De Sitter & String Theory

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IBS-CTPU welcome meeting

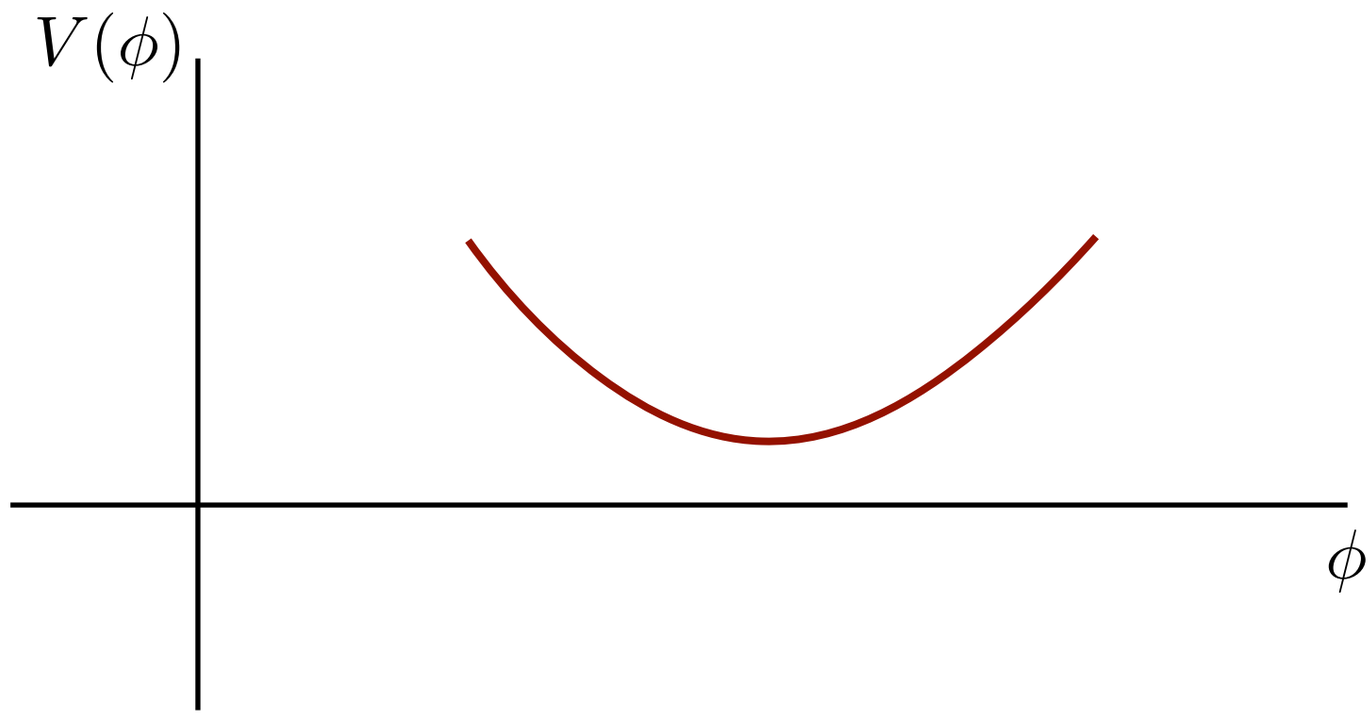
Some of my interests…

- Axions (in string theory)
  - Lectures - June ‘20
- Euclidean wormholes
  - Journal club - Nov ‘20
- Model building in string theory
  - IBS-IFT workshop - Oct ’20
  - **Today**

