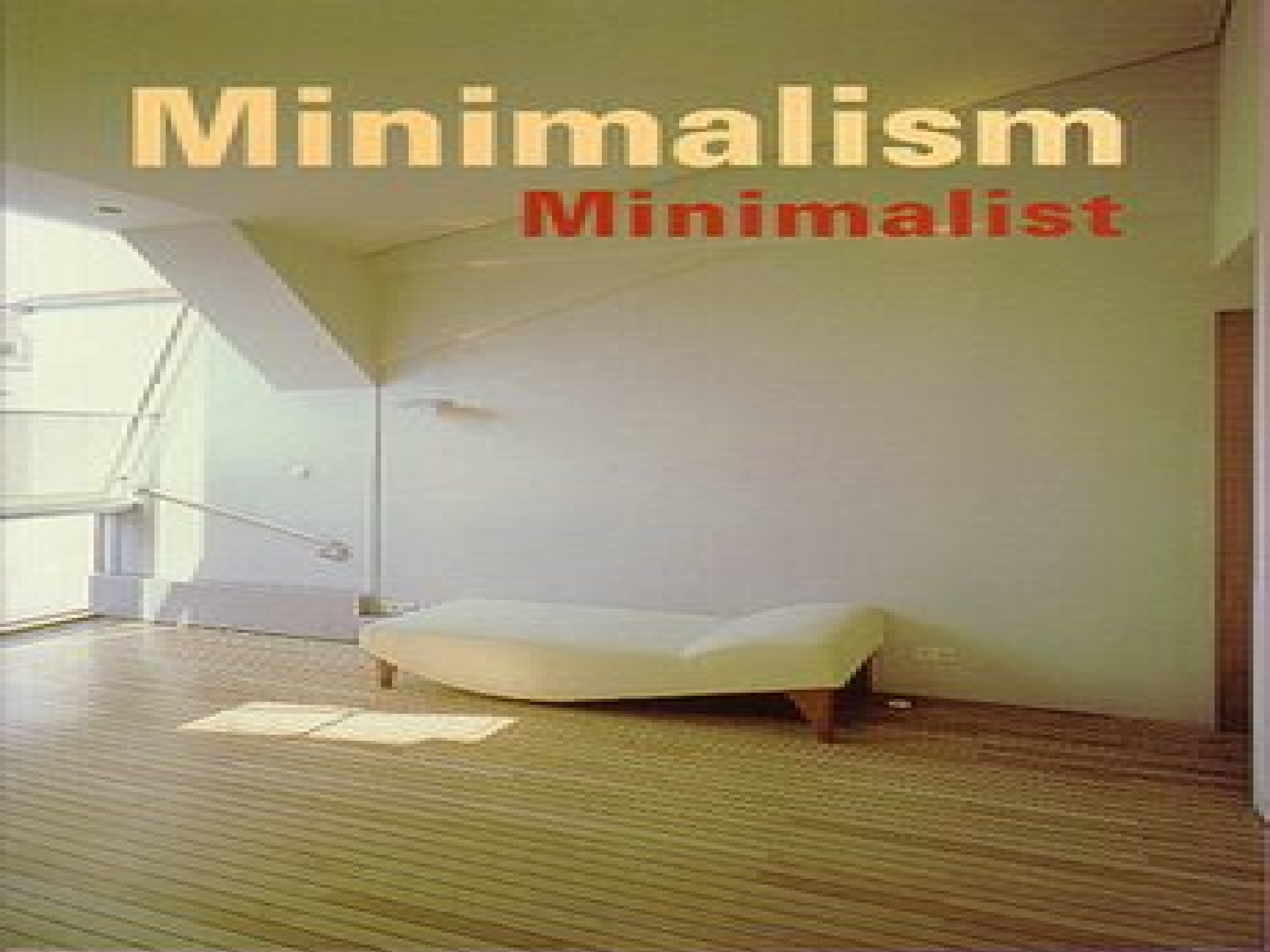
Minimalism
Minimalist

Minimalism

Minimalist

de Sitter Vacua

Bret Underwood

McGill University

Pheno 2009

S. Haque, G. Shiu, *BU*, T. Van Riet, Phys. Rev. D79:086005 (2009), arXiv:0810.5328

Does dS space exist classically from a top-down construction?

