Dark energy and string theory

David Andriot

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arXiv:2201.04152, 2204.05327 (with L. Horer, P. Marconnet)
2208.14462 (with L. Horer)
2209.08015 (with P. Marconnet, M. Rajaguru, T. Wrase)

GdR CoPhy – Kick-off
17/01/23, LPNHE Paris, France

Introduction

Dark energy: energy responsible for accelerated expansion observed: today

early universe (inflation)

Today: well-described by cosmological constant $\Lambda > 0$

Inflation: single scalar field slowly rolling-down potential V > 0 , flat V: $\frac{|V'|}{V} \ll 1$

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(most of the talk: $M_p = 1, \varphi^i \to \varphi$)

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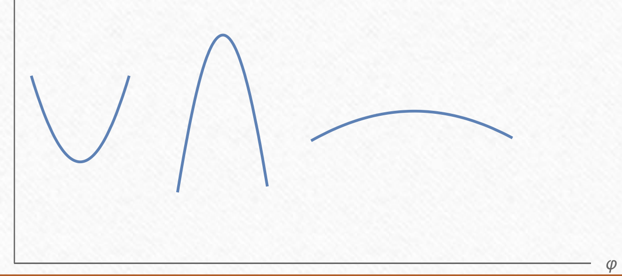
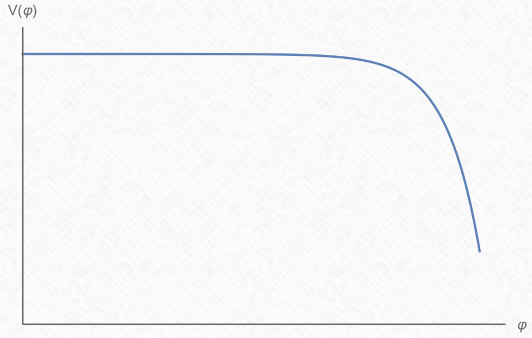
de Sitter solution: critical point of V:

$$\partial_\varphi V = 0, \; \partial\varphi = 0, \; V = V_0 = \Lambda = 1/4\,\mathcal{R}_4 > 0$$



Slow-roll single-field inflation: plateau V:



Nature/origin of dark energy? $\longrightarrow$ Why V? Which V?

Which V: many options for single-field inflation despite constraints Planck '18

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Here: string theory.
Why V: because of the **extra dimensions**!
Getting 4d V in 4d EFT from 10d string theory is very natural:
Compactification on 6 extra (small compact) space dimensions. Fields/string ingredients in 6d generate V.

$$V(\rho,\tau) = \frac{1}{2\kappa_{10}^2}\int \mathrm{d}^6y\sqrt{|g_6|}\; g_s^{-2}\left(\tau^{-2}\left(-\rho^{-1}\mathcal{R}_6 + \frac{1}{2}\rho^{-3}\,|H|^2\right)\right.$$
$$\left. -\,\tau^{-3}\sum_p \rho^{\frac{p-6}{2}}\, g_s\,\frac{T_{10}^{(p)}}{p+1} + \frac{1}{2}\tau^{-4}\, g_s^2\sum_{q=0}^{6}\rho^{3-q}\,|F_q|^2\right)$$

$\longrightarrow$ Good news!

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Which V? $\rightarrow$ Can we get almost flat V?
Can we get (quasi) de Sitter solutions? $\longrightarrow$ **Extremally challenging!**

I. De Sitter solutions

String theory: tree-level / low energy $\longrightarrow$ approximated by 10d supergravity
perturbative corrections (g_s loops, α')
non-perturbative contributions

Different approaches to get de Sitter solutions use different regimes/contributions/ingredients

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Recent progress in finding 4d de Sitter solutions from 10d supergravity Andriot, Horer, Marconnet '22
$\longrightarrow$ they require many ingredients turned-on in 6d (curvature, fluxes, branes/orientifolds) $\longrightarrow$ difficulty

All these ingredients break $\mathcal{N} = 8$ supersymmetry of 4d theory to $\mathcal{N} = 1, 0$ (conjecture)
Good news: automatically get realistic supersymmetry for particle physics!

4d de Sitter solutions from 10d supergravity: **general features**:

At least 3 sets of intersecting branes/orientifolds $\longrightarrow$ $\mathcal{N} = 1, 0$ susy 4d EFT.