Outline

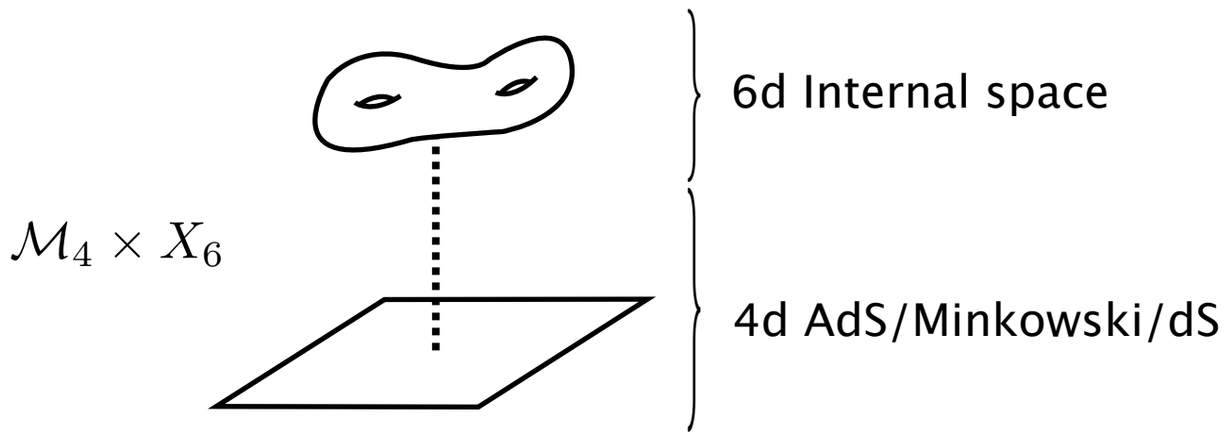
- Why is dS so hard to find?
- The KKLT proposal

Why is dS so hard to find?



dS and the swampland

- Consider a compactification of string theory: $10d \to 4d$



No free parameters: coupling constants in 4d are vevs of scalar fields (moduli), e.g.

$$g_s = \langle e^{-\phi} \rangle \,, \qquad \text{Vol}_{X_6} = \langle \phi \rangle$$

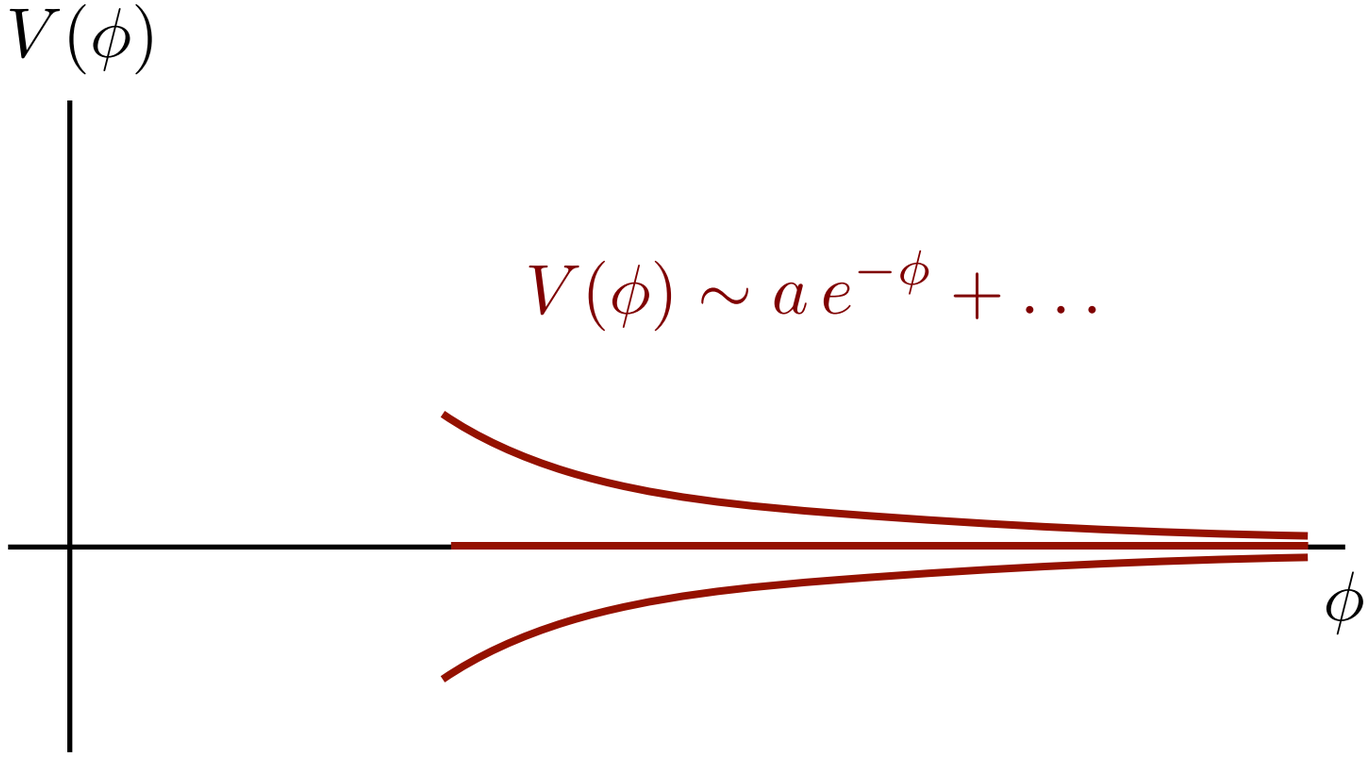
Most computations rely on perturbation theory $\langle \phi \rangle \gg 1$

