

Title: On Moduli Stabilisation in Calabi-Yau Flux Compactifications

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Abstract:

ON MODULI STABILIZATIONS
IN CALABI-YAU
FLUX COMPACTIFICATIONS

PER BERGLUND
U. OF NEW HAMPSHIRE

BALASUBRAMANIAN & P.B.
HEP-TH/0408054

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J. CONLON & F. QUEVEDO
HEP-TH/0502058

Outline

- Review of flux compactifications
- Stringy corrections to the $N=1$ Kähler potential qualitatively alter the scalar potential
- Non-susy vacua are realized by any sufficiently large flux contribution to the superpotential, $W_0 \gtrsim \mathcal{O}(1)$
- Mechanism for solving the cosmological constant problem
 $\Lambda_{\text{cosm}} \ll m_\lambda$

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Flux Compactifications

Consider $N=1$, $d=4$ compactifications of string theory (type IIB on CY orientifolds or F-theory limits thereof)

Turn on NS-NS and RR 3-form fluxes

Gukov, Vafa, Witten

$$W_0 = \int_M \Omega \wedge G$$

Ω holomorphic 3-form on M

$$\frac{\chi(X)}{24} = \int_M F \wedge H$$

$$G = F - \frac{\tau}{2} H$$

$\nwarrow$ RR $\uparrow$ dilaton $\swarrow$ NS-NS

This leads to a scalar potential

$$V = e^K \cdot (G^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2)$$

$$D_i W = \partial_i W + W \partial_i K$$

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$$K = -2 \log \left(\int_M J^3 \right) - \log(\tau - \bar{\tau}) - \log \left(\int_M \Omega \wedge \bar{\Omega} \right)$$

where the moduli are given by

z_j :

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 Kachru, freezes z_j and τ
 Polchinski

SUSY: $D_{z_j} W = D_\tau W = 0$

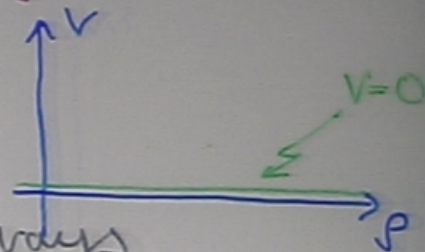
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$= 0$ (cubic nature of K)

No-scale model, i.e. p_j unconstrained

An interesting potential can be generated in two ways



Kachru,
 Kallosh
 Linde
 Trivedi

(1) Non-perturbative contribution to W

Becker
 Hall

(2) Perturbative (& non-perturbative corrections) to K

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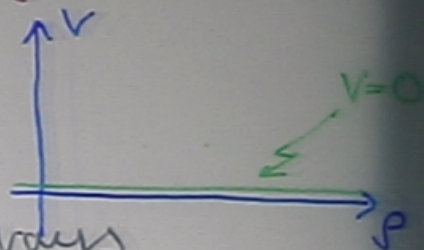
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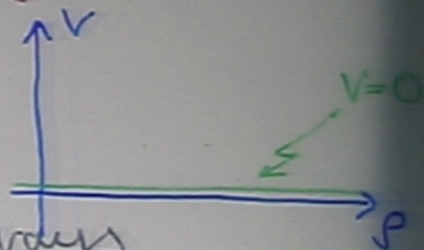
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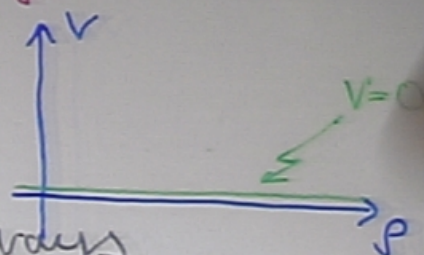
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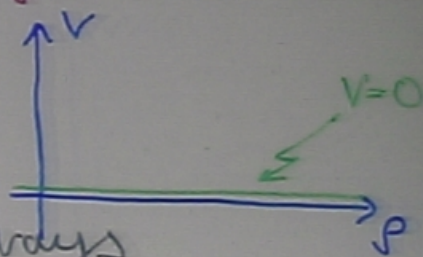
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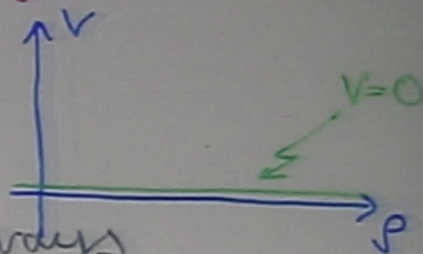
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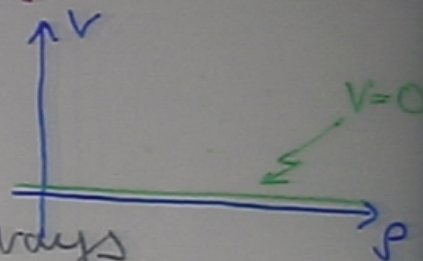
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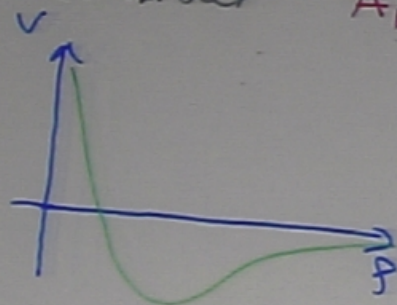
KKLT Non-perturbative corrections to W

