6 < 0$, $p = 4, 5, 6$, $F_{6-p} \neq 0$, + more restrictions.

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↪ Look for IIB de Sitter solutions with intersecting O_5/D_5

D. A., P. Marconnet, T. Wrase [arXiv:2005.12930]

We found **17 new de Sitter solutions**.

Stability

All previously known 10d supergravity de Sitter solutions are pert. **unstable**: 4d tachyon, maximum of a 4d potential.
Many works on understanding/proving this property (+ swampland conj.). Not fully established $\rightarrow$ test stability

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Appropriate tools (4d effective **potential** + kin. terms)

$$\mathcal{S} = \int \mathrm{d}^4x \sqrt{|g_4|} \Bigg(\frac{M_p^2}{2} \mathcal{R}_4 - \frac{M_p^2}{2} \Bigg(\frac{3}{2\rho^2} (\partial\rho)^2 + \frac{2}{\tau^2} (\partial\tau)^2$$

$$+ 12 \Big(\frac{1}{\sigma_1^2} (\partial\sigma_1)^2 + \frac{1}{\sigma_2^2} (\partial\sigma_2)^2 - \frac{1}{\sigma_1\sigma_2} \partial_\mu\sigma_1 \partial^\mu\sigma_2 \Big) \Bigg) - V(\rho, \tau, \sigma_1, \sigma_2) \Bigg)$$

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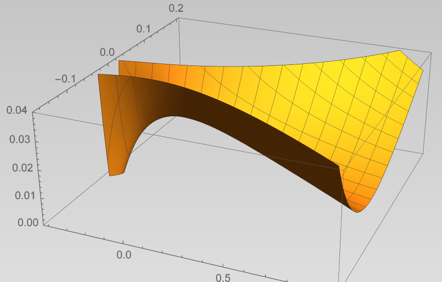
↪ all **17 solutions are pert. unstable**.



$\eta_V \in [-2.9703, -1.7067]$
$\hookrightarrow$ not good for slow-roll single field inflation.

Multi-field inflation with non-geodesic motion or strong bending?

A. R. Brown [arXiv:1705.03023],
S. Garcia-Saenz, S. Renaux-Petel, J. Ronayne [arXiv:1804.11279],
A. Achucarro, G. A. Palma [arXiv:1807.04390],
T. Bjorkmo, M. D. Marsh [arXiv:1901.08603]

To some extent attempted in

V. Aragam, S. Paban, R. Rosati [arXiv:2010.15933]

Classical regime of string theory

D. A., P. Marconnet, T. Wrase [arXiv:2006.01848]

A 10d supergravity solution: a classical string background?

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$\hookrightarrow$ **5** (sufficient) **requirements**: small g_s, etc.
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  ↪ classical de Sitter solutions live *at best* in a **bounded region** of parameter space. Probably not in asymptotics (see swampland conjectures).

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Summary:

- No-gos
- Remaining region $\rightarrow$ find de Sitter supergravity solutions
- Classical regime analysis

Testing swampland de Sitter conjectures

Several swampland conjectures that forbid (classical) de Sitter solutions.

De Sitter swampland conjecture: (initial version)

G. Obied, H. Ooguri, L. Spodyneiko, C. Vafa, [arXiv:1806.08362]

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Criterion: if NOT in the swampland, one has:

- $|\nabla V| \geqslant \frac{c}{M_p} V$ at any point in field space with $c > 0$, $|\nabla V| = \sqrt{g^{ij} \partial_{\phi^i} V \partial_{\phi^j} V}$
- $c \sim O(1)$

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$\Rightarrow$ extremum: $|\nabla V|_0 = 0 \Rightarrow V|_0 \leqslant 0$

$\hookrightarrow$ no de Sitter solution for a theory coming from string theory.

+ more consequences, for e.g. inflation...

Refined de Sitter conjectures

Various criticisms:
- example based (e.g. no-go theorems)/deeper physical reason?
- what is c ?
- allow for maxima!

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$\hookrightarrow$ refinements:

- To include the notion of stability, i.e. V'' or η_V:

  D. A. [arXiv:1806.10999],

  S. K. Garg, C. Krishnan [arXiv:1807.05193],

  H. Ooguri, E. Palti, G. Shiu, C. Vafa [arXiv:1810.05506],

  D. A., C. Roupec [arXiv:1811.08889],

  T. Rudelius [arXiv:1905.05198]

- No de Sitter solution in asymptotics of moduli space, e.g. classical regime(?)

  H. Ooguri, E. Palti, G. Shiu, C. Vafa [arXiv:1810.05506]

  Reminiscent/generalization of Dine-Seiberg argument.

  M. Dine, N. Seiberg *Phys. Lett.* **B 162** (1985) 299

  $\frac{|\nabla V|}{V} \geqslant \frac{c}{M_p}$ for $\varphi \to \infty$.

TCC: Trans-Planckian Censorship Conjecture

A. Bedroya, C. Vafa [arXiv:1909.11063]

→ see talk by R. Brandenberger

Conjectured physical argument on trans-Planckian modes

↪ scalar field φ and potential, in 4d (with $M_p = 1$):

$$0 < V(\varphi) < A\, e^{-c_0\, \varphi} \quad \Rightarrow \quad \left\langle \frac{|V'|}{V} \right\rangle_{\varphi \to \infty} \geqslant c_0 = \sqrt{\frac{2}{3}}$$

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Compare to $\frac{|\nabla V|}{V} \geqslant c$:
⇒ gives a **physical motivation** for such an inequality
⇒ gives a **number**!
⇒ **asymptotic limit** is crucial

$$\text{TCC bound:} \quad c \geqslant c_0 = \sqrt{\frac{2}{3}} \quad \text{in 4d}$$

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$$\text{TCC bound:} \quad c \geqslant c_0 = \sqrt{\frac{2}{3}} \quad \text{in 4d}$$

Consequences on V'' and stability...
Bound on lifetime, related to scrambling time in de Sitter.

