6.4 KKLT

(Kachru, Kallosh, Linde, Trivedi '03)

- Focus on $h^{1,1} = 1$, i.e.

$$K = -3\ln(T+\bar{T}) \; ; \; W = W_0 \leftarrow \text{const. det. by flux choice}$$

$$V \equiv 0 \; ; \; \text{SUSY} \; (m_{3/2} \sim e^{K/2} W_0)$$

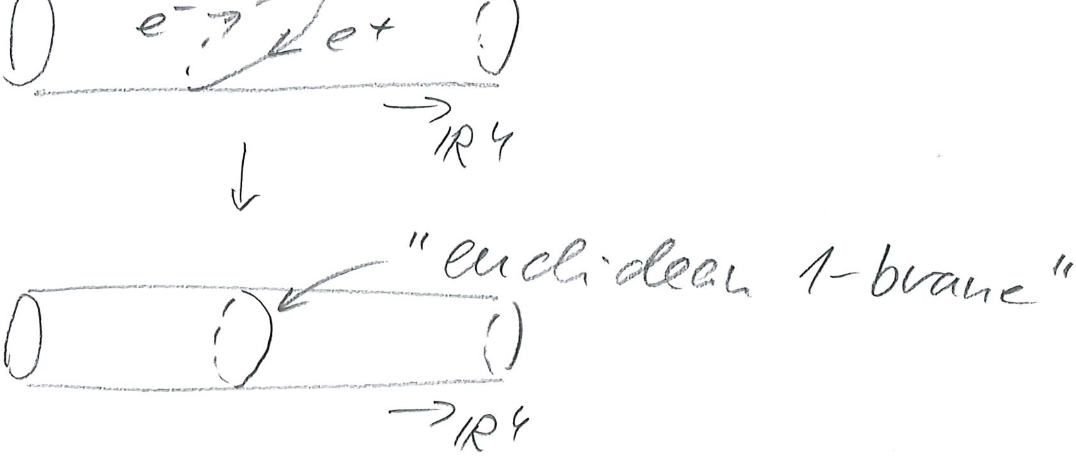
- Quantum corrections will break this "no-scale structure" $(V \equiv 0)$

E.g. Stringy / Exotic / D-brane-Instantons

$$\Downarrow$$

$$W_0 \longrightarrow \underbrace{W_0 + A}_{\text{dep. on } z} e^{-2\pi T}$$

- Idea same as for our toy model instantons in ED in 5d $\longrightarrow$ 4d on S^1



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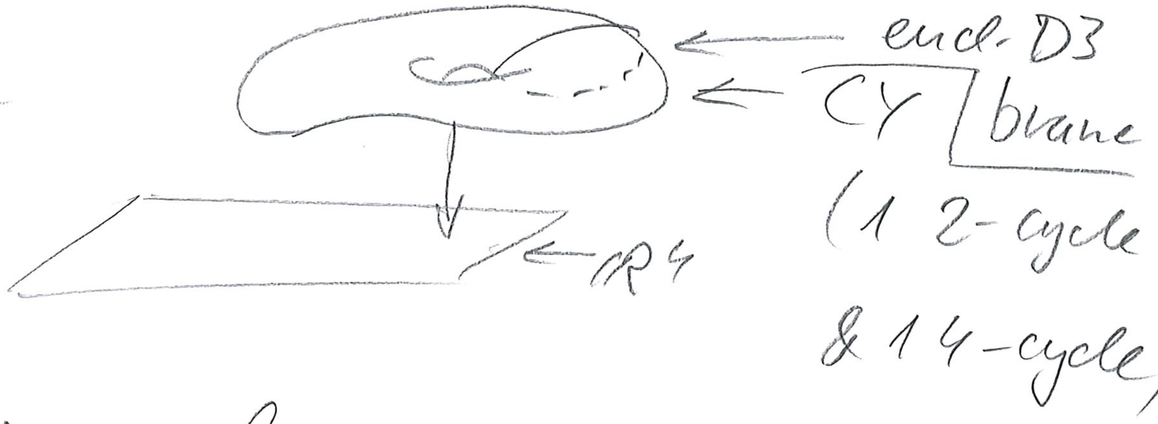


action: $\int_{C_4} \sqrt{g_6} \sim R_{CY}^4 \sim \mathrm{Re}\,T \sim \tau$

4-cycle-volume

couples to C_4 in 10d;

$\int_{C_4} C_4 \sim c$ of $T = \tau + ic$

$\Rightarrow$ single instanton effect: $\sim e^{-2\pi\tau} e^{-ic}$

action suppression of tunneling (e^{-S})

coupling to axion

Sum over all numbers of inst.

