

Heterotic dS Vacua, Modular Symmetry, & Stringy Instantons

arXiv: 22XX.XXXXX
N. Righi & A. Westphal

Jacob M. Leedom

DESY Theory Workshop 2022, 29.09.2022



Overview

- > Work with 4D $\mathcal{N} = 1$ toroidal orbifold compactifications of the Heterotic string, e.g. $X_6 = T^6/\mathbb{Z}_N$
- > Prove no-go theorem for dS minima for Kähler modulus + dilaton sector including non-perturbative effects in superpotential
- > Attempt to extend no-go results to stronger non-perturbative effects in g_s & indicate potential loophole



Heterotic de Sitter: No-Go Results

[Maldacena-Nunez]



Classical SUGRA?

No dS

AdS OK

Heterotic de Sitter: No-Go Results

$$S = \frac{1}{2\kappa^2} \int d^{10}x \sqrt{-g} e^{-2\phi} \left[R + 4(\partial\phi)^2 - \frac{1}{2}|H|^2 - \frac{\alpha'}{4} \left(\text{Tr}|F|^2 - \text{Tr}|R_+|^2 \right) \right]$$

[Maldacena-Nunez]



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[Maldacena-Nunez]



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[Gautason+, '12]



Infinite α' tower?

No dS

No AdS

Heterotic de Sitter: No-Go Results

Includes worldsheet instantons & high curvature solutions

[Maldacena-Nunez]



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[Kutasov+, '15]



Nonperturbative α' ?

No dS

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Heterotic de Sitter: No-Go Results

$$W(S) \sim e^{-S} \rightarrow \delta\mathcal{L} \sim \exp\left[-1/g_s^2\right]$$

$$\frac{g_s^2}{2} = \left\langle \frac{1}{S + \bar{S}} \right\rangle$$

[Maldacena-Nunez]



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Nonperturbative g_s ,
Gaugino Condensation?

No dS*

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[Gonzalo+, '18]



Instantons, Condesates,
Threshold Corrections*?

No dS (numerically)

AdS OK

Two-Moduli Model

> Kähler Modulus T and Dilaton S

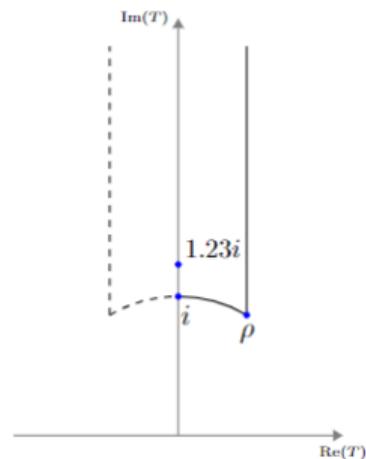
• T has an $SL(2, \mathbb{Z})$ duality:

$$T \rightarrow \gamma \cdot T = \frac{aT + b}{cT + d}$$

[Cvetic,Font,Ibanez,Lust,Quevedo,'91]

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Two-Moduli Model

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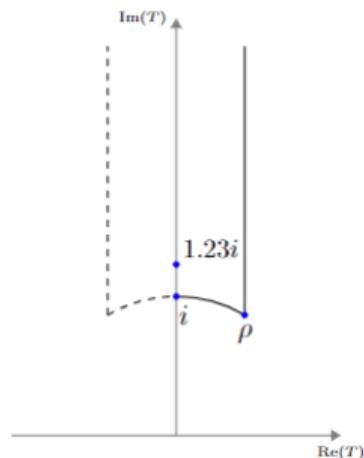
$$T \rightarrow \gamma \cdot T = \frac{aT + b}{cT + d}$$

- Kähler potential

$$\mathcal{K} = -\ln(S + \bar{S}) - 3\ln(i(T - \bar{T}))$$

- Superpotential

$$W(S, T) = \frac{\Omega(S)H(T)}{\eta^6(T)}$$



Two-Moduli Model

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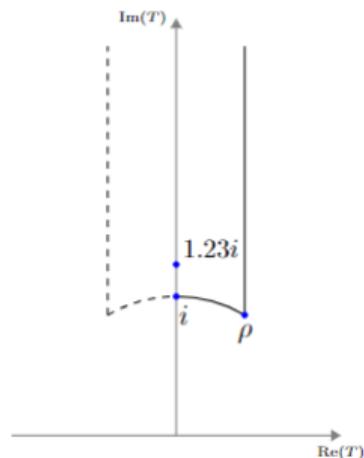
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$$\Omega(S) = h + \sum_a \Lambda_a^3 e^{-k_a S/b_a}$$

$$H(T) = \left(\frac{G_4(T)}{\eta^8(T)} \right)^n \left(\frac{G_6(T)}{\eta^{12}(T)} \right)^m \mathcal{P}(j(T))$$