These effects come in two forms

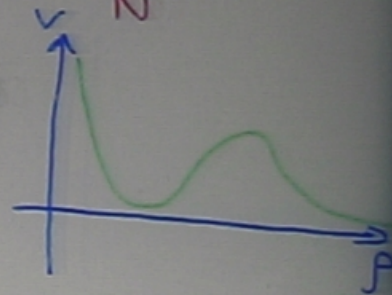
- D3-brane instantons ($N=1$)
- Gaugino condensation ($N=C_2$)

$$W = W_0 + \sum_k A_k e^{i a_k \cdot p_k}$$

Consider $A_k \sim 1$ $a_k = \frac{2\pi}{N}$



Add $\overline{D3}$



In the above scenario

- every divisor (4-cycle) must contribute to W above
- the divisors have to descend from divisors in F-theory w/ arithmetic genus 1

Written
Katz, Vafa

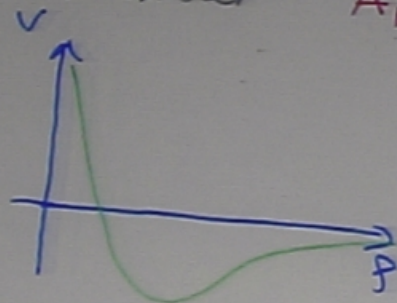
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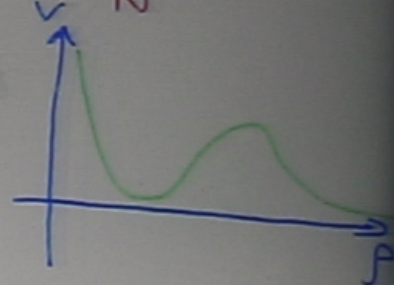
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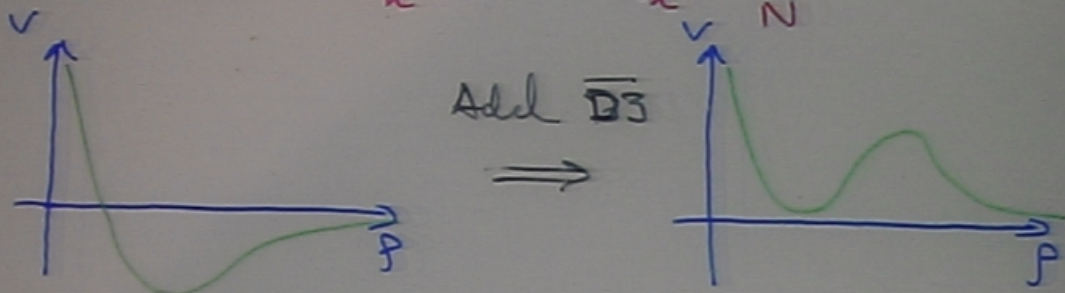
