

General Analysis of LARGE Volume Scenarios with String Loop Moduli Stabilisation

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Based on:

- 1) M. Cicoli, J. Conlon, F. Quevedo arXiv:0708.1873 [hep-th]
- 2) M. Cicoli, J. Conlon, F. Quevedo arXiv:0805.1029 [hep-th]
- 3) M. Cicoli, F. Quevedo (in preparation)

Outline

- Brief Review of Moduli Stabilisation in IIB SUGRA
- General Analysis of LARGE Volume Scenarios
- General Structure of String Loop Corrections in IIB SUGRA
- Inclusion of String Loop Corrections
- Calabi-Yau examples
- Conclusions

Type IIB CY Flux Compactifications

- Low energy limit to N=1 4D Type IIB SUGRA via dimensional reduction
 - ➡ Need to know f , W , K !
- Ubiquitous presence of moduli: massless uncharged scalar particles with effective gravitational coupling that would give rise to long range unobserved fifth forces
 - ➡ Need to stabilise them!
- Closed string moduli: U (complex structure), S (axio-dilaton), T (Kähler)
- Open string moduli: Wilson lines, D3 and D7 moduli
- Turn on background 3-form fluxes (GKP)
 - ➡ $D_U W = D_S W = 0$ fixes U and S moduli **supersymmetrically**
- No-scale structure
 - ➡ flat potential for T moduli at tree level
 - ➡ T moduli still unfixed!
- Need to study perturbative versus non-perturbative corrections!

Perturbative vs Non perturbative

- In general:
$$\begin{cases} K = K_{tree} + K_p + K_{np} \\ W = W_{tree} + W_{np}, \end{cases}$$
← **negligible**

where $W_{np} = \sum_{i,m} A_{i,m}(S,U) e^{-ma_i T_i} \xrightarrow{\text{green arrow}} W_{np} = \sum_i A_i(S,U) e^{-a_i T_i}$ for $a_i T_i \gg 1$

and $K_p = \delta K_{(\alpha')} + \delta K_{(g_s)}$ with $K_0 + \delta K_{(\alpha')} = -2 \ln \left(\mathcal{V} + \frac{\xi}{2} \text{Re}(S)^{3/2} \right) =$
 $= -2 \ln(\mathcal{V}) - \frac{\xi \text{Re}(S)^{3/2}}{\mathcal{V}} + \mathcal{O}(1/\mathcal{V}^2)$

Neglect loop corrections and get

$$\begin{aligned} V &= V_{np} + V_{(\alpha')} = \\ &= e^K \left[K^{jk} \left(a_j A_j a_k \bar{A}_k e^{-(a_j T_j + a_k \bar{T}_k)} - \left(a_j A_j e^{-a_j T_j} \bar{W} K_k + a_k \bar{A}_k e^{-a_k \bar{T}_k} W K_j \right) \right) \right. \\ &\quad \left. + 3\xi \frac{(\xi^2 + 7\xi\mathcal{V} + \mathcal{V}^2)}{(\mathcal{V} - \xi)(2\mathcal{V} + \xi)^2} |W|^2 \right] \end{aligned}$$

LARGE Volume

- Fix T moduli in a natural way
- Set $W_0 \sim 1-10$ and $V \sim \exp(a_i \tau_i)$
- ➔ α' and non-perturbative corrections compete naturally to give an exponentially large volume AdS minimum that breaks SUSY
- Need to up-lift to dS (anti-D3, D-terms, F-terms, non-perturbative α' corr.)
- Simplest realisation of LVS: 👍 $P^4_{[1,1,1,6,9]}$ with $h_{11}=2$

$$\mathcal{V} = \frac{1}{9\sqrt{2}} \left(\tau_5^{\frac{3}{2}} - \tau_4^{\frac{3}{2}} \right) \quad \tau_4 \propto \xi^{\frac{2}{3}} \quad \text{and} \quad \langle \mathcal{V} \rangle \propto W_0 e^{\frac{a_4 \tau_4}{g_s}}.$$

- Generalisation: Swiss-cheese CY (F_{11} , 👍 $P^4_{[1,3,3,3,5]}$, 👍 $P^4_{[1,1,3,10,15]}$ for $h_{11}=3$)

$$\mathcal{K} = \mathcal{K}_{cs} - 2 \ln \left[\alpha \left(\tau_1^{3/2} - \sum_{i=2}^n \lambda_i \tau_i^{3/2} \right) + \frac{\xi}{2} \right],$$

$$W = W_0 + \sum_{i=2}^n A_i e^{-a_i \tau_i},$$



$$V = \sum_i \frac{8(a_i A_i)^2 \sqrt{\tau_i}}{3\mathcal{V} \lambda_i \alpha} e^{-2a_i \tau_i} - \sum_i 4 \frac{a_i A_i}{\mathcal{V}^2} W_0 \tau_i e^{-a_i \tau_i} + \frac{3\xi W_0^2}{4\mathcal{V}^3}.$$

