Classical de Sitter solutions and the swampland

David ANDRIOT

CERN, Geneva, Switzerland

Based on arXiv:1609.00385 (with J. Blåbäck), 1710.08886
arXiv:1806.10999, 1807.09698

Vistas over the Swampland
20/09/2018, IFT-Madrid, Spain

Introduction

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$\Rightarrow$ constraints on cosmological models.
Still, many models ✓ $\Rightarrow$ theoretical constraints?

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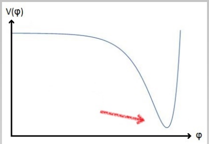
"mainstream" models (✓ with observ.) exhibit de Sitter solutions:



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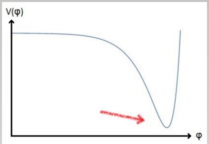

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⇒ Get de Sitter solutions from quantum gravity?

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   For a 4d theory of minimally coupled scalars ϕ_i ($M_4 = 1$)

$$\mathcal{S} = \int \mathrm{d}^4x \sqrt{|g_4|} \left(\mathcal{R}_4 + \text{kin. terms} - V(\phi_i) \right)$$

   solutions as extrema of potential: $\partial_{\phi_i} V|_0 = 0$, $\mathcal{R}_4 = 2V|_0$
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Criterion: if NOT in the swampland, one has:

$$|\nabla V| \geqslant c\, V$$

with $c > 0$, $|\nabla V| = \sqrt{g^{ij} \partial_{\phi_i} V \partial_{\phi_j} V}$.
Extremum: $|\nabla V|_0 = 0 \Rightarrow V|_0 \leqslant 0$: no de Sitter solution.

Conclusion:

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Plan:

- Comments on de Sitter solutions in string theory and the swampland
- Constraints on classical de Sitter solutions

De Sitter solutions in string theory

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Stringy constructions to get de Sitter:

- "4d approaches"

- "10d approach"

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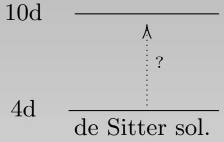
Stringy constructions to get de Sitter:

- "4d approaches": (at some point) include an ingredient at 4d level ⇒ controlled realisation in string theory?

  Prime example: KKLT: include 4d non-perturbative contributions, 4d potential term for $\overline{D}_3$...

  Non-geometric: many different non-geometric fluxes ⇒ realise as a non-trivial stringy background?



  NS Bianchi identities not satisfied: exotic sources? (some 4d non-geometric fluxes lifted to an understood 10d realisation)

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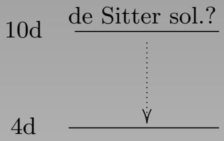

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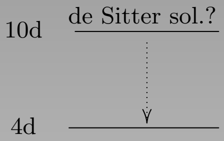

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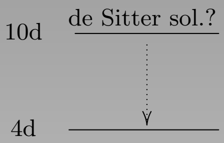

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$$\begin{aligned}
\Lambda_4 \;=\; & -\frac{e^{2A}}{8}\Big(*_\perp H|_\perp + e^\phi F_0\Big)^2 - \frac{e^{2A}}{4}\Big(e^{4A} *_\perp \mathrm{d}e^{-4A} - e^\phi F_2^{(0)}\Big)^2 \\
& -\frac{e^{2A}}{8}\sum_{a_{||}}\Big(*_\perp \mathrm{d}e^{a_{||}}|_\perp - e^\phi(\iota_{a_{||}}F_2^{(1)})\Big)^2 \\
& -\frac{e^{2A+2\phi}}{8}\Big(2\big(F_4^{(0)}\big)^2 + 2\big(F_4^{(1)}\big)^2 + \big(F_4^{(2)}\big)^2 + \big(F_6\big)^2\Big) \\
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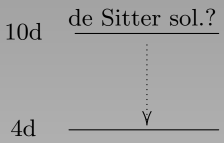

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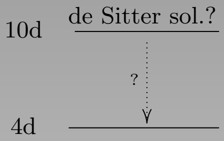

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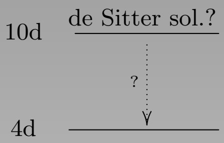

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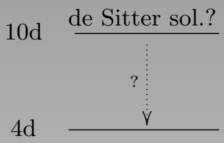

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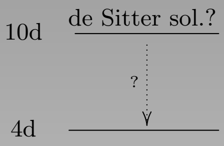

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3 points in favor of de Sitter swampland criterion.