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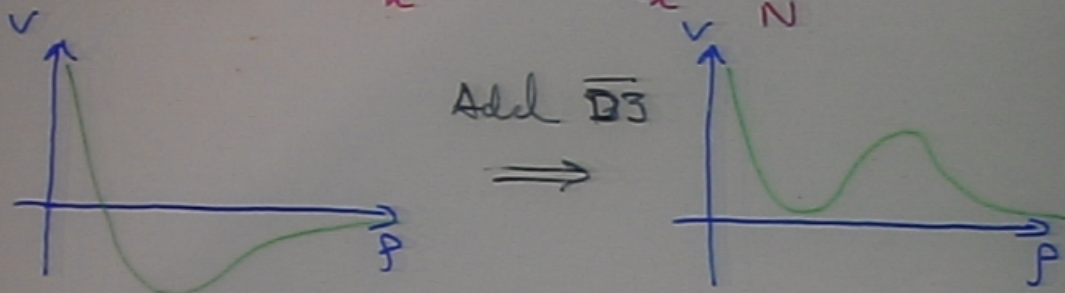
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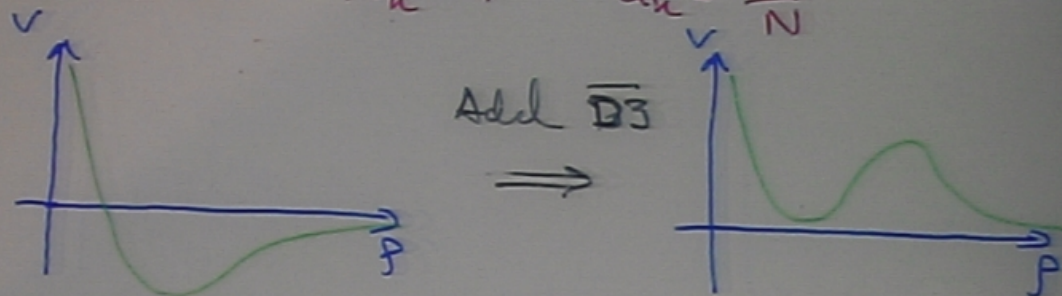
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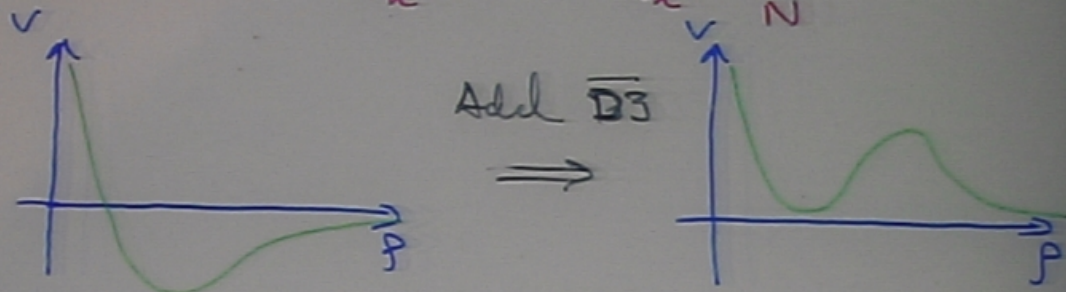
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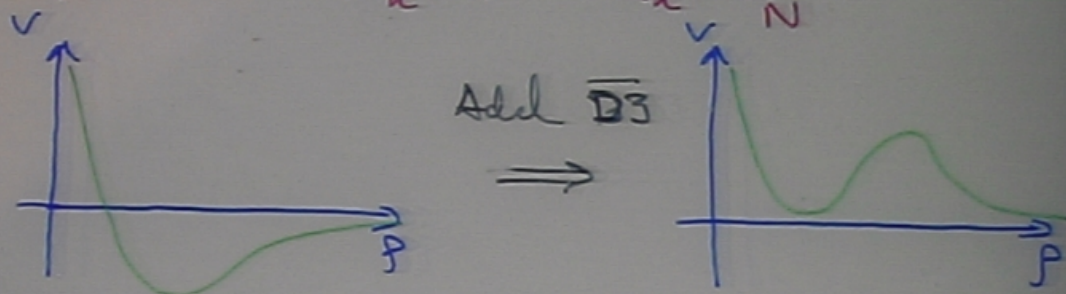
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Perturbative corrections to K

The $N=1$ Kähler potential receives first correction @ $\mathcal{O}(\alpha'^3)$ corresponding to R^4 term in action

BBHL

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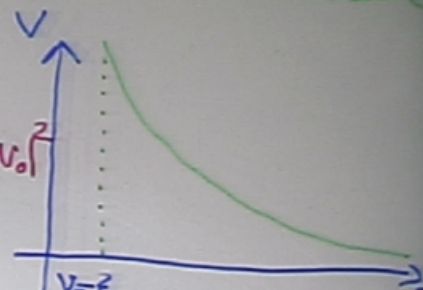
Higher order corrections suppressed by powers and exponentials of volumes