L. Aalsma, G. Shiu [arXiv:2002.01326],

A. Bhattacharyya, S. Das, S. Shajidul Haque, B. Underwood [arXiv:2005.10854]

Testing conjectures with no-go theorems

"Parameter space" for classical de Sitter solutions:

p	A de Sitter solution requires $T_{10} > 0$ and $\mathcal{R}_6 \geqslant 0$	$\mathcal{R}_6 < 0$
3	$\times$	$\times$
4	$\times$	??
5	$\times$	??
6	$\times$	??
7	$\times$	$\times$
8	$\times$	$\times$
9	$\times$	$\times$

In remaining corner, reason preventing us from accessing classical regime?
No clear no-go theorem formulation of this...
$\hookrightarrow$ focus on all other no-go theorems

9 no-go theorems (for parallel D_p/O_p)

p	A de Sitter solution requires $T_{10} > 0$ (**1.**) and	
	$\mathcal{R}_6 \geqslant 0$	$\mathcal{R}_6 < 0$
3	(**4.**)	
4		F_{6-p} (**2.**),
5	(**3.**)	${f^{\vert\vert}}_{\perp\perp}$ (**5.**), (**6.**), (**9.**), ${f^{\perp}}_{\perp\vert\vert}$ (**7.**), (**8.**),
6		linear combi (**5.**), (**6.**)
7		
8	(**2.**), (**3.**)	(**2.**)
9		

(**number.**) = no-go theorem;
entry = necessary ingredient

$\Rightarrow$ put them in swampland conjecture format!

No-go theorem (2.): for $p = 7, 8$, or $p = 4, 5, 6$ & $F_{6-p} = 0$

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10d type II supergravities e.o.m.:

$$(p-3)\ \mathcal{R}_4 = -2|H|^2 - g_s^2 \sum_{q=0}^{6} (q+p-8)|F_q|^2$$

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10d type II supergravities e.o.m.:

$$(p-3)\ \mathcal{R}_4 = -2|H|^2 - g_s^2 \sum_{q=0}^{6} (q+p-8)|F_q|^2 \leqslant \mathbf{0}$$

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$\rightarrow$ all 9 no-go theorems...

Done in D. A., N. Cribiori, D. Erkinger [arXiv:2004.00030]

No-go number	Condition for the no-go	c
(1.)	$T_{10} \leqslant 0$	$\sqrt{2}$
(2.)	$p = 7, 8,$ or $p = 4, 5, 6$ & $F_{6-p} = 0$	$\sqrt{\frac{2(p-3)^2}{3+(p-4)^2}} \geqslant \sqrt{\frac{2}{3}}$
(3.)	$\mathcal{R}_6 \geqslant 0,\ p \geqslant 4$	$\sqrt{\frac{2(p+3)^2}{3+p^2}} > 1$
(4.)	$p = 3$	$2\sqrt{\frac{2}{3}}$
(5.)	$\mathcal{R}_{\vert\vert} + \mathcal{R}_{\vert\vert}^{\perp} + \frac{\sigma^{-12}}{2} \vert f^{\vert\vert}{}_{\perp\perp}\vert^2 \leqslant 0,\ p \geqslant 4$	$\sqrt{\frac{2(p-3)}{p-1}} \geqslant \sqrt{\frac{2}{3}}$
(6.)	$-2\rho^2\sigma^{2(p-6)}(\mathcal{R}_{\vert\vert} + \mathcal{R}_{\vert\vert}^{\perp}) + \vert H^{(2)}\vert^2 \leqslant 0$	$2\sqrt{\frac{2}{3}}$
(7.)	$\lambda \leqslant 0,\ p \geqslant 4$	$\sqrt{\frac{2}{3}}$
(9.)	$\exists\, a_{\vert\vert}$ s.t. $f^{a_{\vert\vert}}{}_{ij} = 0\ \ \forall i, j \neq a_{\vert\vert},\ p \geqslant 4$	$\sqrt{\frac{2}{3}}$

TCC bound always satisfied! Sometimes with saturation.

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All swampland conjectures are related: a **web of conjectures**.
Translate the impossibility of getting classical de Sitter to another conjecture?
$\hookrightarrow$ the **distance conjecture**...

Conclusion

- Connection to cosmology → (quasi) **de Sitter string backgrounds**? → **classical** ones (simplicity, well-controlled)
- Constrained by **no-go theorems** → **a corner** of parameter space remains → we look there and find new de Sitter solutions of 10d supergravity
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- **Connection to other conjectures**/criteria, e.g. the distance conjecture? Yes!
  → translation of the obstruction against de Sitter to other properties of EFT
  ↪ better understanding?

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list of conjectures may look arbitrary/not constructive
but tests, refinements, proofs: very precise, require expertise!
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Highlighted several directions where to make progress on this important matter.

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Thank you for your attention!

Back up slide

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Inspired by examples in literature + new quantitative tests of conj., **we proposed a bound**

$$\text{4d}: \quad \lambda \geqslant \lambda_0 = \frac{1}{2}\sqrt{\frac{2}{3}}\ , \quad \lambda_0 = \frac{1}{2} c_0$$

To justify bound on λ: **generalization** of distance conj.
To justify relation to c_0: **relation** between conj. $\frac{m}{m_i} \simeq \left|\frac{V}{V_i}\right|^{\frac{1}{2}}$.
$\hookrightarrow$ translates the "no de Sitter" into asymptotic bound on m.
A new perspective.