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↪ refine de Sitter swampland criterion

$\exists\ b_i \in \mathbb{R}, c_i \in \mathbb{R}_+$ such that

$$V + \sum_i b_i\ \phi_i \partial_{\phi_i} V + \sum_i c_i\ \phi_i^2 \partial_{\phi_i}^2 V \leqslant 0$$

Solution: $V|_0 + \sum_i c_i\ (\phi_i^2 \partial_{\phi_i}^2 V)|_0 \leqslant 0$

⇒ **no stable de Sitter solution**, tachyonic de Sitter sol. ✓

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

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Interesting general statements.
The whole situation now requires more precise studies.
Less example based and more **analytical** results, understanding.

$\Rightarrow$ constraints on 10d classical de Sitter solutions

Constraints on 10d classical de Sitter solutions

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Reasoning and known results

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Combine 3 equations, get constraints

Existence of sol.: necessary ingredients (parallel D_p/O_p)

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

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$p = \dots$	$\mathcal{R}_6 \geqslant 0$	$\mathcal{R}_6 < 0$
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Considering on top the 10d sourced Bianchi identity

$$\mathrm{d}F_{8-p} - H \wedge F_{6-p} = \varepsilon_p \frac{T_{10}}{p+1} \mathrm{vol}_\perp$$

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Analogous results derived for intersecting D_p/O_p:
sligthly less constraining $\leftrightarrow$ solutions known.

G. Shiu, Y. Sumitomo [arXiv:1107.2925], D. Andriot [arXiv:1710.08886]

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Introduce **new scalar** field σ: distinguishes $||, \perp$ dir. of D_p/O_p

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$$
\boxed{\begin{aligned}
V(\rho,\tau,\sigma) = & -\tau^{-2}\left(\rho^{-1}\mathcal{R}_6(\sigma) - \frac{1}{2}\rho^{-3}\sum_n \sigma^{-An-B(3-n)}|H^{(n)}|^2\right) \\
& - g_s\tau^{-3}\rho^{\frac{p-6}{2}}\sigma^{B\frac{p-9}{2}}\,\frac{T_{10}}{p+1} \\
& + \frac{1}{2}g_s^2\left(\tau^{-4}\sum_{q=0}^{4}\rho^{3-q}\sum_n \sigma^{-An-B(q-n)}|F_q^{(n)}|^2 - \tau^4\rho^3|F_6|^2\right. \\
& + \frac{1}{2}\sum_n(\tau^{-4}\rho^{-2}\sigma^{-An-B(5-n)}|F_5^{(n)}|^2 \\
& \left. - \tau^4\rho^2\sigma^{-An-B(1-n)}|(*_6F_5)^{(n)}|^2)\right)
\end{aligned}}
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\text{with } \mathcal{R}_6(\sigma) = & \ \sigma^{-B}\left(\mathcal{R}_\perp + \delta^{ab}\partial_{a_\perp}f^{c_\perp}{}_{c_\perp b_\perp} + \mathcal{R}_\perp^{||} + |f^{||}{}_{\perp\perp}|^2\right) \\
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and $A = p-9,\ B = p-3$

On **group manifolds** (with constant fluxes): constraints in terms of $\lambda = -\frac{\delta^{cd} f^{b_\perp}{}_{a_{||} c_\perp} f^{a_{||}}{}_{b_\perp d_\perp}}{\frac{1}{2}\delta^{ab}\delta^{cd}\delta_{ij} f^{i_{||}}{}_{a_\perp c_\perp} f^{j_{||}}{}_{b_\perp d_\perp}}$:

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Stability island:
a de Sitter solution would have $\partial_\rho^2 V|_0 > 0$, $\partial_\tau^2 V|_0 > 0$, $\partial_\sigma^2 V|_0 > 0$ for

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$\Rightarrow$ Tiny region of parameter space where
possible stable de Sitter solutions (with parallel D_p/O_p)
$\hookrightarrow$ explore!

Remark on the Bianchi identity and the swampland

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$p=3$, no flux, ρ, τ

$$\mathcal{S} = \int \mathrm{d}^4 x \sqrt{|g_4|} \left(\mathcal{R}_4 + \text{kin. terms} - V \right)$$

$$\text{with} \quad V(\rho,\tau) = -\tau^{-2}\rho^{-1}\mathcal{R}_6 - \tau^{-3}\rho^{-\frac{3}{2}} g_s \frac{T_{10}}{4}$$

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3 equations of motion ⇒ de Sitter solution with

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⇒ landscape of 4d theories $(\mathcal{R}_6, T_{10})$, some with de Sitter solutions.

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⇒**Illustration of de Sitter swampland criterion**

Similar with $\lambda \leqslant 0$: inconclusive without Bianchi identity, exclusion de Sitter with it.

Summary

- What cosmological model is (not) in the swampland?
- $\leftrightarrow$ Get, in a controlled manner, de Sitter vacua from string theory?
- de Sitter swampland criterion, or a refined version?

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Thank you for your attention!