[Rademacher,Zuckerman,'38]

[Discontinuous Groups and Automorphic Functions - Lehner]

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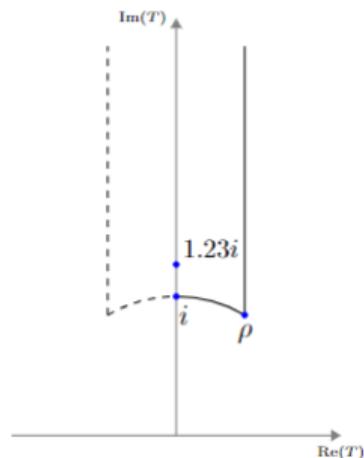
$$\mathcal{K} = -k(S, \bar{S}) - 3 \ln(i(T - \bar{T}))$$

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- Scalar Potential

$$\begin{aligned} V(S, T) &= e^{\mathcal{K}} (K^{S\bar{S}} F_S \bar{F}_{\bar{S}} + K^{T\bar{T}} F_T \bar{F}_{\bar{T}} - 3\bar{W}W) \\ &= e^{k(S, \bar{S})} Z(T, \bar{T}) |\Omega(S)|^2 \left\{ |H(T)|^2 (A(S, \bar{S}) - 3) + \hat{V}(T, \bar{T}) \right\} \end{aligned}$$



$$A(S, \bar{S}) = \frac{K^{S\bar{S}} F_S \bar{F}_{\bar{S}}}{|W|^2} = \frac{K^{S\bar{S}} |\Omega_S + K_S \Omega|^2}{|\Omega|^2}$$

$$Z(T, \bar{T}) = \frac{1}{i(T - \bar{T})^3 |\eta(T)|^{12}}$$

$$\hat{V}(T, \bar{T}) = \frac{-(T + \bar{T})^2}{3} \left| H'(T) - \frac{3i}{2\pi} H(T) \hat{G}_2(T, \bar{T}) \right|^2$$

Two-Moduli Model

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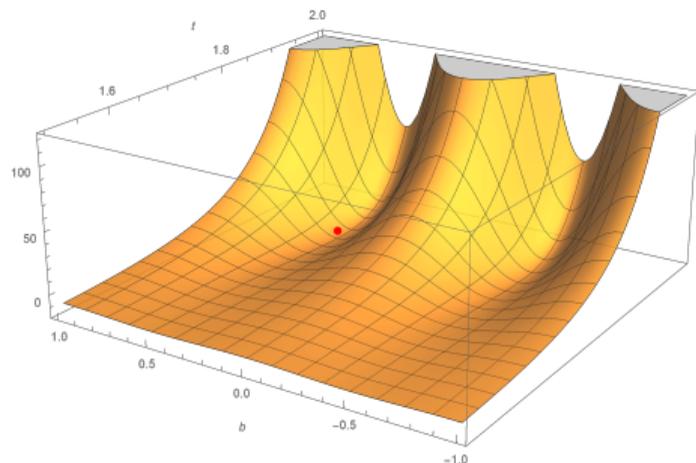
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A dS No-Go Result

> Extrema in dilaton sector come in two classes

Class A: $\Omega_S(S) + K_S\Omega(S) = 0 \rightarrow F_S = 0$

Class B: $F_S \neq 0$



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> Proof by contradiction: Assume Class A extremum that is a dS vacuum.
We can focus only on the Kähler modulus sector

$$\begin{aligned} V_0 &= \Lambda^4 > 0 \\ (\partial_T V)_0 &= 0 \\ (\text{Hes}_T[V])_0 \ \&\ (\partial_t^2 V)_0 > 0 \end{aligned}$$



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$$\begin{aligned} \partial_t^2 V &= 2\partial_T \partial_{\bar{T}} V - 2\text{Re}(\partial_T^2 V) \\ (\partial_T \partial_{\bar{T}} V)_0 \propto -2\Lambda^4 < 0 &\Rightarrow \partial_a^2 V = 2\partial_T \partial_{\bar{T}} V + 2\text{Re}(\partial_T^2 V) \\ \partial_t \partial_a V &= -2\text{Im}(\partial_T^2 V) \end{aligned}$$



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Cannot both be positive



dS minima not possible



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Class A extrema
can never be dS vacua



Beyond the No-Go

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- > All mixed derivatives of T & S are weight 2 modular forms \Rightarrow Hessian factorizes



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- > All mixed derivatives of T & S are weight 2 modular forms \Rightarrow Hessian factorizes
- > Self dual points always extremum - when are they minima in T -sector?