Mass scales

The mass scales present are: (for $V \sim 10^{15} \ell_s^6$)

- Planck scale: $M_P = 2.4 \times 10^{18} \text{GeV}$.
- String scale: $M_S = \frac{M_P}{\sqrt{V}} \sim 10^{11} \text{GeV}$.
- KK scale $M_{KK} = \frac{M_P}{V^{2/3}} \sim 10^9 \text{GeV}$.
- Gravitino mass $m_{3/2} = \frac{M_P}{V} \sim 30 \text{TeV}$.
- Small Kähler moduli
 $m_{\tau_s} \sim m_{3/2} \ln(M_P/m_{3/2}) \sim 1000 \text{TeV}$.
- Complex structure moduli $m_U \sim m_{3/2} \sim 30 \text{TeV}$.
- Soft terms $m_{susy} \sim \frac{m_{3/2}}{\ln(M_P/m_{3/2})} \sim 1 \text{TeV}$.
- Volume modulus $m_{\tau_b} \sim \frac{M_P}{V^{3/2}} \sim 1 \text{MeV}$.

NB Get a robust effective field theory and generate hierarchies (axionic, weak and neutrino scale)!!!

Some open questions in LVS

- No general analysis: what happens for an arbitrary CY?
⇒ LARGE Volume Claim
- No inclusion of loop corrections for an arbitrary CY (except Swiss-cheese CY by BHP)
⇒ general structure of string loop corrections in IIB SUGRA
- Tension between moduli stabilisation and chirality
⇒ string loop corrections can give a solution: 👍 $P^4_{[1,3,3,3,5]}$
- Inflation flatness spoiled by loop corrections
- No detectable tensor modes
⇒ string loop corrections can give a solution: K3 Fibration ???

LARGE Volume Claim

Claim 1 (*LARGE Volume*) Let X be a Calabi-Yau three-fold and let the large volume limit be taken in the following way:

$$\begin{cases} \tau_j \text{ remains small, } \forall j = 1, \dots, N_{small}, \\ \mathcal{V} \rightarrow \infty \text{ for } \tau_j \rightarrow \infty, \forall j = N_{small} + 1, \dots, h_{1,1}(X), \end{cases} \quad (2.10)$$

within type IIB $\mathcal{N} = 1$ 4D supergravity where the Kähler potential and the superpotential in Einstein frame take the form:




$$\begin{cases} K = K_{cs} - 2 \ln(\mathcal{V} + \hat{\xi}), \\ W = W_0 + \sum_{j=1}^{N_{small}} A_j e^{-a_j T_j}. \end{cases} \quad (2.11)$$

Then the scalar potential admits a set H of AdS non-supersymmetric minima at exponentially large volume located at $\mathcal{V} \sim e^{a_j \tau_j} \forall j = 1, \dots, N_{small}$ if and only if $h_{2,1}(X) > h_{1,1}(X) > 1$, i.e. $\hat{\xi} > 0$ and τ_j is a local blow-up mode resolving a given point-like singularity $\forall j = 1, \dots, N_{small}$. In this case

$$\begin{cases} \text{if } h_{1,1}(X) = N_{small} + 1, H = \{\text{a point}\}, \\ \text{if } h_{1,1}(X) > N_{small} + 1, H = \{(h_{1,1}(X) - N_{small} - 1) \text{ flat directions}\}. \end{cases} \quad (2.12)$$

Proof: 40 pages long \rightarrow skip it!

Necessary and Sufficient Conditions for LARGE Volume

- $h_{12} > h_{11} > 1$  $\xi > 0$
- At least one blow-up mode (point-like singularity) with a non-perturbative superpotential (guaranteed since the cycle is rigid!)
- Blow-up modes fixed by non-perturbative effects, volume by α' corrections + W_{np}
- For N_{small} blow-up modes, there are still $L=(h_{11}-N_{small}-1)$ moduli which are sent large (e.g. fibration moduli)
 their non-perturbative corrections are switched off
- Get L flat directions!
- These directions are usually lifted by string loop corrections
 **L moduli lighter than the volume!**