dS Space

Bottom Up

To construct classical dS solutions, just add cosmological constant

$$H^2 = \frac{1}{3M_p^2}\left(\rho + \Lambda_{cc}\right)$$

dS Space

Bottom Up

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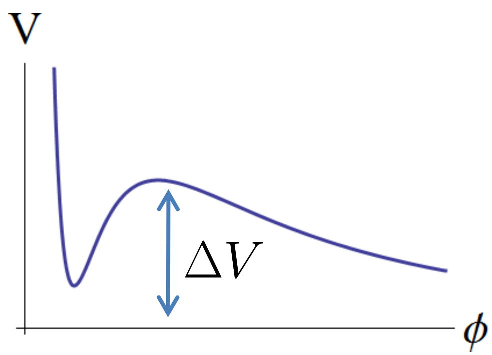
Top Down

Cosmological constant comes from scalar potential with positive energy local minimum.



Constructions require moduli stabilization, *quantum effects*. [KKLT, 03], [LARGE volume, 05],…

Is nature telling us that dS space is inherently quantum, or do *classical* top-down constructions exist?

Other interesting features:

- Typically $\Delta V \sim M_p^2 m_{3/2}^2, \;\; \Rightarrow H_{inf} < m_{3/2}$
- Typically $m_\phi \sim \mathcal{O}(\mathrm{few} \times \mathrm{TeV})$ non-thermal decay into DM

No-Go Theorems

Dimensional reduction of 10d supergravity → potential in 4D:

Two scalar fields always present in any compactification

$$\rho \equiv (\mathrm{Vol})^{1/3}, \ \tau \equiv e^{-\phi}(\mathrm{Vol})^{1/2}$$

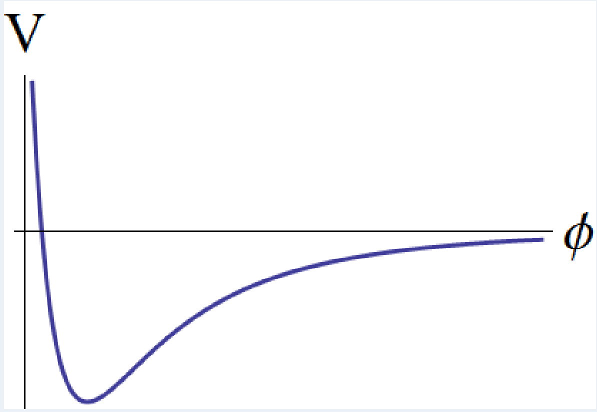
$$V(\rho,\tau) = a(\rho)\tau^{-2} - b(\rho)\tau^{-3} + c(\rho)\tau^{-4}$$

Internal curvature, H_3 flux, KK5-branes, NS5-branes, (indefinite sign)	D-branes O-planes (indefinite sign)	p-form fluxes (always positive)

No-Go: [Maldacena, Nunez, 00]

"If no sources, then no dS"

$$V(\rho,\tau) = a(\rho)\tau^{-2} - \cancel{b(\rho)\tau^{-3}} + c(\rho)\tau^{-4}$$



Always has minimum with V<0

No-Go Theorems

$$V(\rho,\tau) = a(\rho)\tau^{-2} - b(\rho)\tau^{-3} + c(\rho)\tau^{-4}$$

Finding dS vacua is as easy as "a,b,c":

dS vacua $\Leftrightarrow$ Minimizing the quantity $\frac{4ac}{b^2} \approx 1$ [Silverstein, 08]

No-Go: [Tegmark et al, 07]

"If IIA, fluxes, O6/D6, then no dS vacua"

$$a(\rho) = \frac{A_{NSNS}}{\rho^3}$$ H3 flux, (always positive)

$$b(\rho) = n_{O6}A_{O6} - n_{D6}A_{D6}$$ D-branes O-planes (indefinite sign)

$$c(\rho) = \sum_p \rho^{3-p} A_p^{RR}$$ p-form fluxes (always positive)

$$\frac{4ac}{b^2} = (\text{const}) \sum_p \rho^{-p} A_p^{RR}$$

Cannot be minimized in ρ direction:

No dS vacua!