The Modular Landscape: $T = i$

$$V(S, \bar{S}, i, -i) = \frac{2^{4n+9} \pi^{8n+9}}{\Gamma^{12}(1/4)} |\Omega(S)|^2 |\mathcal{P}(1728)|^2 e^{k(S, \bar{S})} (A(S, \bar{S}) - 3)$$

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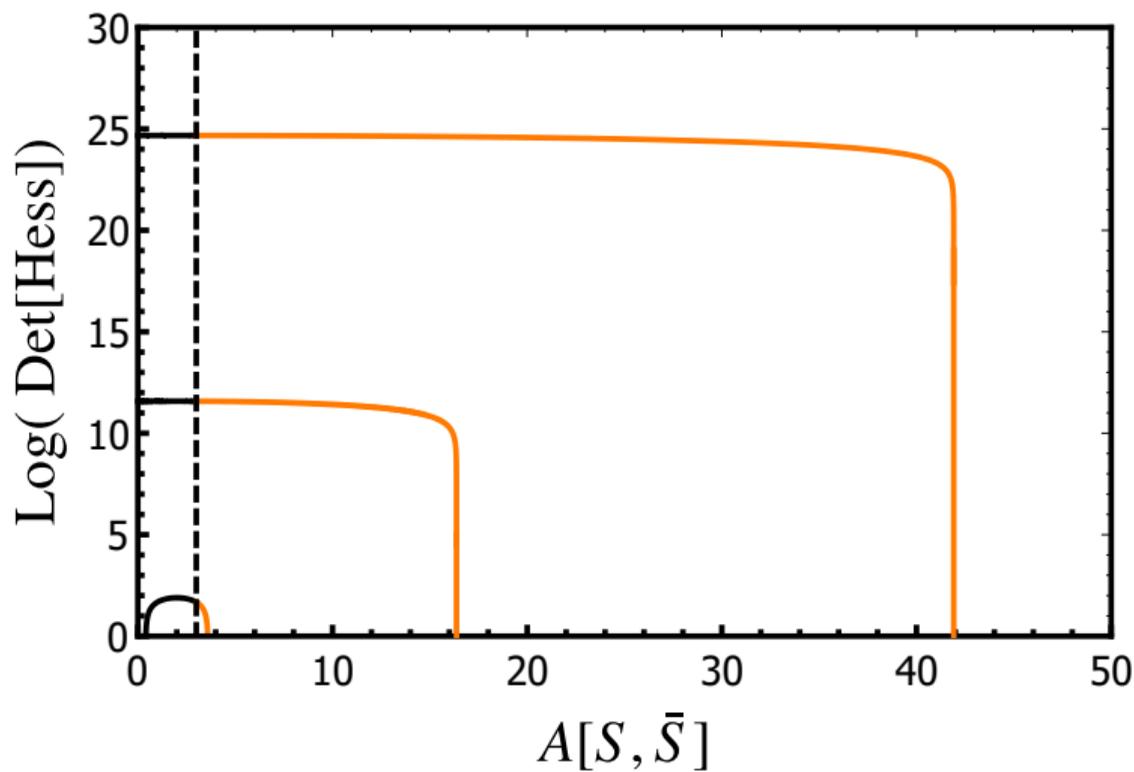
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- > dS extremum at $T = i$ if dilaton is stabilized with $\langle A(S, \bar{S}) \rangle > 3$
- > If we set $\mathcal{P}(j(T)) = 1$, then this point is stable in T sector if

$$2 - \frac{(1 + 8n)\Gamma^8(1/4)}{192\pi^4} < A(S, \bar{S}) < 2 + \frac{(1 + 8n)\Gamma^8(1/4)}{192\pi^4}$$

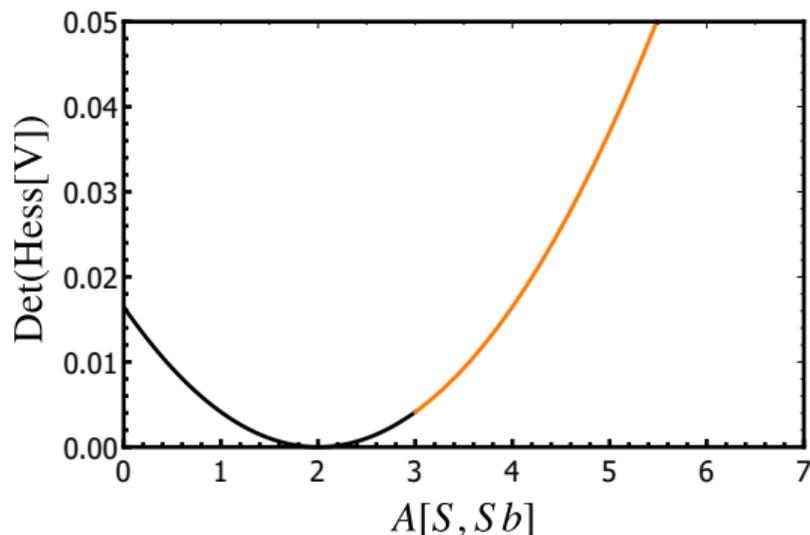
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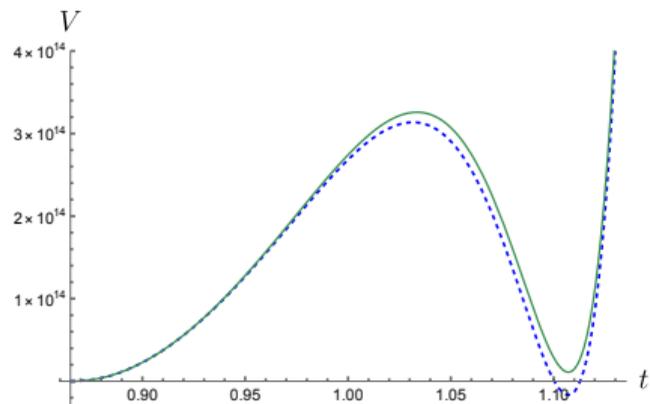
The Modular Landscape: $T = \rho$