Just like corrections to W , α'^3 correction to K breaks the no-scale structure

If $W = W_0$

$$V = 3 - \xi \frac{(\xi^2 + 75V + V^4)}{(V - \xi)(2V + \xi)^2} e^{K|W_0|^2}$$

The singular nature



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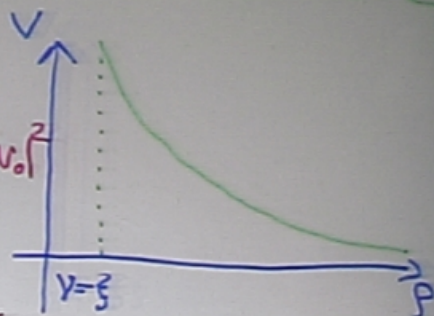
$$K = -2 \log \left(2 \cdot V \cdot e^{-3\phi_0/2} + \xi \left(\frac{-i(\tau - \bar{\tau})}{2} \right)^{3/2} \right) \\ - \log(-i(\tau - \bar{\tau})) - \log \left(-i \int_M \Omega \wedge \bar{\Omega} \right) \\ \xi = - \frac{5(3) \chi(M)}{(2\pi)^3 \cdot 2} > 0 \quad \chi(M) < 0 \\ (\ell_s^2 = 1)$$

Higher order corrections suppressed by powers and exponentials of volumes

Just like corrections to W , α'^3 correction to K breaks the no-scale structure

If $W = W_0$

$$V = 3 \cdot \xi \frac{(\xi^2 + 75V + V^4)}{(V - \xi)(2V + \xi)^2} e^{K|W_0|^2}$$



The singular nature of V arises from $(\bar{\tau} - \tau)^{3/2}$

Other corrections to K

The analysis of TSBHL was carried out w/o fluxes.

One might expect that a non-trivial G would lead to further corrections to K and to the scalar potential V

Green,
Sinha

At $\mathcal{O}(\alpha'^3)$ there's a term G^8 in the ten-dimensional action

$$\int d^{10}x \sqrt{g} \alpha'^3 G^8$$

Reduction to 4-dim. 2 Weyl rescaling to Einstein frame gives contribution to V

$$V_{G^8} \sim \frac{1}{V} \alpha'^3 G^8$$

But $G^2 \sim \frac{1}{V}$ since G flux through 3-cycle of Calabi-Yau

So,
$$V_{G^8} \sim \alpha'^3 \cdot \frac{1}{V^5}$$

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and R^4
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$$V \sim e^K$$

$$V_{R^4} \sim \alpha'^3 \frac{1}{V^3}$$

$$V \sim \frac{e^K}{V^2} \alpha'^3$$

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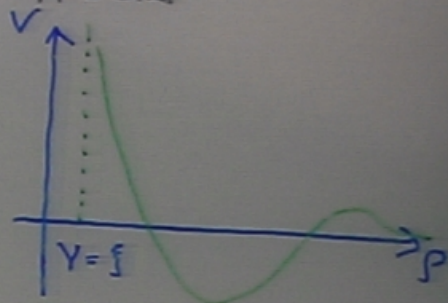
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(Non) Perturbative corrections to K & W

Balasubramanian
P.B. If we combine the two effects

$$K = -2 \log(2V + 3) + \dots$$

$$W = W_0 + \sum A_n e^{i a_n P_n}$$



Thus, the potential is qualitatively changed at large volume - barrier

This is not surprising since perturbative effect dominating for large V

Note that for an $N=2$ (non-orientifold/flux) compactification $V=3$ singularity becomes the conifold locus in the mirror manifold.

While we expect higher order corrections to $N=1$ Kähler potential to become important at small V we do not think they will change the overall structure

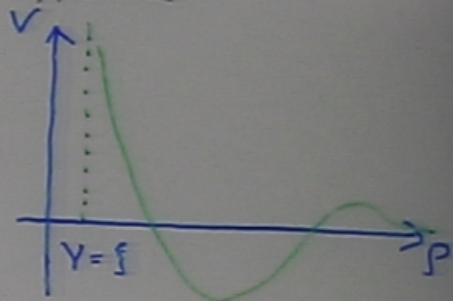
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Supersymmetry Breaking

Consider scenario when $D_{\bar{z}_j} W = D_{\bar{c}} W = 0$
and look for conditions
on W_0 when

$$D_{p_k} W = 0$$

cannot be solved.