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Andriot, Marconnet, Rajaguru, Wrase '22

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Solutions of 10d supergravity are only candidate classical string backgrounds:
certain tree-level conditions/low energy approximations need to be verified $\longrightarrow$ often not the case!

Technical but… **no classical de Sitter solution** known for now! Difficult to find/verify…

Interlude

High Energy Physics - Theory

arXiv:1804.01120 (hep-th)

[Submitted on 3 Apr 2018 (v1), last revised 17 Apr 2018 (this version, v2)]

What if string theory has no de Sitter vacua?

Ulf H. Danielsson, Thomas Van Riet

Download PDF

We present a brief overview of attempts to construct de Sitter vacua in string theory and explain how the results of this 20-year endeavor could point to the fact that string theory harbors no de Sitter vacua at all. Making such a statement is often considered controversial and "bad news for string theory". We discuss how perhaps the opposite can be true.

Comments: 30 +9 pages, 1 figure, v2: references added

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arXiv:1806.08362 (hep-th)

[Submitted on 21 Jun 2018 (v1), last revised 17 Jul 2018 (this version, v3)]

De Sitter Space and the Swampland

Georges Obied, Hirosi Ooguri, Lev Spodyneiko, Cumrun Vafa

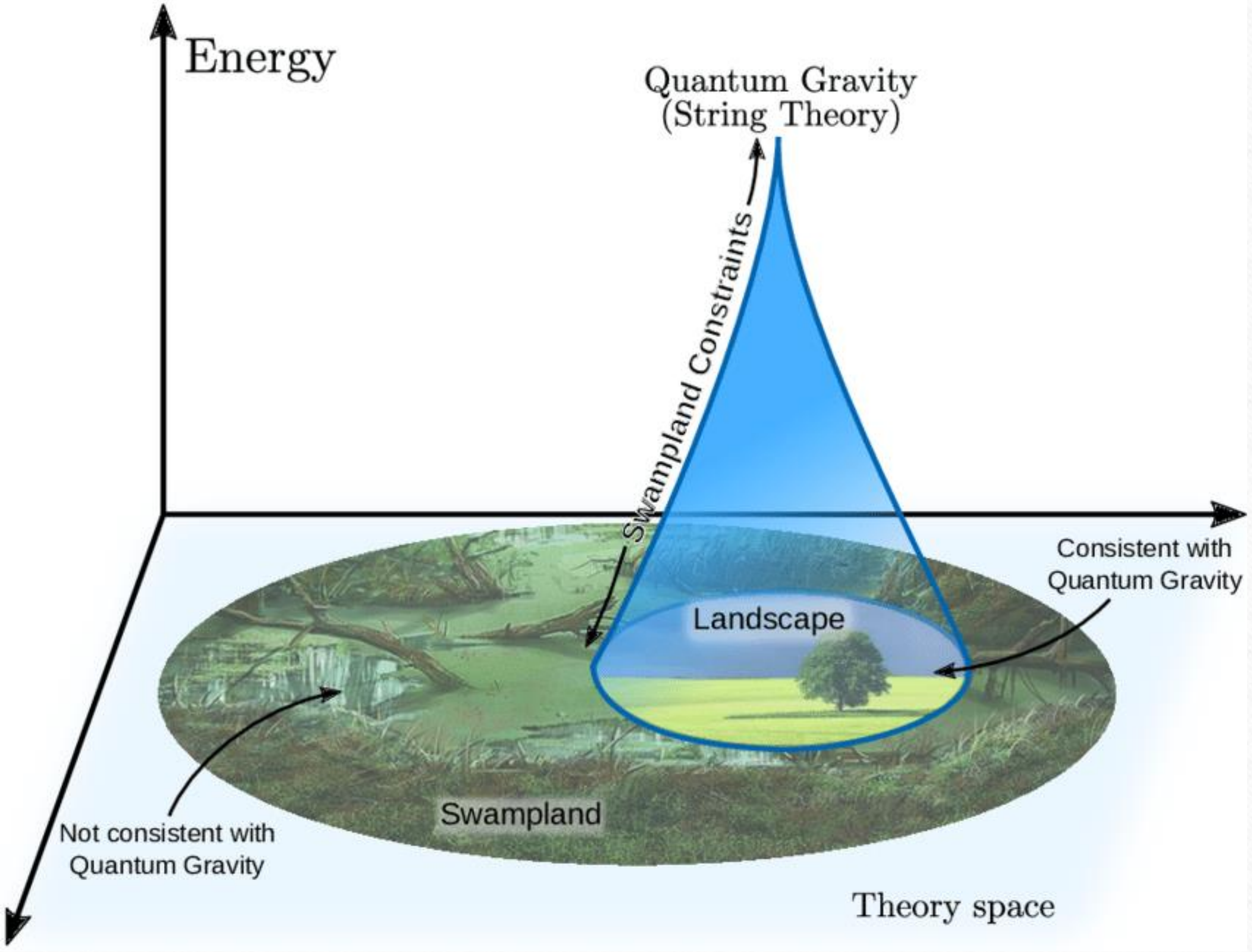
Download PDF

It has been notoriously difficult to construct a meta-stable de Sitter (dS) vacuum in string theory in a controlled approximation. This suggests the possibility that meta-stable dS belongs to the swampland. In this paper, we propose a swampland criterion in the form of $|\nabla V| \geq c \cdot V$ for a scalar potential V of any consistent theory of quantum gravity, for a positive constant c. In particular, this bound forbids dS vacua. The existence of this bound is motivated by the abundance of string theory constructions and no-go theorems which exhibit this behavior. We also extend some of the well-known no-go theorems for the existence of dS vacua in string theory to more general accelerating universes and reinterpret the results in terms of restrictions on allowed scalar potentials.

Swampland program: Vafa ’05, Palti ’19

Characterise which (4d) model couples consistently to quantum gravity
⟶ what comes from string theory?

E.g.: which V can be obtained?



van Beest, Calderón-Infante, Mirfendereski, Valenzuela '21

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- Weak gravity conjecture
- Distance conjecture
- De Sitter conjecture
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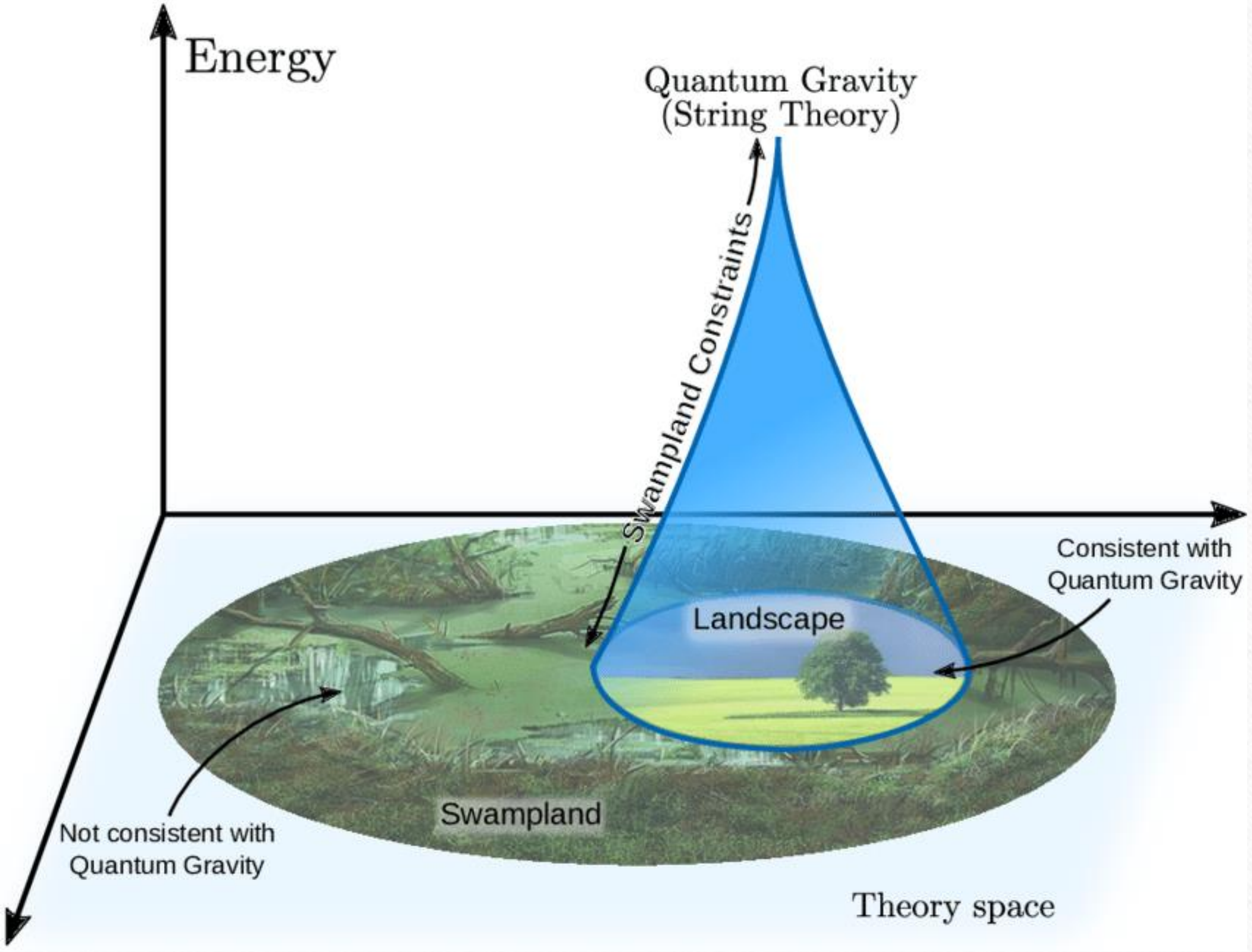