> This point is remarkable:

$$\partial_t^2 V|_{T=\rho} = \partial_a^2 V|_{T=\rho} = \frac{2^{8m+13} \pi^{12m+12}}{3^{3(m+1)} \times 1225^m} |\Omega(S)|^2 |\mathcal{P}(0)|^2 e^{k(S, \bar{S})} (A(S, \bar{S}) - 2)$$



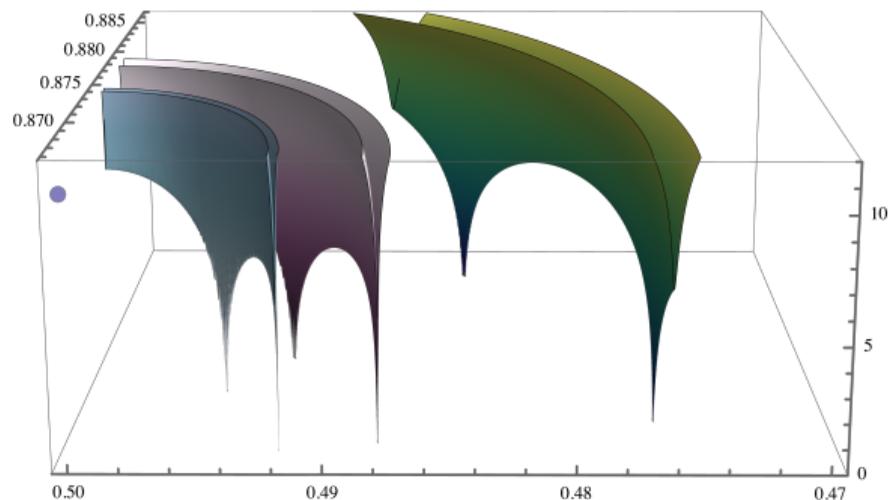
The Modular Landscape: Into the Fundamental Domain



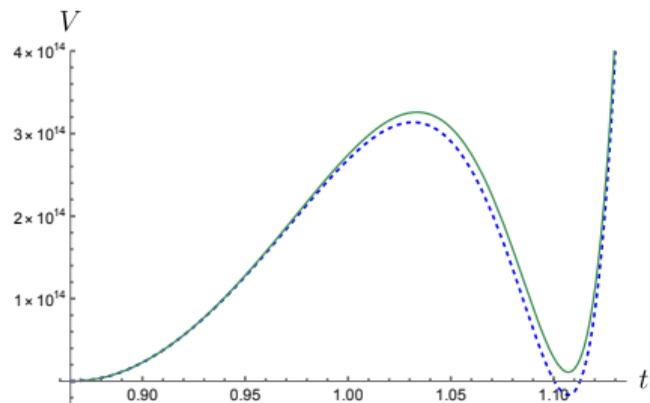
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[Novichkov+, '22]



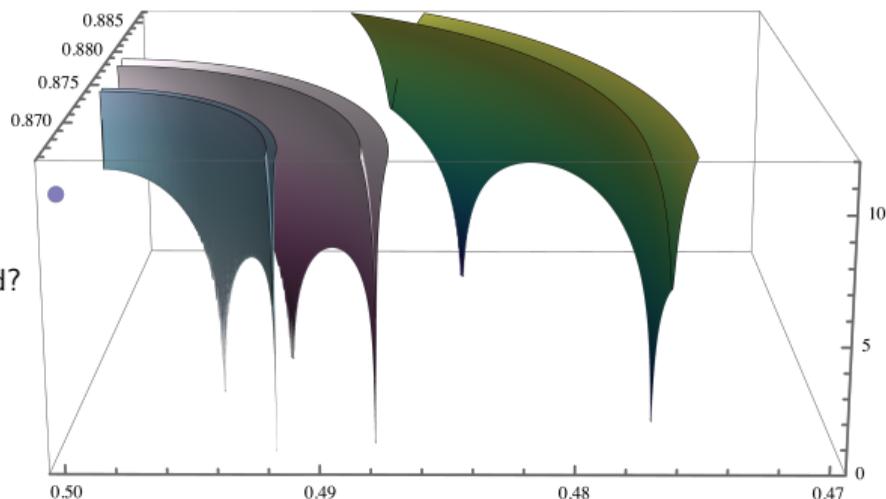
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[Novichkov+, '22]