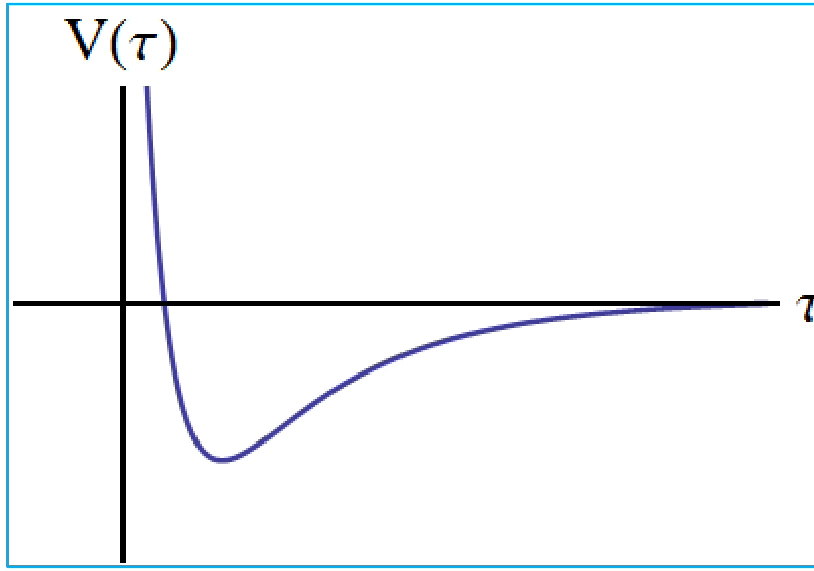
Minimal dS vacua [Underwood et al 08]

$$V = \left(\frac{A_{curvature}}{\rho} + \frac{A_{NSNS}}{\rho^3} \right) \tau^{-2} - (n_{O6} - n_{D6}) A_6 \tau^{-3} + \left(\sum_p \rho^{3-p} A_p^{RR} \right) \tau^{-4}$$

$$A_{curvature} \sim -\int R_6$$

Zero Curvature:

$$A_{curvature} \sim -\int R_6 = 0$$



Positive Curvature:

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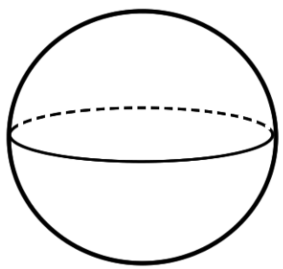

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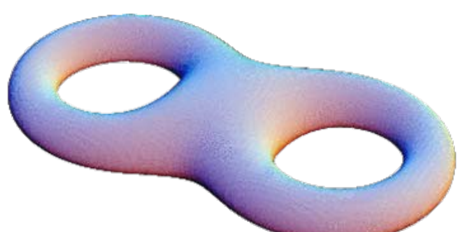

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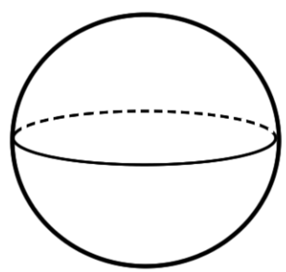

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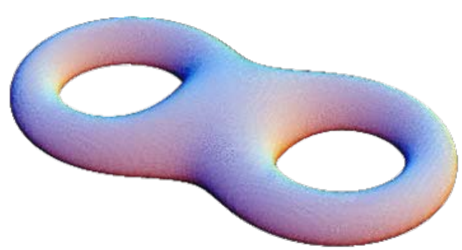

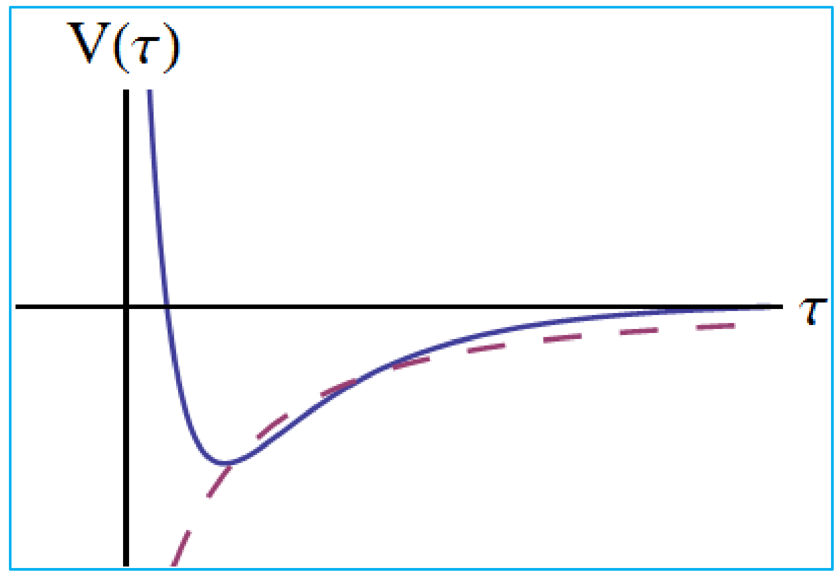

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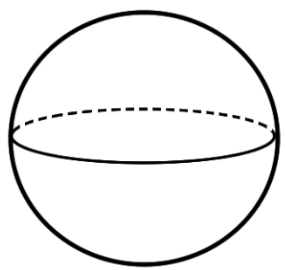