$\Rightarrow$ exponentiation

Non-SUSY $\quad e^{-2\pi\tau} \cos(c)$

SUSY: $\quad W_0 \to W_0 + A e^{-T}$

(or $K \to K + e^{-T} + \text{c.c.}$)

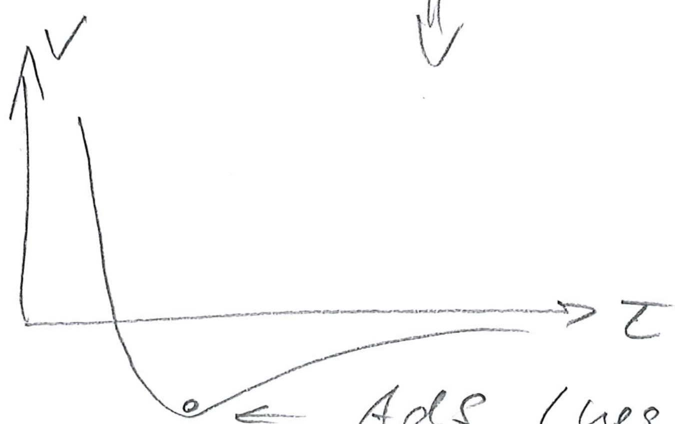
<u>Now</u>: $K = -3\ln(T+\bar{T})$

$W = W_0 + e^{-T}$ ($A = a = 0$ for simplic.)

$\Downarrow$

$V = V(\tau)$ (assume $V(\tau, c)$ is minimized in c; ignore c)

$\Downarrow$



$\leftarrow$ AdS (neg.-Λ) minimum

(SUSY restored; can check: $DW = 0$ at this minimum)

$\uparrow$ technically

$$DW = -e^{-T} - \frac{3}{T+\bar{T}}(W_0 + e^{-T}) \overset{!}{=} 0$$

$\Updownarrow$ (assume $c=0$)

$$W_0 = -\left(1 + \tfrac{2}{3}\tau\right) e^{-\tau}$$

Need $W_0 \ll 1$ (& real, neg.) to be in parametric control ($R_{cy} \gg 1$).

- **Note:** This works for any phase of W_0, just $c=0$ will be modified.

$\Rightarrow$ so far: landscape of AdS vacua. (SUSY)

- **Want:** dS ; ~~SUSY~~

- "Macroscopic" description

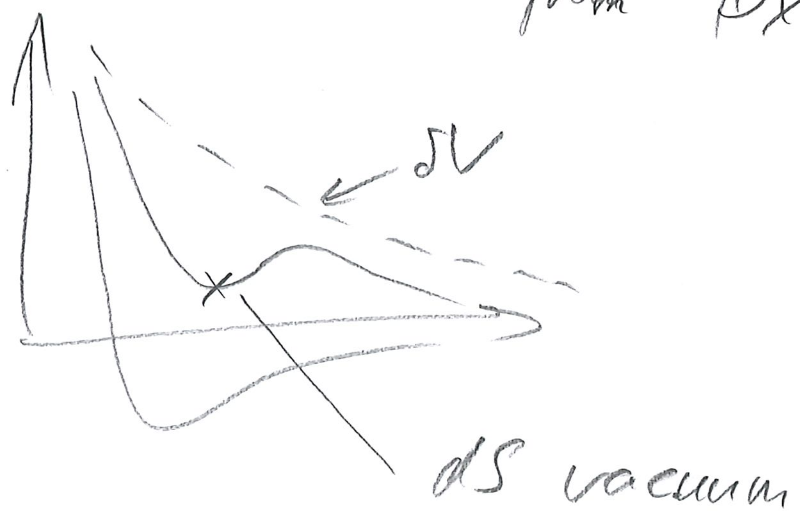
$$K \to K(T,\bar{T}) + \delta K(X,\bar{X})$$

$$W \to \underbrace{W(T) + \delta W(X)}$$

"O'Raifeartaigh-type ~~SUSY~~ sector"

$$\Rightarrow V \to V + \delta V$$

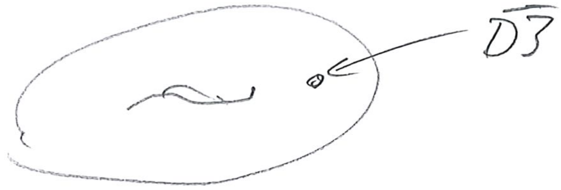
from $|D_X W|^2 \neq 0$



- Presumably many such options in (huge) landscape
- Explic. realization not trivial (exist even opinion that impossible for fundamental reasons)
- Hist. first & simplest idea (KKLT): Add $\overline{D3}$-brane (breaks SUSY relative to the $O3/D3$ planes/branes which are already present)