> How can Class B vacua & $\langle A[S, \bar{S}] \rangle \geq 3$ be achieved?

One method: Shenker-like Stringy Instantons

Stringy Instantons: Shenker-like Effects

- > All closed string theories have non-perturbative contributions of strength e^{-1/g_s}
- > Bit odd in Heterotic - no D-branes!

[Shenker, '90]



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$$S^{HO} \supset \frac{g_s^{-1/2}}{2^9 (2\pi)^7 4! \ell_H^2} \int_{\mathcal{M}_{10}} \sqrt{-G} t_8 t_8 R^4 E_{3/2}(g_s^{-1})$$

$$E_{\frac{3}{2}}(g_s) = 2\zeta(3)g_s^{-3/2} + 2\zeta(2)g_s^{1/2} + \sum_{n \in \mathbb{Z}^+} 8\pi\sigma_{-1}(|n|)e^{-\frac{2\pi|n|}{g_s}} (1 + \mathcal{O}(g_s))$$



A Loophole Example

> Linear Multiplet Formalism: $L \supset \{\ell, \psi, B_2\}$

$$\langle \ell \rangle = \frac{g_s^2}{2}$$

$$\mathcal{L}_{KE} = \int d^4\theta E \left(-2 + f(L) \right) \quad k(L) = \ln(L) + g(L)$$

A Loophole Example

> Linear Multiplet Formalism: $L \supset \{\ell, \psi, B_2\}$

$$\left\langle \frac{\ell}{1 + f(\ell)} \right\rangle = \frac{g_s^2}{2}$$

$$\mathcal{L}_{KE} = \int d^4\theta E \left(-2 + f(L) \right) \quad k(L) = \ln(L) + g(L)$$

> Parametrize Shenker-like effects [Gaillard & Nelson,'07]+:

$$f(\ell) = \sum_{n=0} A_n \ell^{-q_n} e^{-B/\sqrt{\ell}} \quad L \frac{df}{dL} = -L \frac{dg}{dL} + f$$



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> Scalar potential for single gaugino condensate:

$$V(\ell) = \frac{\mathcal{T}}{\ell} \left[(1 + \ell g')(1 + b\ell)^2 - 3b^2 \ell^2 \right] e^{g-(f+1)/b\ell}$$

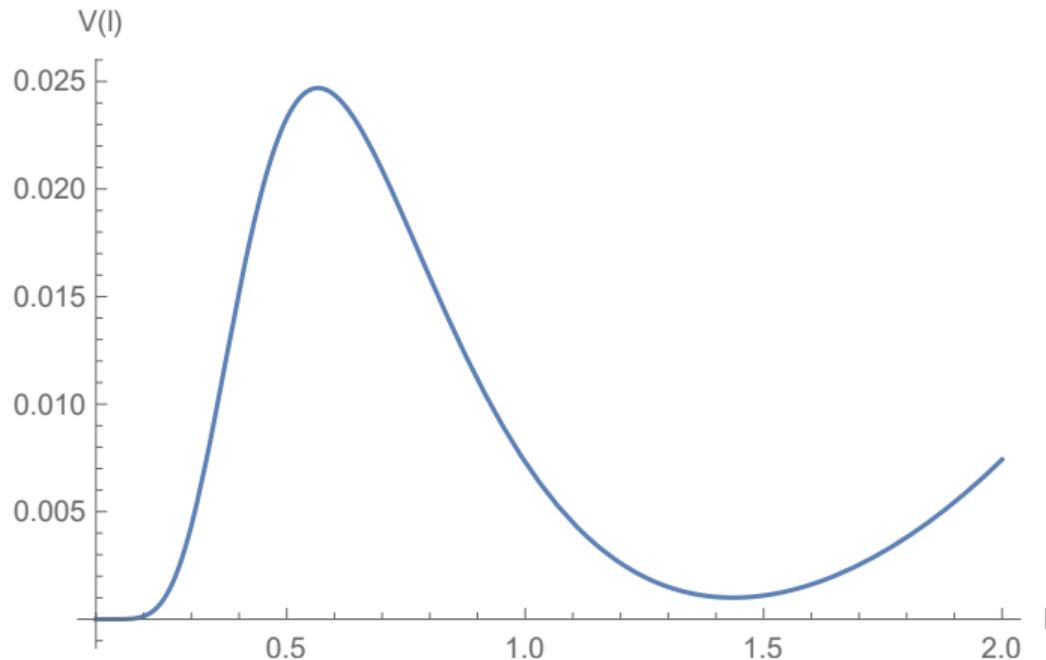
A Loophole Example

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$$\left\langle \frac{\ell}{1 + f(\ell)} \right\rangle = \frac{g_s^2}{2}$$