String Loop Corrections to K

- Explicit calculation known only for unfluxed toroidal orientifolds as $N=1$ $T^6 / (\mathbb{Z}_2 \times \mathbb{Z}_2)$ (BHK)

$$\delta K_{(g_s)} = \delta K_{(g_s)}^{KK} + \delta K_{(g_s)}^W,$$

where

$$\delta K_{(g_s)}^{KK} = -\frac{1}{128\pi^4} \sum_{i=1}^3 \frac{\mathcal{E}_i^{KK}(U, \bar{U})}{\text{Re}(S) \tau_i}$$

is due to the exchange of KK strings between D7s and D3s and

$$\delta K_{(g_s)}^W = -\frac{1}{128\pi^4} \sum_{i \neq j \neq k=1}^3 \frac{\mathcal{E}_i^W(U, \bar{U})}{\tau_j \tau_k}$$

is due to the exchange of Winding strings between intersecting D7s

NB Complicated dependence on the U moduli BUT simple dependence on the T moduli!

Generalisation to CY

- Generalisation to Calabi-Yau three-folds (BHP)

$$\langle V_U V_{\bar{U}} \rangle_s \sim g(U, T, S) \iff \langle V_U V_{\bar{U}} \rangle_E \sim g(U, T, S) \frac{e^{\varphi/2}}{\mathcal{V}_E}$$

where either $g(U, T, S)$ originates from KK modes as m_{KK}^{-2}

or $g(U, T, S)$ goes as $m_W^{-2} \sim t^{-1}$

In fact for $T^6/(\mathbb{Z}_2 \times \mathbb{Z}_2)$: $\mathcal{V} = t_1 t_2 t_3 = \sqrt{\tau_1 \tau_2 \tau_3} \quad \longrightarrow \quad \tau_1 = \frac{\partial \mathcal{V}}{\partial t_1} = t_2 t_3 = \frac{\mathcal{V}}{t_1}$

$$\delta K_{(gs), \tau_1}^{KK} \sim \frac{1}{\tau_1} = \frac{t_1}{\mathcal{V}} = \frac{m_{KK}^{-2}}{\mathcal{V}}, \quad \delta K_{(gs), \tau_2 \tau_3}^W \sim \frac{1}{\tau_2 \tau_3} = \frac{1}{\mathcal{V} t_1} = \frac{m_W^{-2}}{\mathcal{V}}$$

Conjecture for
an arbitrary CY!



$$\delta K_{(gs)}^{KK} \sim \sum_{i=1}^{h_{1,1}} \frac{C_i^{KK}(U) m_{KK,i}^{-2}}{\text{Re}(S) \mathcal{V}} \sim \sum_{i=1}^{h_{1,1}} \frac{C_i^{KK}(U) t_i}{\text{Re}(S) \mathcal{V}} \quad \leftarrow \text{transverse to D7}$$

$$\delta K_{(gs)}^W \sim \sum_i \frac{C_i^W(U) m_{W,i}^{-2}}{\mathcal{V}} \sim \sum_i \frac{C_i^W(U)}{\mathcal{V} t_i} \quad \leftarrow \text{intersection of D7s}$$

Low Energy Approach

- The reduced DBI action contains a term like

$$\delta S_{DBI} \supset \int d^4x \sqrt{-g^{(4)}} \tau F^{\mu\nu} F_{\mu\nu}$$

- Expand τ around its VEV

$$\tau = \langle \tau \rangle + \tau', \quad \longrightarrow \quad \delta S_{DBI} \supset \int d^4x \sqrt{-g^{(4)}} (\langle \tau \rangle F^{\mu\nu} F_{\mu\nu} + \tau' F^{\mu\nu} F_{\mu\nu})$$

- Read off the gauge coupling $g^2 = \frac{1}{M_s^4 \tau}$

- Loop corrected kinetic terms

$$S_{Einstein} \supset \int d^4x \sqrt{-g^{(4)}} \left(\frac{\partial^2 (K_{tree})}{\partial \tau^2} + \frac{\partial^2 (\delta K_{(g_s)}^{KKK})}{\partial \tau^2} \right) (\partial \tau)^2$$

- Analogy with charged scalar fields

$$\int d^4x \sqrt{-g^{(4)}} \frac{1}{2} (1 + A) \partial_\mu \varphi \partial^\mu \varphi, \quad A \simeq \frac{g^2}{16\pi^2}$$

$$\longrightarrow \quad \frac{\partial^2 (\delta K_{(g_s)}^{KKK})}{\partial \tau^2} \sim \frac{f(\text{Re}(S))}{16\pi^2} \frac{1}{\tau} \frac{\partial^2 (K_{tree})}{\partial \tau^2}$$