$$V(\phi) = a_0 + \frac{a_1}{\phi} + \frac{a_2}{\phi^2} + \ldots \qquad \text{or} \qquad V(\phi) = b_0 + b_1\, e^{-\phi} + b_2\, e^{-2\phi} + \ldots$$

dS and the swampland

- It is notoriously difficult to obtain string dS vacua.
- The difficulty can be traced back to the **Dine-Seiberg problem**:

  At weak coupling ($\phi \to \infty$), vacuum energy vanishes



- V>0: runaway (quintessence?)
- V=0: flat (massless)
- V<0: roll to strong coupling

Dine, Seiberg ’85

dS and the swampland

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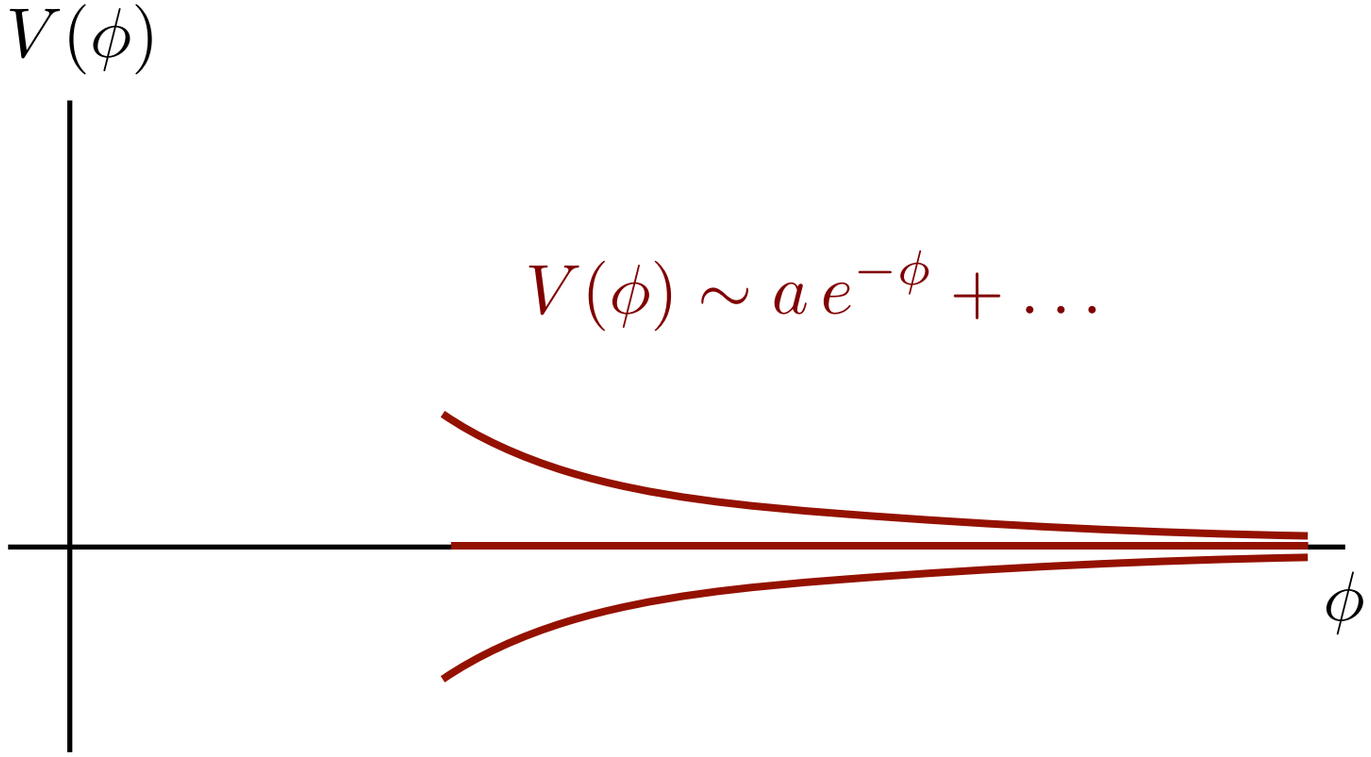