$$A_0 = 27$$

$$B = \pi$$

$$b_{E_8} = \frac{30}{8\pi^2}$$

$$g_s = 0.98$$

A Loophole Example

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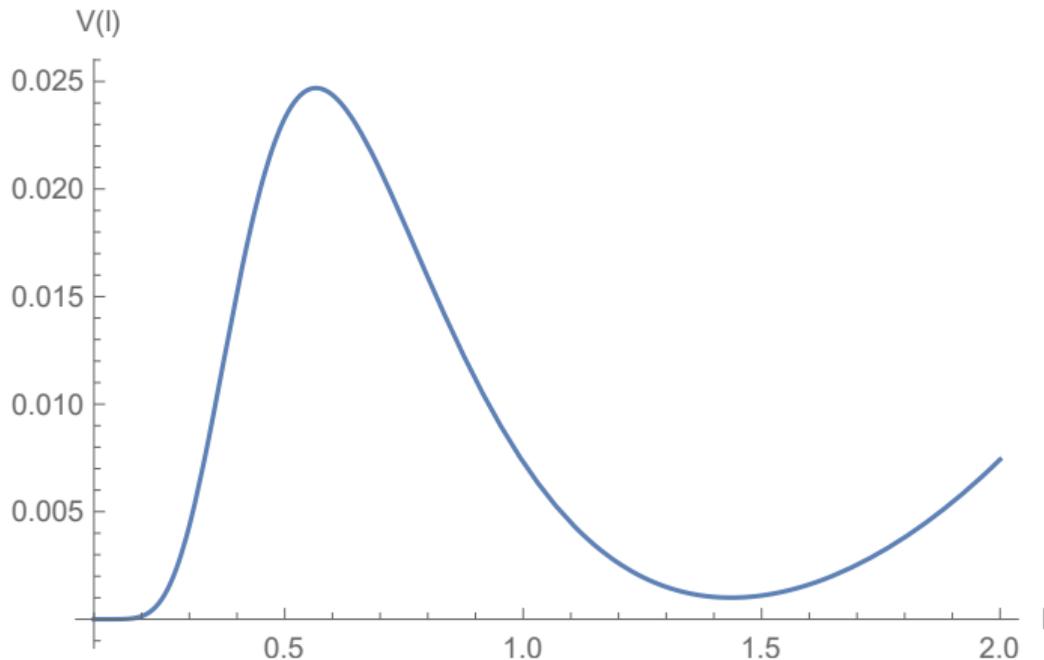
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$$\langle e^{-B/\sqrt{\ell}} \rangle \sim 0.07$$

$$\langle e^{-2B/\sqrt{\ell}} \rangle \sim 0.005$$

>



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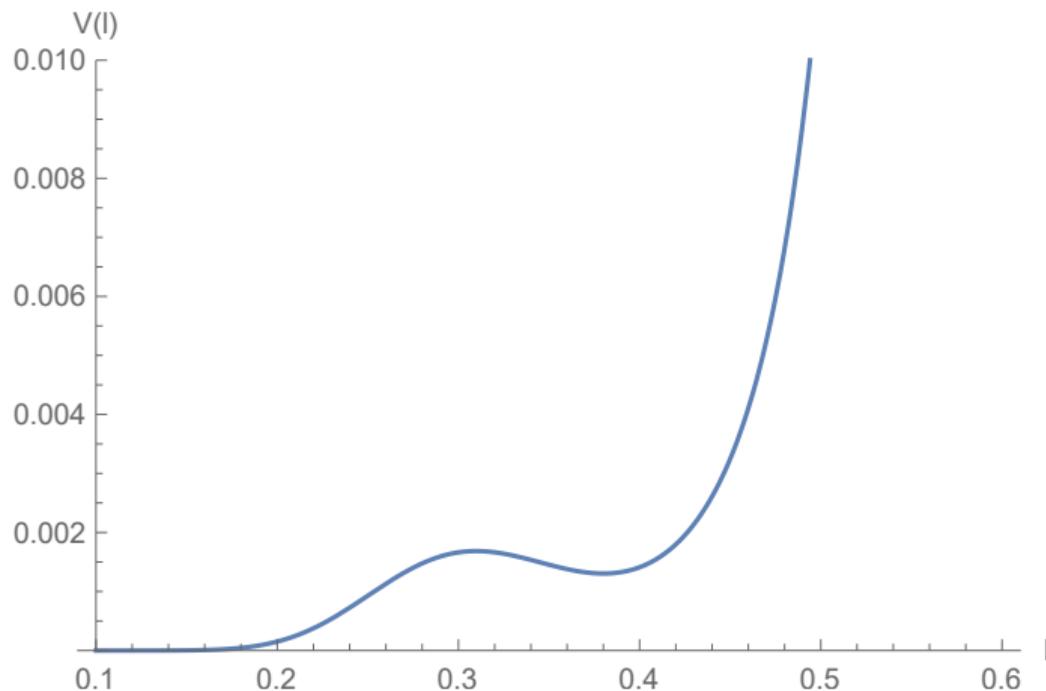
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$$f(\ell) = (A_0 + A_1 \ell^{-0.3}) e^{-B/\sqrt{\ell}}$$