Example: 👍 $P^4_{[1,1,1,6,9]}$

- Match the conjecture for $N=1$ $T^6 / (\mathbb{Z}_2 \times \mathbb{Z}_2)$
- Loop corrections from the conjecture for 👍 $P^4_{[1,1,1,6,9]}$

$$\mathcal{V} = \frac{1}{9\sqrt{2}} \left(\tau_5^{3/2} - \tau_4^{3/2} \right) \simeq \tau_5^{3/2}$$

$$\delta K_{(gs)}^{KKK} \sim \frac{C_4^{KK} \sqrt{\tau_4}}{\text{Re}(S) \mathcal{V}} + \frac{C_5^{KK} \sqrt{\tau_5}}{\text{Re}(S) \mathcal{V}} \simeq \frac{C_4^{KK} \sqrt{\tau_4}}{\text{Re}(S) \mathcal{V}} + \frac{C_5^{KK}}{\text{Re}(S) \tau_5} \quad (\text{BHP})$$

NB Loops are leading with respect to the α' corrections!

Low Energy Interpretation: $\frac{\partial^2 (K_{tree})}{\partial \tau_4^2} \simeq \frac{1}{\sqrt{\tau_4} \mathcal{V}}, \quad \frac{\partial^2 (K_{tree})}{\partial \tau_5^2} \simeq \frac{1}{\tau_5^2}.$

➡ $\left\{ \begin{array}{l} \frac{\partial^2 (\delta K_{(gs)}^{KKK})}{\partial \tau_4^2} \sim \frac{1}{16\pi^2} \frac{1}{\text{Re}(S)} \frac{1}{\tau_4^{3/2} \mathcal{V}} \\ \frac{\partial^2 (\delta K_{(gs)}^{KKK})}{\partial \tau_5^2} \sim \frac{1}{16\pi^2} \frac{1}{\text{Re}(S)} \frac{1}{\tau_5^3} \end{array} \right. \quad \text{OK!}$

- Match the conjecture also for 👍 $P^4_{[1,1,2,2,6]}$

Extended No-scale Structure

Let X be a Calabi-Yau three-fold and consider type IIB $N = 1$ 4D SUGRA where the Kähler potential and the superpotential in the Einstein frame take the form:

$$\begin{cases} K = K_{tree} + \delta K, \\ W = W_0. \end{cases} \quad (4.1)$$

If and only if the loop correction δK to K is a homogeneous function in the 2-cycles volumes of degree $n = -2$, then at leading order

$$\delta V_{(g_s)} = 0. \quad (4.2)$$

Proof: Expand K^{-1} and use homogeneity! $\delta V_{(g_s)} = V_0 + \varepsilon \delta V_1 + \varepsilon^2 \delta V_2 + \mathcal{O}(\varepsilon^3)$

$$\delta V_1 = -\frac{|W|^2}{\mathcal{V}^2} \frac{1}{4} (3n + n(n-1)) \delta K = -\frac{|W|^2}{\mathcal{V}^2} \frac{1}{4} n(n+2) \delta K.$$

$$\begin{cases} n = -2 & \text{for } \delta K_{(g_s)}^{KK}, \\ n = -4 & \text{for } \delta K_{(g_s)}^W, \end{cases} \quad \longrightarrow \quad \begin{cases} \delta V_{(g_s),1}^{KK} = 0, \\ \delta V_{(g_s),1}^W = -2 \delta K_{(g_s)}^W \frac{|W|^2}{\mathcal{V}^2}. \end{cases}$$

The loop corrections to V are subleading with respect to the α' ones BUT are crucial to stabilise the SM cycle or to lift the L flat directions!!!

General formula for the 1 loop corrections to V

$$\delta V_2 = \left(K_0^{ij} \delta K_i \delta K_j - 2K_0^{im} \delta K_{ml} K_0^{lj} K_i^0 \delta K_j + K_0^{im} \delta K_{mp} K_0^{pq} \delta K_{ql} K_0^{lj} K_i^0 K_j^0 \right) \frac{|W|^2}{\mathcal{V}^2}$$

Homogeneity allows us to simplify it to:

$$\delta V_{(gs)}^{1loop} = \sum_i \left(\frac{(c_i^{KK})^2}{\text{Re}(S)^2} K_{ii}^0 - 2\delta K_{(gs),\tau_i}^W \right) \frac{W_0^2}{\mathcal{V}^2}$$

NB We know the sign of these corrections!!!