SUSY is preserved when

$$W_0 = - \left(i \frac{A_k \cdot a_k \cdot e^{i a_k p_k}}{\partial_{p_k} K} + \sum_j A_j e^{i a_j p_j} \right)$$

assume
leading
correction
to K

$$= - \left(\frac{2 \cdot A_k \cdot a_k \cdot (V + \frac{\xi}{2})}{t^k} \cdot e^{i a_k p_k} + \sum_j A_j e^{i a_j p_j} \right)$$

KKLT

DDF

Berg
Haack,
Kors

When W_0 is very small it has been
shown that location for susy vacua
occurs for V very large — α'^3 correction
will not change this result.

However, exists a $W_{\max} \geq |W_0|$ for
the susy minima.

This follows from

$$V \geq \xi$$

and susy constrained

Kähler ~~cone~~
cone



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CKLT
DF
very
stable,
ions

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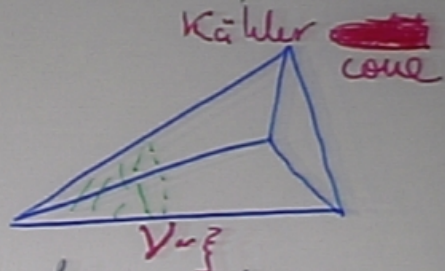
This follows from

$$V \geq \xi$$

and susy constraint,

$$\text{i.e. } t^k > 0$$

implies $|W_0|$ bounded from above.



Thus,

$$D_{P\mu} W = 0$$

cannot be solved for

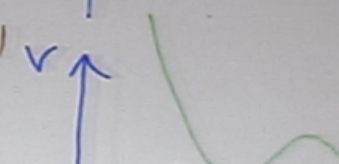
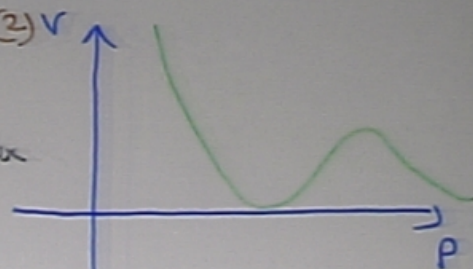
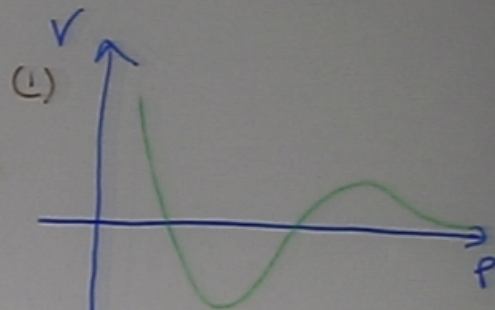
$$|W_0| \gtrsim W_{\max}$$

In this region we will get three different kind of non-supersymmetric vacua

- (1) Non-susy AdS
- (2) Non-susy Minkowski
- (3) Non-susy dS

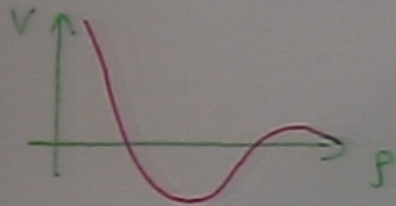
The three scenarios occur in the above order as $|W_0|$ is increased past $W_{\max}$

Note that location of minimum occurs for increasing volume V

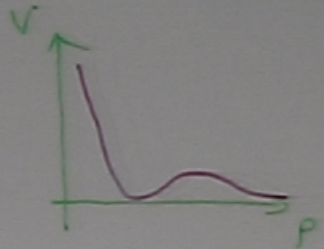
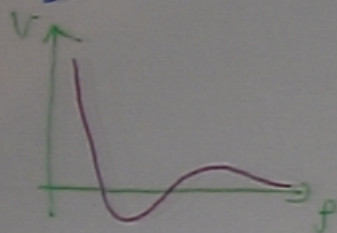