  "anti"
- For us: Add point-like "pos. tension" object in CY

  "pos. λ"

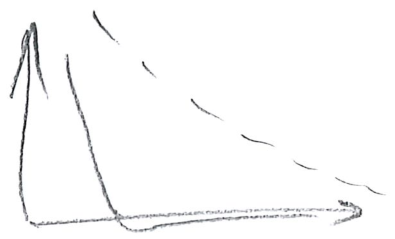


$\Rightarrow \delta V = $ const. in "Brans-Dicke-frame"

$$(S \sim V_6 R_4 + \dots)$$

go to "Einstein frame" $(S \sim R_4 + \dots$ by $g_{\mu\nu} \to g_{\mu\nu}/V_6)$

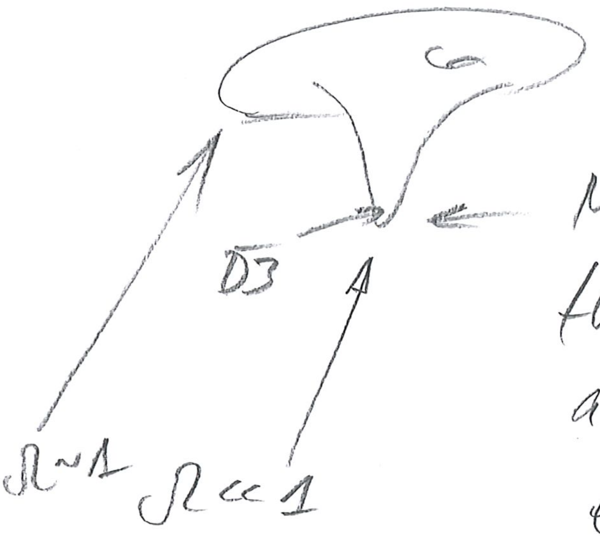
$$\Rightarrow \delta V \sim \frac{1}{V_6^2} \sim \frac{1}{\tau^3}$$



no dS minimum since uplift too strong.

<u>Idea</u>: (Based on a feature already present in GKP)

Place $\overline{D3}$ in "strongly warped region"



Metric is such that in this region all energies are scaled down exponentially

("Klebanov-Strassler-Throat")

<u>Indeed</u>: general compactification ansatz:

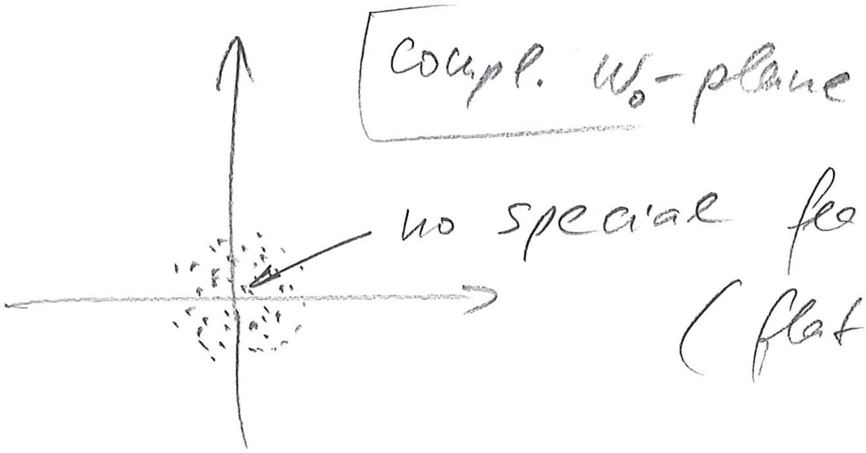
$$ds^2 = \Omega^2(y)\,\eta_{\mu\nu}\,dx^\mu dx^\nu + g_{ij}\,dy^i dy^j$$

warp factor

max. symm.