NB Everything in terms of K_{ij} and δK^W !!!

$$\delta V_{(gs),1loop}^{KKK} = \sum_{i=1}^{h_{1,1}} \left(0 \cdot \frac{(c_i^{KK})}{\text{Re}(S)} K_i^0 + \frac{(c_i^{KK})^2}{\text{Re}(S)^2} K_{ii}^0 + \mathcal{O} \left(\frac{(c_i^{KK})^3}{\text{Re}(S)^3} \right) \right) \frac{W_0^2}{\mathcal{V}^2}$$

Field Theory Interpretation

- Use the Coleman-Weinberg Potential

$$\delta V_{1loop} = \frac{1}{64\pi^2} \left[\Lambda^4 STr (M^0) \ln \left(\frac{\Lambda^2}{\mu^2} \right) + 2\Lambda^2 STr (M^2) + STr \left(M^4 \ln \left(\frac{M^2}{\Lambda^2} \right) \right) \right]$$

where $STr (M^0) = 0$ due to SUSY

 **SUSY is the physical explanation for the extended no-scale structure!**

- Single modulus example

$$\mathcal{V} = \tau^{3/2}$$

$$\begin{aligned} \delta V_{(gs),1loop}^{KK} &= \left[0 \cdot c^{KK} \frac{\partial K_0}{\partial \tau} + \alpha_2 (c^{KK})^2 \frac{\partial^2 K_0}{\partial \tau^2} \right. \\ &\quad \left. + \alpha_3 (c^{KK})^3 \frac{\partial^3 K_0}{\partial \tau^3} + \mathcal{O} \left(\frac{\partial^4 K_0}{\partial \tau^4} \right) \right] \frac{W_0^2}{\mathcal{V}^2} \\ &= \left(0 \cdot \frac{-3c^{KK}}{\mathcal{V}^{8/3}} + \frac{3\alpha_2 (c^{KK})^2}{\mathcal{V}^{10/3}} - \frac{6\alpha_3 (c^{KK})^3}{\mathcal{V}^4} + \mathcal{O} \left(\frac{1}{\mathcal{V}^{14/3}} \right) \right) W_0^2 \end{aligned}$$

Evaluation of the Coleman-Weinberg

$$STr(M^2) \simeq m_{3/2}^2 \quad \text{where} \quad m_{3/2}^2 = e^K W_0^2 \simeq \frac{1}{\mathcal{V}^2} \implies STr(M^2) \simeq \frac{1}{\mathcal{V}^2}$$

$$\Lambda = m_{KK} \simeq \frac{M_s}{R} = \frac{M_s}{\tau^{1/4}} = \frac{1}{\tau^{1/4}} \frac{1}{\sqrt{\mathcal{V}}} M_P = \frac{M_P}{\mathcal{V}^{2/3}}$$



$$\begin{aligned} \delta V_{1loop} &\simeq 0 \cdot \Lambda^4 + \Lambda^2 STr(M^2) + STr\left(M^4 \ln\left(\frac{M^2}{\Lambda^2}\right)\right) \simeq \\ &\simeq 0 \cdot \frac{1}{\mathcal{V}^{8/3}} + \frac{1}{\mathcal{V}^{10/3}} + \frac{1}{\mathcal{V}^4} \end{aligned}$$

Perfect matching!!!

NB It is possible to get a matching with the Coleman-Weinberg also for the $\text{P}^4_{[1,1,1,6,9]}$ and the $\text{P}^4_{[1,1,2,2,6]}$ case

Inclusion of loop corrections

Loop corrections are subleading w.r.to V_{np} and V_{α} ,

→ do not destroy the exponentially large volume minimum $V \sim \exp(a_i \tau_i)$