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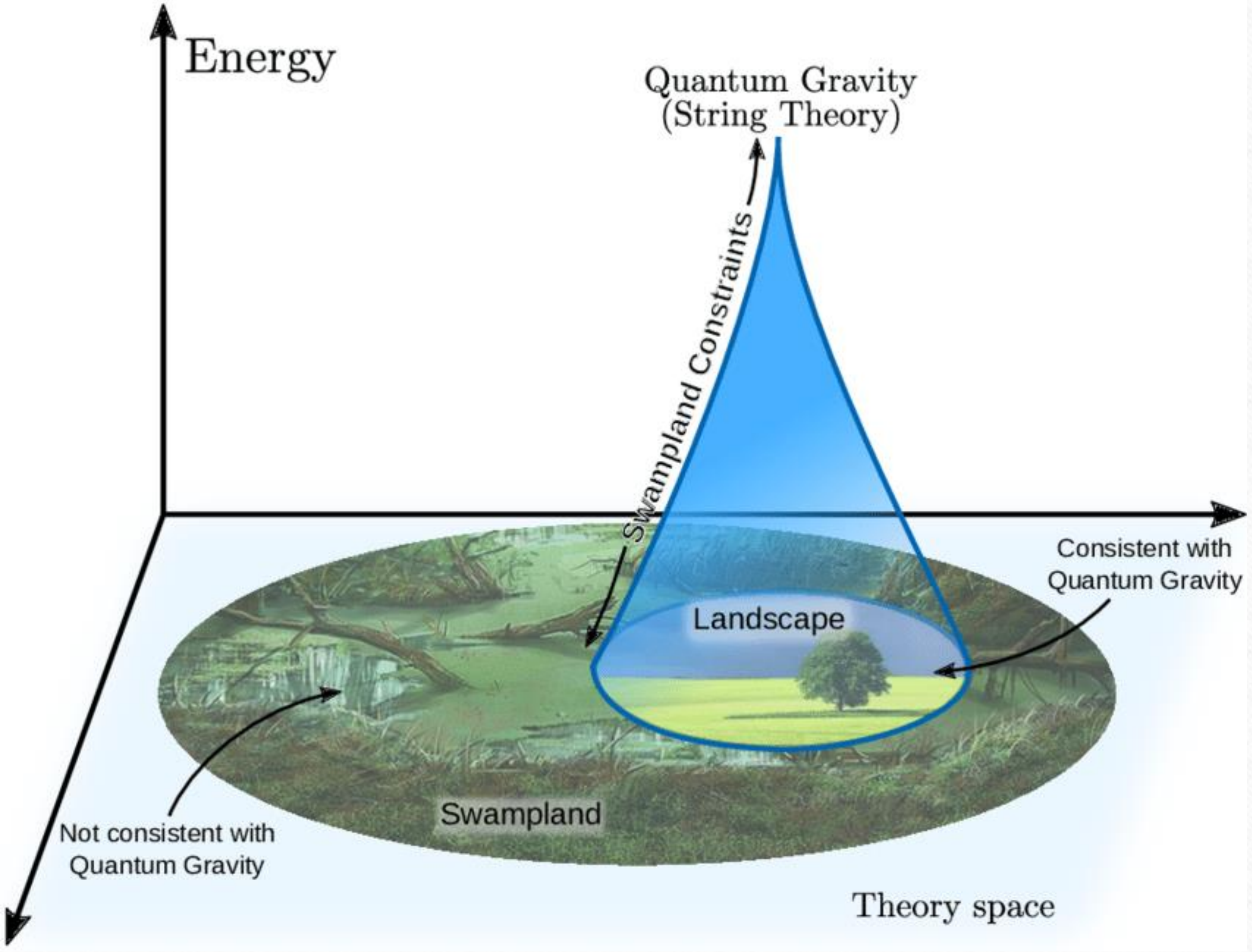