$$A_0 = -5.1 \times 10^4$$

$$A_1 = 4.5 \times 10^4$$

$$B = 2\pi$$

$$b_{E_8} = \frac{30}{8\pi^2}$$

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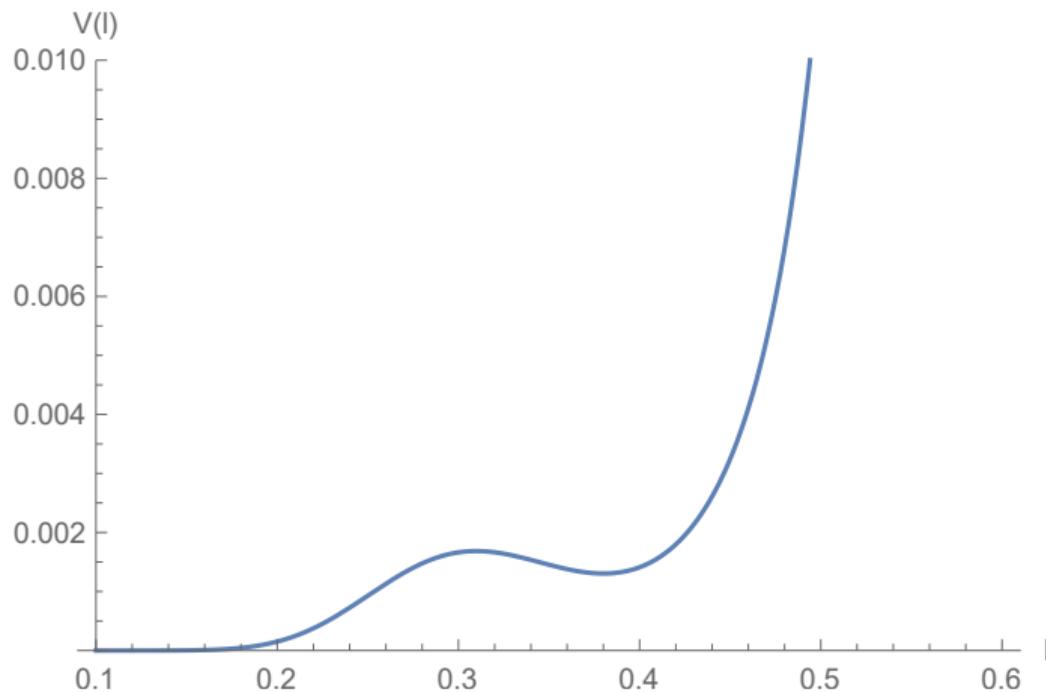
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$$B = 2\pi$$

$$b_{E_8} = \frac{30}{8\pi^2}$$

$$g_s = 0.75$$

$$\langle e^{-B/\sqrt{\ell}} \rangle \sim 3.7 \times 10^{-5}$$

$$\langle e^{-2B/\sqrt{\ell}} \rangle \sim 1.4 \times 10^{-9}$$

Conclusion

[Maldacena-Nunez]



Classical SUGRA?

No dS

AdS OK

[Green+, '11]



Leading α' ?

No dS

AdS OK

[Gautason+, '12]



Infinite α' tower?

No dS

No AdS

[Kutasov+, '15]



Nonperturbative α' ?

No dS

AdS OK

[Quigley, '15]



Nonperturbative g_s ,
Gaugino Condensation?

No dS*

No AdS*

[Gonzalo+, '18]



Instantons, Condesates,
Threshold Corrections*?

No dS (numerically)

AdS OK

Conclusion

[Maldacena-Nunez]



Classical SUGRA?

No dS

AdS OK

[Green+, '11]



Leading α' ?

No dS

AdS OK

[Gautason+, '12]



Infinite α' tower?