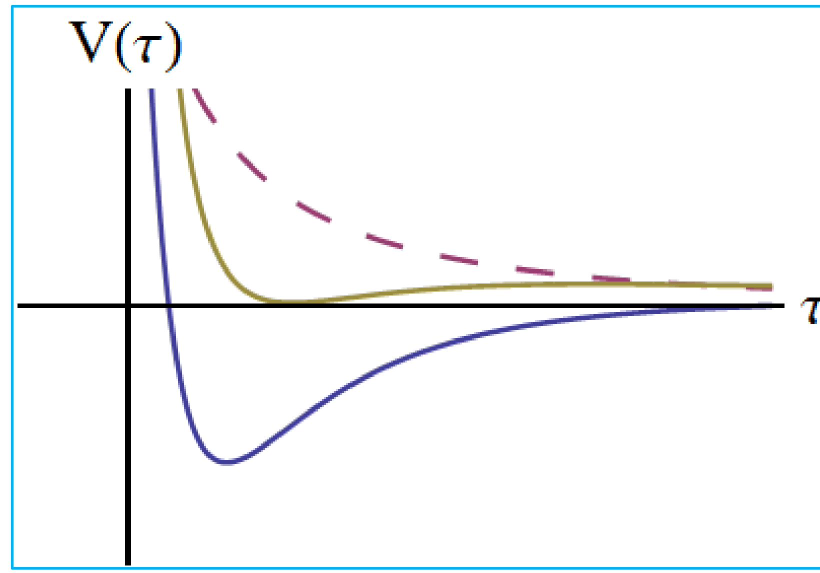

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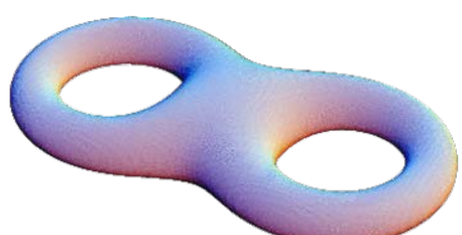

Minimal dS vacua:
"If IIA, fluxes, O6/D6, negative curvature, then dS vacua possible"

Minimal dS vacua [Underwood et al 08]

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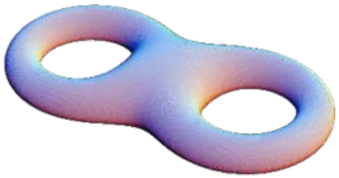

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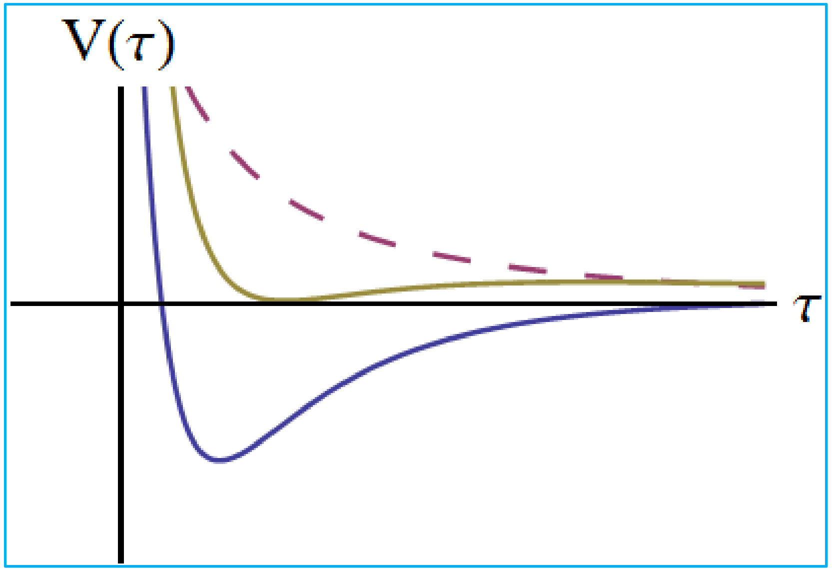