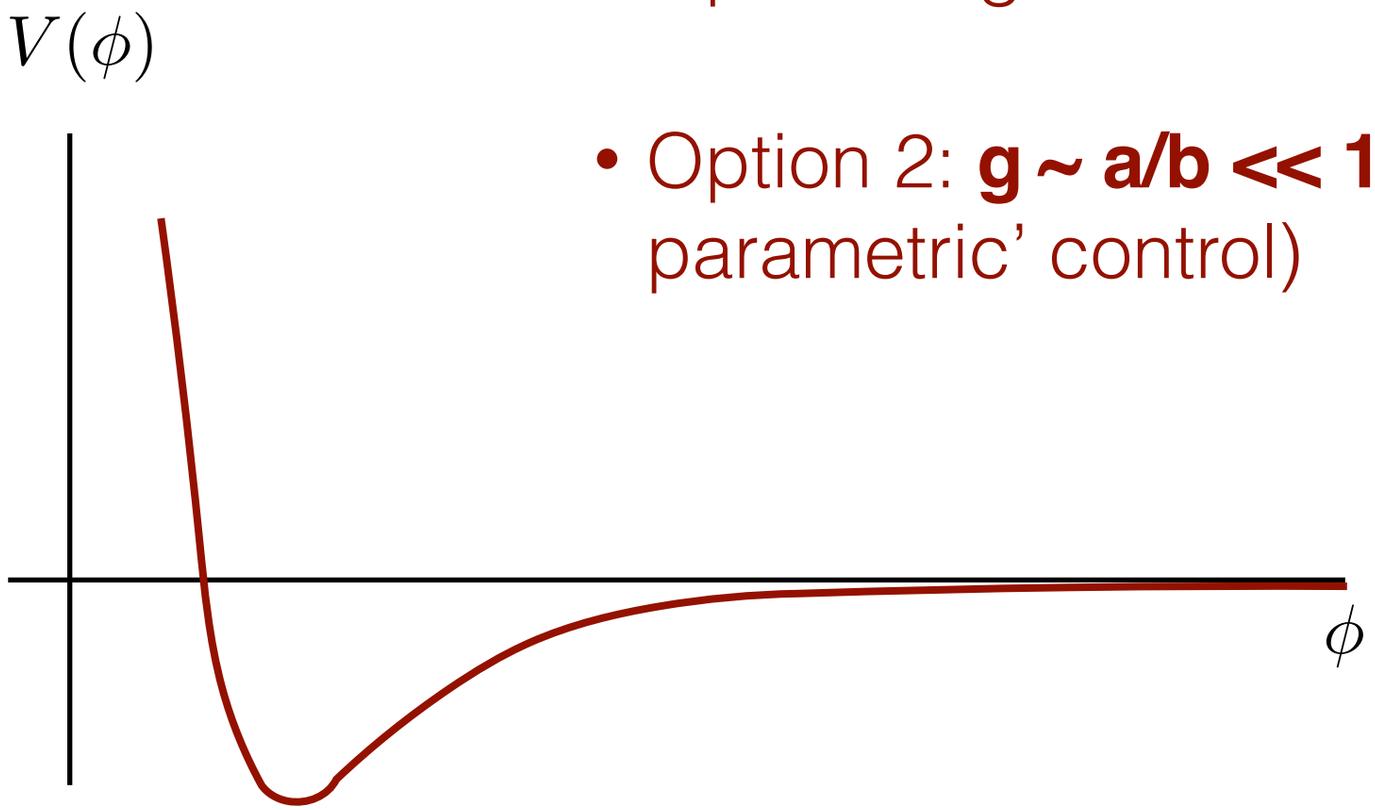
No stable vacuum exists at
parametrically weak coupling!