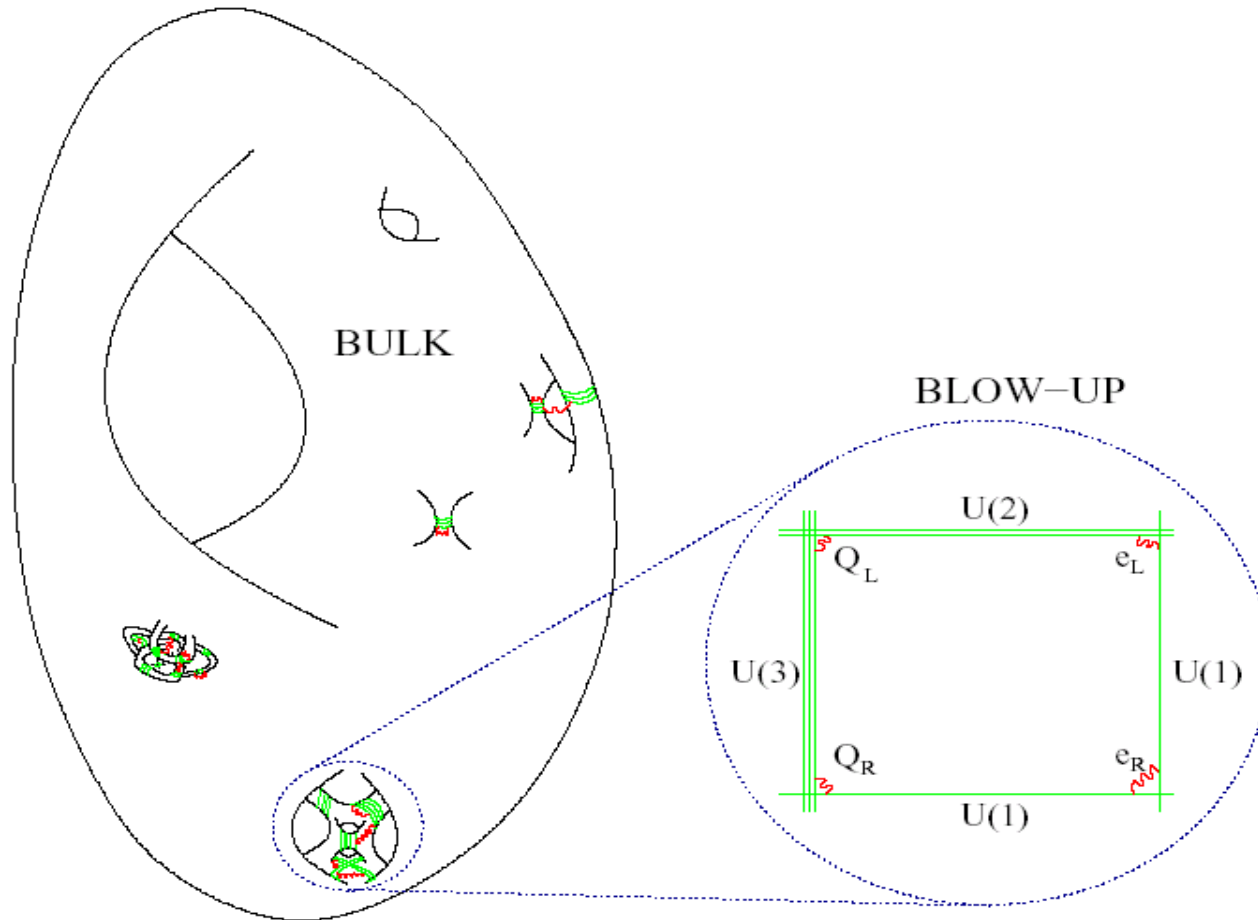
BUT they can:

- Stabilise the L non-blow moduli LARGE
- Fix the SM cycle which does not get any non-perturbative W

$$W_{\text{string}} \sim \left[\prod_i \Phi_i \right] e^{-S_{\text{inst}}} = 0 \quad \text{for } \langle \Phi_{\text{SM}} \rangle = 0 \quad (\text{BMP})$$