Thus, we have 3 different regions

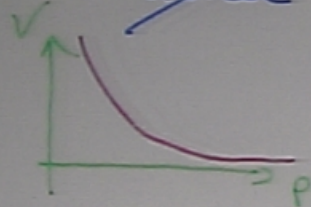
(I) ~~susy~~ vacuum $|W_0| < W_{\max}$



(II) ~~susy~~ vacuum $W_{\max} < |W_0| < \tilde{W}_{\max}$



(III) ~~vacuum~~ $|W_0| > \tilde{W}_{\max}$



In toy models $\frac{\tilde{W}_{\max} - W_{\max}}{W_{\max}} \sim 5-10\%$

Thus, to get a non-susy vacuum requires some fine tuning but the existence

Cosmological Constant

Once SUSY is broken there will be 1-loop (and higher) corrections to Λ

Can these destabilize our vacua?

In flat space ($\Lambda=0$)

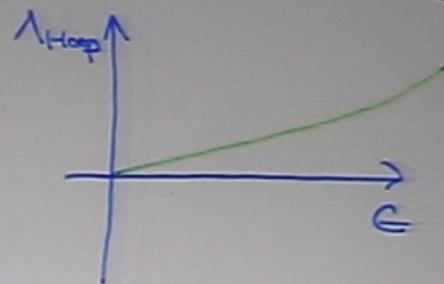
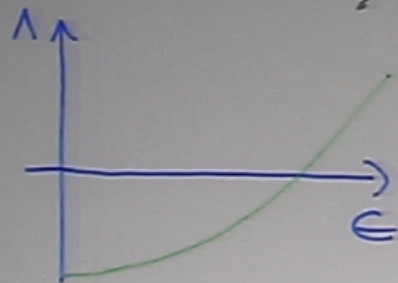
$$\Lambda_{1-loop} \sim C \cdot m_\chi^2 \cdot M_P^2$$

$$m_\chi \sim e^{K/2} |W| \quad m_\chi \text{ gravitino mass}$$

When $\Lambda < 0$ harder to estimate Λ_{1-loop}

Still for a SUSY AdS vacuum $\Lambda_{1-loop} = 0$

Parameterize SUSY w/ $E = |W_0| - W_{max}$



Can tune

$$\Lambda + \Lambda_{1-loop} \gtrsim 0$$

V

V_{corr}

Can these destabilize our vacua?

In flat space ($\Lambda=0$)

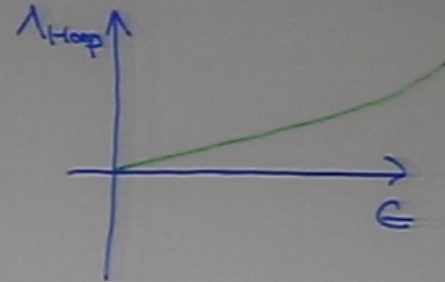
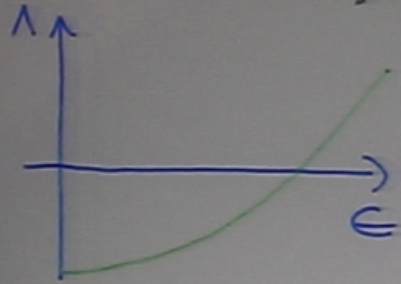
$$\Lambda_{1-loop} \sim C \cdot m_\lambda^2 \cdot M_P^2$$

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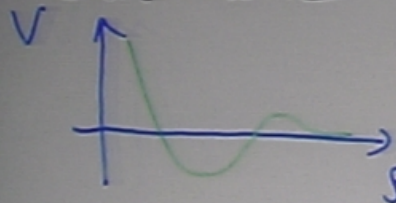
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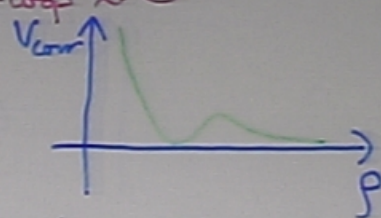
Parameterize sys w/ $E = |W_0| - W_{max}$



Can tune $\Lambda + \Lambda_{1-loop} \gtrsim 0$



$\Rightarrow$



We've assumed discreteness for $|W_0|$ a la
Bousso-Polchinski

Conclusions

- Perturbative α' corrections important to consider in studies of stabilization of Kähler moduli
 - existence of non-susy vacua for $W_0 \sim \mathcal{O}(1)$ generically
 - special directions in "moduli space" with non-susy AdS vacua at large volume and large values of $W_0 \gg 1$
- Cosmological constant