Dine, Seiberg ’85

dS and the swampland

- To find a minimum, one needs higher order corrections in the potential, but then perturbativity is endangered

$$V(\phi) = -a\, e^{-\phi} + b\, e^{-2\phi} + \ldots \qquad \Longrightarrow \qquad g = e^{-\langle\phi\rangle} = \frac{a}{2b}$$



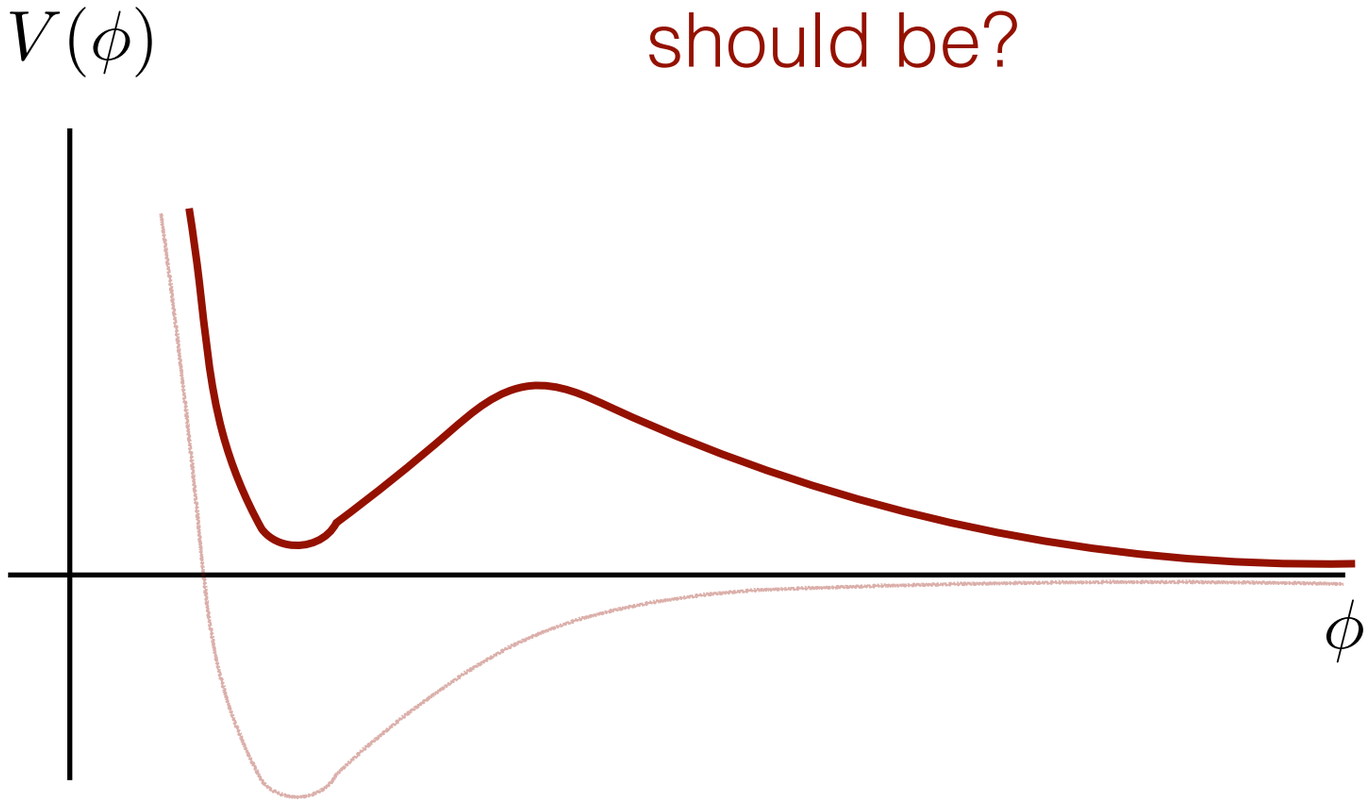
- Option 1: g ~ a/b~1 strong coupling (no control)!
- Option 2: **g ~ a/b << 1** AdS at small coupling (‘non-parametric’ control)