The Standard Model in the CY

- SM on a small cycle as $g^2=1/\tau_{SM}$

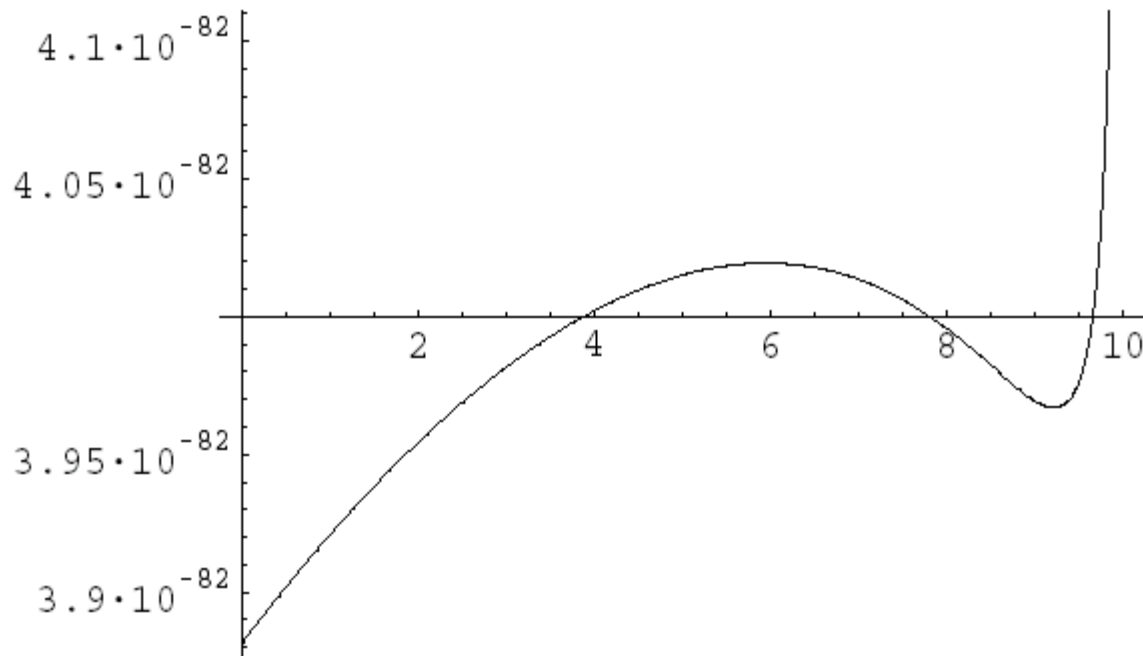


- BUT τ_{SM} cannot have any non-perturbative superpotential!

Example 1: SM cycle fixed by loops

- Solution: fix τ_{SM} via string loops
- 👍 $\mathbf{P}^4_{[1,3,3,3,5]}$ for $h_{11}=3$

$$V + \delta V_{(g_s)} = \frac{\lambda_1 \left(\sqrt{5(2\tau_{E3} + \tau_{SM})} + \sqrt{\tau_{E3} - \tau_{SM}} \right) e^{-4\pi\tau_{E3}}}{\mathcal{V}} - \frac{3\lambda_2\tau_{E3}e^{-2\pi\tau_{E3}}}{\mathcal{V}^2} + \frac{\lambda_3}{\mathcal{V}^3} + \left(\frac{\lambda_4}{\sqrt{\tau_{E3} - \tau_{SM}}} + \frac{\lambda_5}{\sqrt{2\tau_{E3} + \tau_{SM}}} \right) \frac{1}{\mathcal{V}^3}.$$



Example 2: Flat directions lifted by loops

- K3 Fibration with $h_{1,1}=2$: 👍 $\mathbf{P}^4_{[1,1,2,2,6]}$

$$\mathcal{V} = \frac{1}{2} \sqrt{\tau_1} \left(\tau_2 - \frac{2}{3} \tau_1 \right)$$

- No blow-up mode \longrightarrow No LARGE Volume

$$V = -\frac{4}{\mathcal{V}^2} W_0 a_1 \tau_1 e^{-a_1 \tau_1} + \frac{3}{4} \frac{\xi}{\mathcal{V}^3} W_0^2$$

- K3 Fibration with $h_{1,1}=3$

$$\mathcal{V} = \alpha \left[\sqrt{\tau_1} (\tau_2 - \beta \tau_1) - \gamma \tau_3^{3/2} \right]$$

- Now τ_3 is a blow-up mode \longrightarrow LARGE Volume

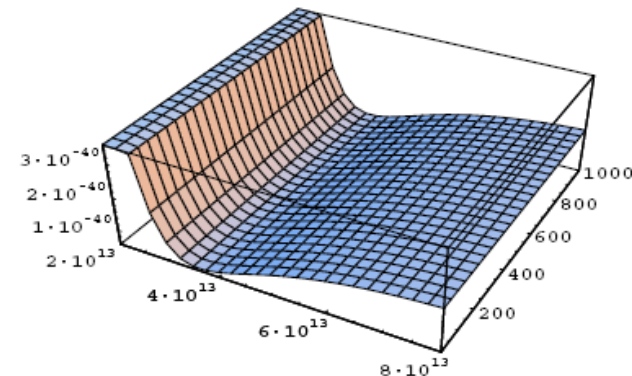
- Field redefinition

$$(\tau_1, \tau_2) \longrightarrow (\mathcal{V}, \Omega) : \begin{cases} \mathcal{V} \simeq \alpha [\sqrt{\tau_1} (\tau_2 - \beta\tau_1)] \\ \Omega = \alpha [\sqrt{\tau_1} (\tau_2 + \beta\tau_1)] \end{cases}$$

- Scalar potential without loop corrections

$$V = \frac{16a_3^2}{3\mathcal{V}} \sqrt{\tau_3} e^{-2a_3\tau_3} - \frac{4}{\mathcal{V}^2} a_3\tau_3 e^{-a_3\tau_3} + \frac{3}{2g_s^{3/2}\mathcal{V}^3}$$

➡ Ω is a flat direction, $V \sim \exp(a_3\tau_3)$!