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Critical view: Cassé, Silk ’23

“*This is why astroparticle physicists, at least by curiosity, should be aware of such speculations, taking them however with a grain of salt*”

II. Potential slope and rolling fields

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If no de Sitter critical point: $V > 0,\ V' \neq 0,\ \frac{|V'|}{V} > 0$

Can we get $\frac{|V'|}{V} \ll 1$: quasi de Sitter / almost flat V ? $\longrightarrow$ Very unlikely!

There must be a **lower bound**: $\frac{|V'|}{V} \geq c$: how much?

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Discussions, refinements: this cannot be true everywhere in field space
$\longrightarrow$ only true in the **asymptotics** of field space: $\varphi \to \infty$

Trans-Planckian-Censorship Conjecture Bedroya, Vafa '19
(**TCC**):

$$\varphi \to \infty,\ \frac{|V'|}{V} \geq \sqrt{\frac{2}{3}} \approx 0.82$$

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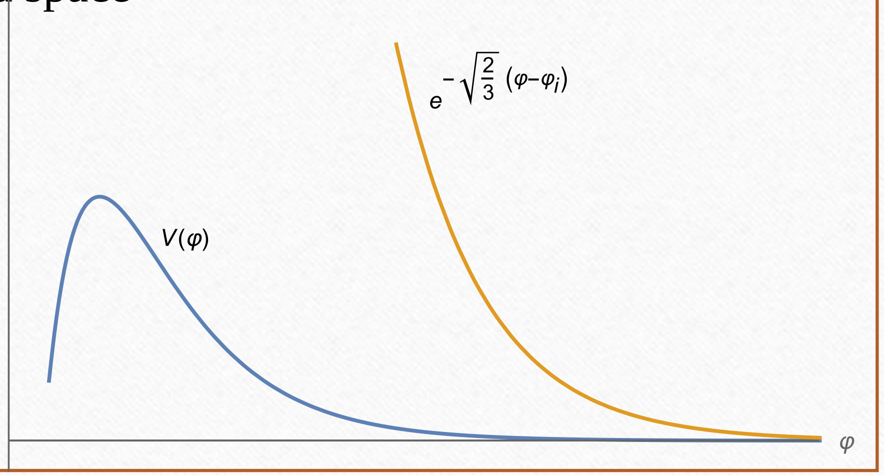
Slow-roll inflation or de Sitter solution:
could be realised in the bulk of field space
(technically challenging for string theory)



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Well tested in many string theory compactifications — Andriot, Cribiori, Erkinger '20 , Andriot, Horer '22

But maybe exceptions…? $\frac{|V'|}{V} \geq \sqrt{\frac{2}{7}} \approx 0.53$ — Calderon-Infante, Ruiz, Valenzuela '22

Multifield: Strong de Sitter conjecture: $\frac{\nabla V}{V} \geq \sqrt{2}$ — Rudelius '21, '22

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$\lambda \leq 0.6,\ w \leq -0.96$ Agrawal, Obied, Steinhardt, Vafa '18,

see also Akrami, Kallosh, Linde, Vardanyan '18, Heisenberg, Bartelmann, Brandenberger, Refregier '20

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Asymptotic accelerated expansion: bound: $\lambda \leq \sqrt{2}$ Halliwell '86, Copeland, Liddle, Wands '97