dS and the swampland

- To find a minimum, one needs higher order corrections in the potential, but then perturbativity is endangered

$$V(\phi) = a\, e^{-\phi} - b\, e^{-2\phi} + c\, e^{-3\phi} + \dots$$

  - With one more term, one can obtain potentials with dS minima at g << 1. Not ideal, but who said it should be?



Moduli stabilization and constructions of vacua (AdS, Mink or dS) exploit this mechanism

KKLT ‘03, LVS ’05;…

dS and the swampland

- Recent suggestion: the potential must satisfy **asymptotically**

$$|\nabla V(\phi)| \geq \alpha\, V \qquad\qquad \alpha \sim \mathcal{O}(1)\,,\ \phi \to \infty$$

Obied, Ooguri, Spodyneiko, Vafa '18

This behaviour arises naturally in string theory, and is required asymptotically by swampland conjectures.

Ooguri, Palti, Shiu, Vafa '18

- **De Sitter swampland conjecture:** this must hold (with minor qualifications) throughout moduli space, forbidding dS vacua.

dS vacua (KKLT, LVS)	vs.	dS swampland conjecture
Necessarily complicated Vacuum energy		Simple but speculative Quintessence

The KKLT proposal

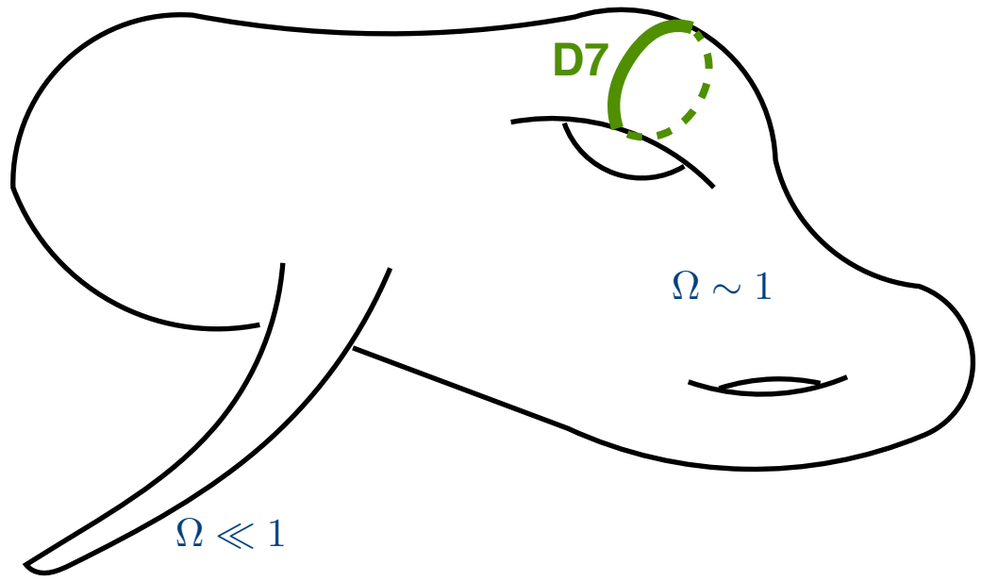
Kachru, Kallosh, Linde, Trivedi ’03

KKLT

- Type IIB compactification with one Kahler (volume) modulus T.