- Consider loop corrections
- Wrap D7s around τ_1 , τ_2 and τ_3
- KK corrections in τ_3 do not depend on Ω and are subleading w.r.to the α' ones

$$\delta V_{(g_s), \tau_3}^{KK} \sim \frac{1}{\mathcal{V}^3 \sqrt{\tau_3}} \quad \text{➡ negligible!}$$

- The 4-cycle τ_3 is a blow up mode ➡ it does not intersect with the other 4-cycles ➡ No winding coorections!

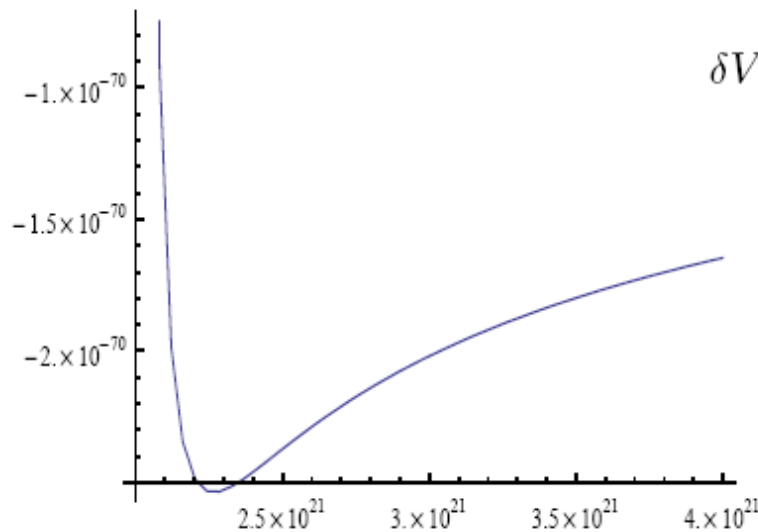
- Relevant loop corrections

$$\delta V_{(g_s)} = \delta V_{(g_s),\tau_1}^{KK} + \delta V_{(g_s),\tau_2}^{KK} + \delta V_{(g_s),\tau_1\tau_2}^W$$

➡

$$\delta V_{(g_s)} = \frac{A}{\tau_1^2 \mathcal{V}^2} + \frac{C}{\sqrt{\tau_1} \mathcal{V}^3} + \frac{D\tau_1}{\mathcal{V}^4}$$
NB $A > 0, D > 0$!!!

- Loop corrections for $A=1, C=-20, D=2/9$



$$\delta V = \left(\frac{2}{3}\right)^{1/3} \frac{\Omega^2 - 62\Omega\mathcal{V} + 63\mathcal{V}^2}{3(\Omega - \mathcal{V})^{4/3} \mathcal{V}^4}$$

NB The minimum lies within the Kähler cone
 $\mathcal{V} < \Omega < 2\mathcal{V}$

NO D7 wrapping τ_1 ➡ NO minimum

NO D7 wrapping τ_2 ➡ Minimum at $\Omega = 3\mathcal{V}$ ➡ out of the Kähler cone!

New candidate inflatons

Cicoli, Quevedo (in preparation)

- Main source of SUSY breaking: still V , $F_V \neq 0$

→ no drastic changes in phenomenology expected!

- $L = (h_{11} - N_{\text{small}} - 1)$ flat directions lifted by loops are light
- $m_\Omega^2 = V^{-10/3}$, $H \sim m_V^2 = V^{-3}$

→ $\eta \sim m^2/H \sim V^{-1/3} \text{ @ } 1$

→ Get L good inflaton candidates!

- i. Loop corrections under control!??
- ii. Detectable tensor modes!?? with $0.009 < r < 0.01$
- iii. Spectral index $0.966 < n < 0.971$
- iv. Need $V = 10^2$ to keep the Volume minimum stable!

Conclusions

- Non-perturbative effects fix only blow-up Kähler moduli
- Then α' effects + W_{np} fix the Volume exponentially large
- All the other Kähler moduli are flat directions
- Loop corrections to K are leading w.r. to the α' ones
- Loop corrections to V are SUB-leading w.r. to the α' ones due to the “extended no-scale structure”
- Coleman-Weinberg potential gives a nice physical understanding of this cancellation: SUSY!
- Loop corrections needed to fix the rest of Kähler moduli!
- Loop corrections crucial to:
 - 1) Extend LVS to fibration CYs
 - 2) Fix SM cycle
 - 3) Get natural inflation with $r=0.01$?
 - 4) Give a forest of monochromatic lines?

Need to compute explicit g_s corrections for arbitrary CY!!!