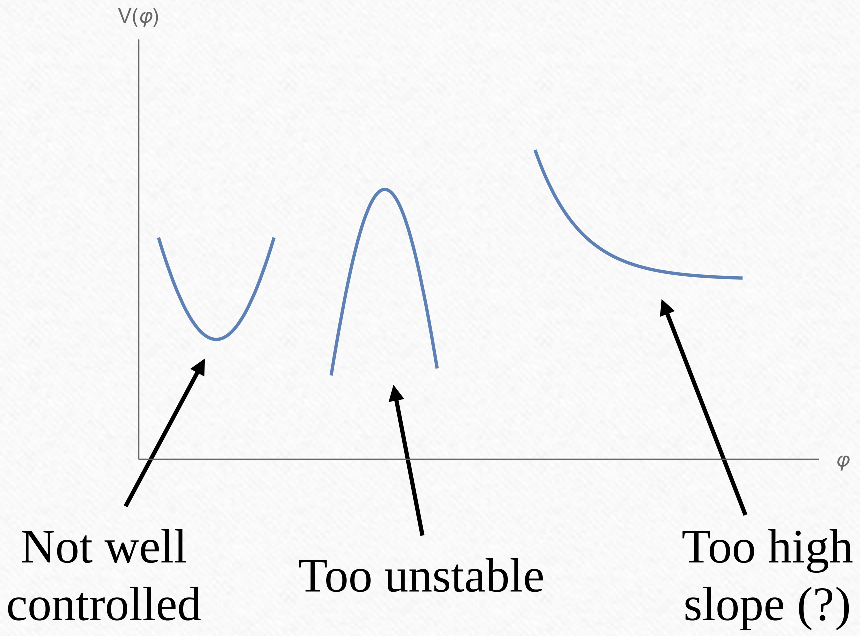
$\longrightarrow$ seems all **tight** to realise accelerated expansion asymptotically!

Summary

What we want

What we want

What we get



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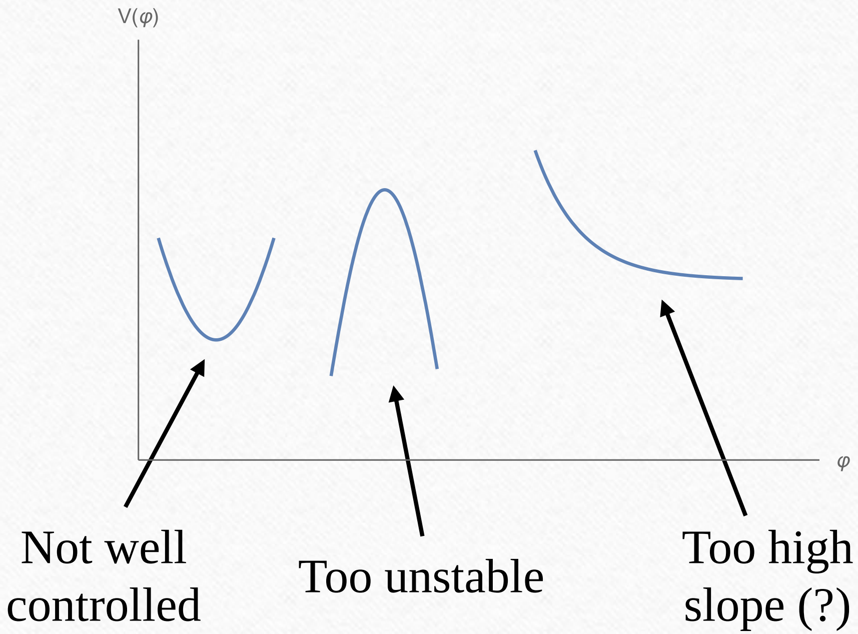

Still: string theory naturally provides some dark energy $V(\varphi^i)$ with a tendancy towards 4d and $\mathcal{N}=1,0$ supersymmetry EFT

$\longrightarrow$ search for more examples / (dis)prove conjectures

$\longrightarrow$ alternatives?