  Step 0: warped compactification to Minkowski with O7-planes, D3/D7-branes and fluxes

$$V(T) = 0$$ (no-scale, c.s. stabilised)



$$ds_{10}^2 = \Omega^2(y)\,\eta_{\mu\nu}\,dx^\mu\,dx^\nu + g_{mn}\,dy^m\,dy^n$$

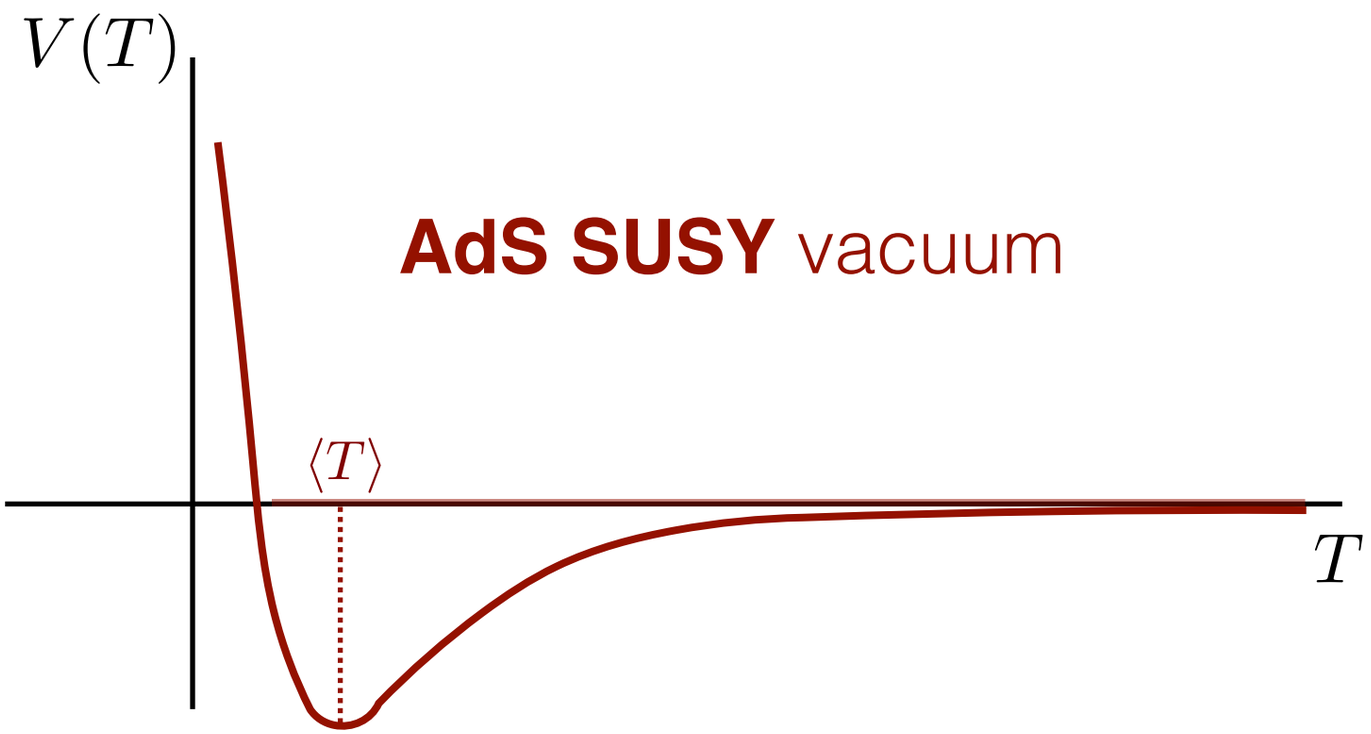
Giddings, Kachru, Polchinski ‘01

KKLT

- Type IIB compactification with one Kahler (volume) modulus T.