No dS

No AdS

[Kutasov+, '15]



Nonperturbative α' ?

No dS

AdS OK

[Quigley, '15]



Nonperturbative g_s ,
Gaugino Condensation?

No dS*

No AdS*

[This Work]



Instantons, Condesates,
Threshold Corrections*?

No dS (Class A)

AdS OK

Conclusion

[Maldacena-Nunez]	[Green+, '11]	[Gautason+, '12]	[Kutasov+, '15]	[Quigley, '15]	
Classical SUGRA?	Leading α' ?	Infinite α' tower?	Nonperturbative α' ?	Nonperturbative g_s , Gaugino Condensation?	Instantons, Condesates, Threshold Corrections*?
No dS	No dS	No dS	No dS	No dS*	No dS (Class A)
AdS OK	AdS OK	No AdS	AdS OK	No AdS*	AdS OK

Conclusion



Classical SUGRA?

No dS

AdS OK



Leading α' ?

No dS

AdS OK



Infinite α' tower?

No dS

No AdS



Nonperturbative α' ?

No dS

AdS OK



Nonperturbative g_s ,
Gaugino Condensation?

No dS*

No AdS*

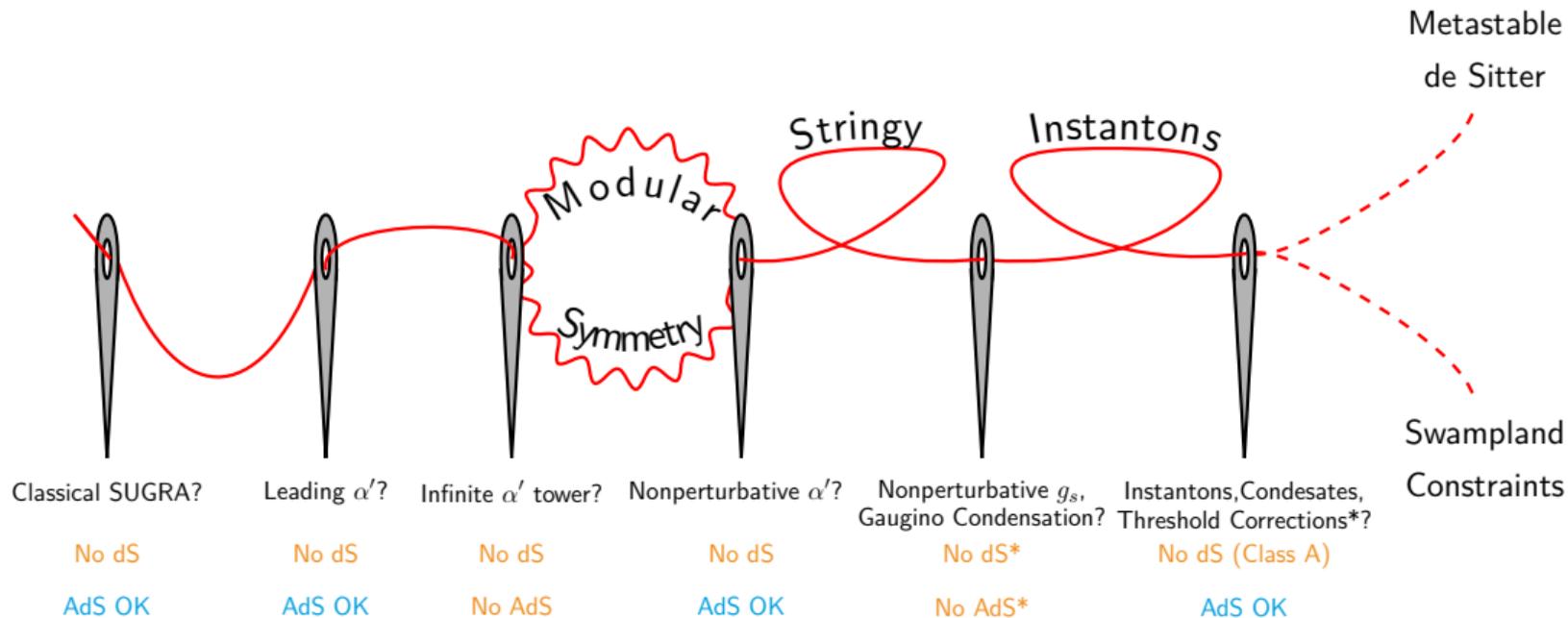


Instantons, Condesates,
Threshold Corrections*?

No dS (Class A)

AdS OK

Conclusion



Contact

Contact

DESY. Deutsches
Elektronen-Synchrotron

www.desy.de

Jacob M. Leedom
 0000-0003-4911-2188
Theory - Cosmology
jacob.michael.leedom@desy.de
Office O1.142