- Topological Gravity Agrawal, Gukov, Obied, Vafa ’20
- Dark bubble Banerjee, Danielsson, Giri
- Transcient scenarios Marconnet, Tsimpis ’22
- …
- Multifield inflation and rapid turns
- Ekpyrosis, bounce, and negative potentials

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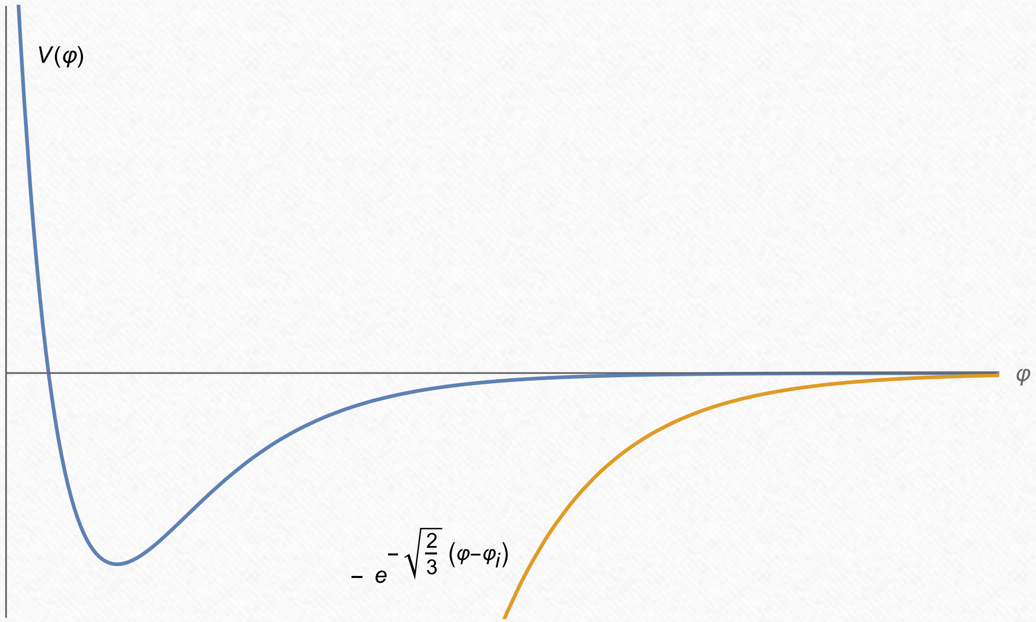

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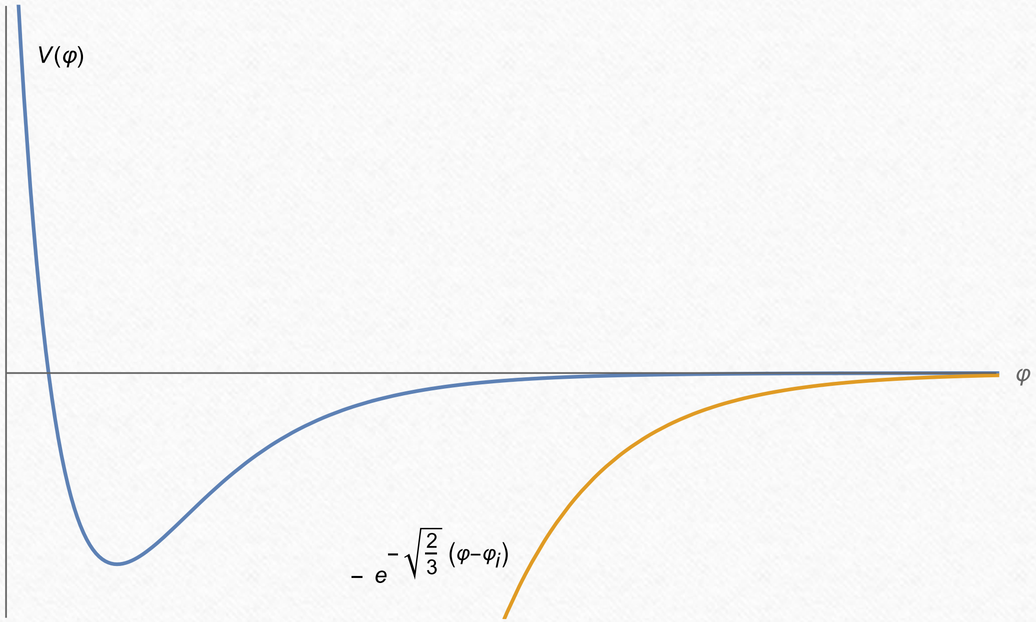

$\longrightarrow$ **Stay tuned!**

Thank you for your attention!