Step 1: take into account non-perturbative effects, e.g. gaugino condensation on D7-branes

$$\langle \lambda\lambda \rangle \sim e^{-T} \qquad \Longrightarrow \qquad V(T) \sim \frac{1}{T} e^{-2T} - \frac{2}{T^2} W_0 e^{-T}$$



AdS SUSY vacuum

W_0: flux superpotential

$$W_0 \sim e^{-\langle T \rangle}$$

Computational control:

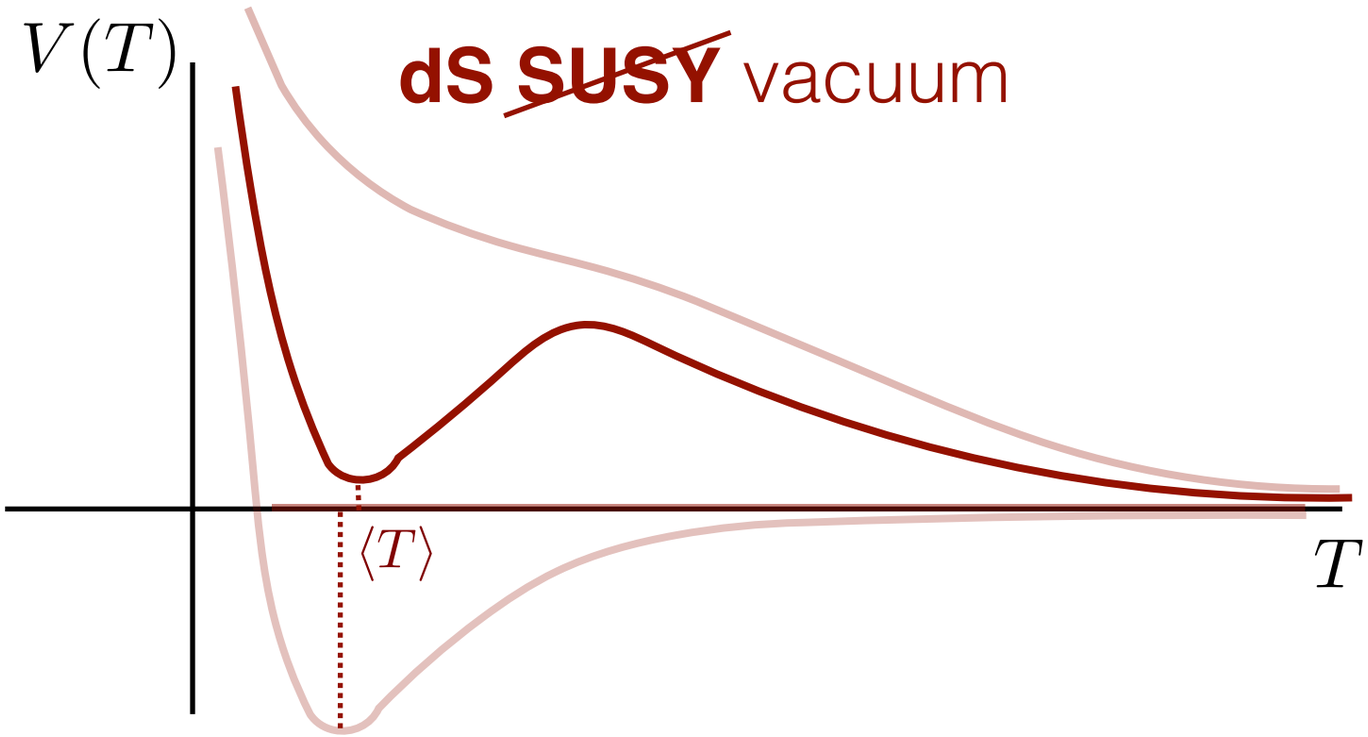
$$\langle T \rangle > 1 \implies W_0 \ll 1$$

KKLT

- Type IIB compactification with one Kahler (volume) modulus T.

  Step 2: introduce anti-D3-brane at the tip of the throat

$$V(T) \sim \frac{1}{T} e^{-2T} - \frac{2}{T^2} W_0 e^{-T} + \frac{\mu_3}{T^2}$$



$\mu_3 << 1$: warped D3-tension

If μ_3 not small enough

$\Rightarrow$ runaway

KKLT

- The KKLT proposal combines string theory ingredients (fluxes, non-perturbative effects & anti-branes) in a clever way

  Individually, each ingredient is relatively well understood

  It is their combination in a single setup that is poorly controlled

- Despite thorough scrutiny since proposed, it has resisted strong criticism rather well.

  On the other hand, no explicit construction obtained so far

- If (strong) no-dS conjecture holds they should be pathological

  Renewed interest and attacks on KKLT and LVS.