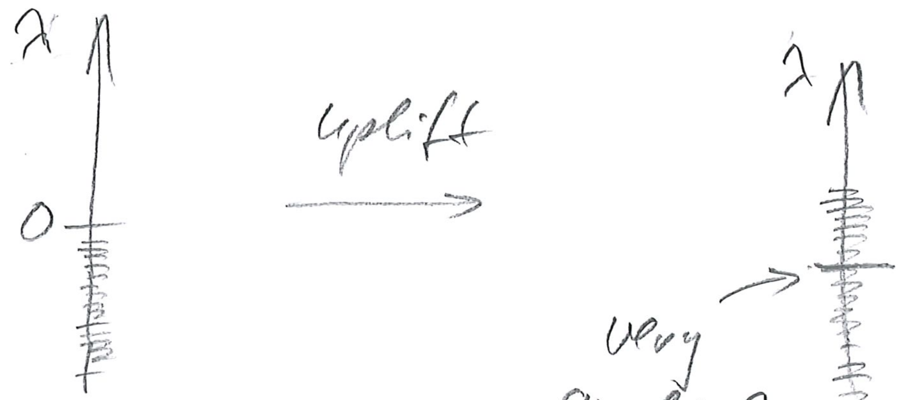
6.5 Statistics

Assuming this works and using W_0 - distribution found by Denef / Douglas '04



no special feature near 0
(flat 2d distrib.)

$\Rightarrow$ KKLT, step 1 KKLT, step 2



very small λ will be present with statistical certainty.

Overall number of vacua:

due to $\int C_4 \wedge F_3 \wedge H_3$ → fluxes source C_4 - need opp. charge from O3-planes or similar effects, limit at

$$(h, f)^2 \lesssim L_* \lesssim 10^4$$

max "tadpole"

(feature of CY orientifold).

$$N_{vac.} \sim \frac{L_*^k}{k!} \sim \left(\frac{L_*}{k}\right)^k$$

\# of 3-cycles

Say, $k = 300$, $L_* = 3000 \Rightarrow N_{vac.} \sim 10^{300}$

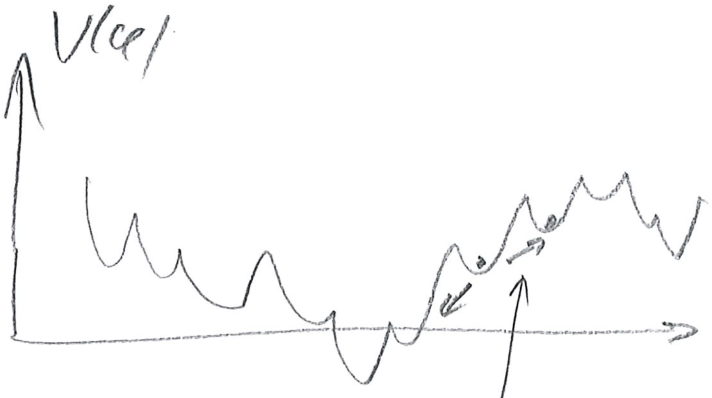
(really, much larger!)

Rough other estimate:

300 cycles; $\underbrace{2 \text{ flux from } \underbrace{-10 \dots 10}_{20}}_{40}$

$$\Rightarrow 40^{300} \sim 10^{500}$$

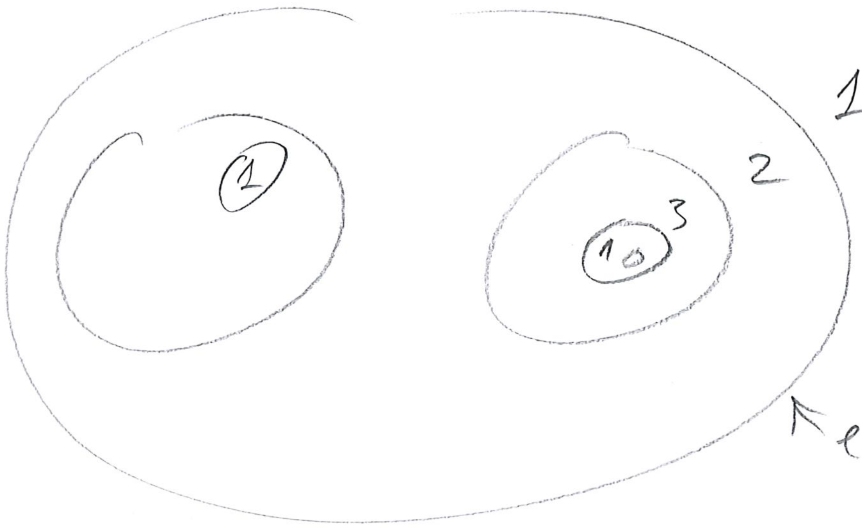
7 Eternal Infl. & Measure problem



← really: $\{\varphi_1, \dots, \varphi_N\}$ $N \gg 1$

tunneling in dS

(also upward possible)



1 ← type of vacuum

exp. bubbles

In Penrose diagram

stat. predict.

⇒ count observers

(galaxies, planets?)

⇒ Cutoff / Prescript. dep. is open problem ("Measure problem")