Minimal dS vacua:

"If IIA, fluxes, O6/D6, negative curvature, then dS vacua possible"

$$\frac{4ac}{b^2} = (\text{const})\sum_p A_p^{RR}[A_{curvature}\rho^{2-p} + A_{NSNS}\rho^{-p}]$$

Can minimize $\frac{4ac}{b^2} \approx 1$

Summary

Minimal Ingredients for 10d dS (in IIA):

"If IIA, fluxes, O6/D6, internal curvature, then dS vacua possible"

Examples…?

- "Twisted 3-tori": Can classify all possibilities. All fail – additional moduli lead to runaway directions. [Underwood et al, 08]
- "Twisted 6-tori": simple constructions all fail [Caviezel et al, 08] [Flauger et al, 08]
- "Compact Hyperbolic Manifolds": Seem to work!" [Underwood et al, 08]

Lift to 10D? Solving 10D equations tricky…

[Underwood et al, in progress]

Summary

Minimal Ingredients for 10d dS (in IIA):

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Lift to 10D? Solving 10D equations tricky…

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Q: Is nature telling us that dS vacua are inherently quantum, or do *classical* top-down constructions exist?

A: Minimal (necessary) ingredients known, but are they sufficient?

Example: Compact Hyperbolic Manifolds

Consider 6D internal space to be product of 3-dimensional compact hyperbolic spaces:

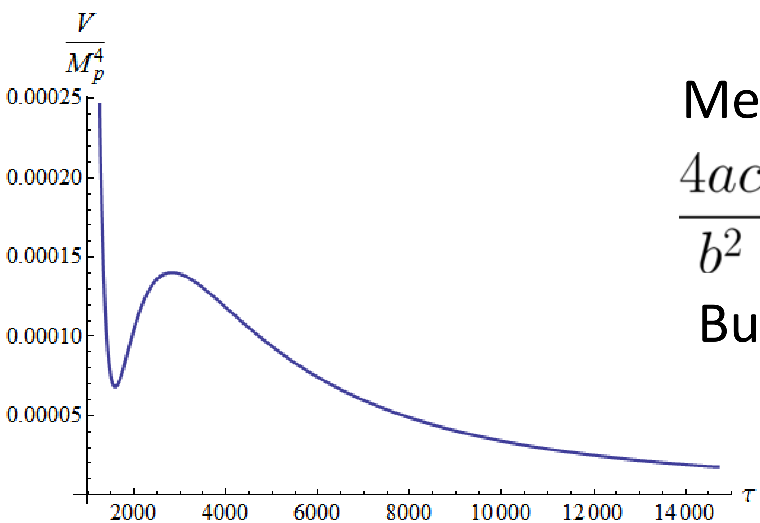
$$ds_6^2 = d\mathbb{H}_3^2 + d\tilde{\mathbb{H}}_3^2 \qquad d\mathbb{H}_3^2 = \frac{6}{\Lambda}(d\varphi^2 + \sinh^2(\varphi)d\Omega_2^2)$$

O6-plane maps $\mathbb{H}_3 \leftrightarrow \tilde{\mathbb{H}}_3$

$f_6 \in \mathbb{Z}, \ f_0 = 1, 2$

$$\frac{V(\tau,\rho)}{M_p^2\alpha'^{-1}} = \tau^{-2}\left[\frac{1}{\rho} + \frac{32\pi^4}{f_0^2}\rho^{-3}\right] - 4\sqrt{8}\pi\tau^{-3} + \left[\frac{f_0^2}{16\pi^2}\rho^3 + \frac{(2\pi)^{10}f_6^2}{\rho^3}\right]\tau^{-4}$$

Curvature NSNS flux O6-plane 0-form flux 6-form flux



Meta-stable solutions exist:

$$\frac{4ac}{b^2} \approx 1.03, \ \rho_{dS} \approx 90, \ V_{dS}/M_p^4 \approx 8 \times 10^{-5}$$

But with tradeoffs…

$$g_s \approx \frac{\sqrt{\rho_{dS}}}{4\pi\sqrt{2}} \approx 0.56 \qquad \frac{H^{-1}}{r_c} \sim 5 \qquad m_{moduli} \sim m_{kk}$$