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Seeking de Sitter Vacua in the String Landscape

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In memory of our late colleague and friend Graham

A few facts about Cosmology and de Sitter Vacua

▲ $\exists$ ongoing **Accelarating Expansion of the Universe**

▲ *Standard Interpretation:*
Universe dominated by **Dark Energy** permeating all of space

▲ *in G.R. framework:*
Einstein's equs with a positive cosmological constant of the order:

$$\Lambda \approx 10^{-120} \text{ (in } M^4_{Planck} \text{ units)}$$

▲ A rather intringuing coincidence:

$$m_\nu^4 \lesssim 10^{-116} \text{ (in } M^4_{Planck} \text{ units)}$$

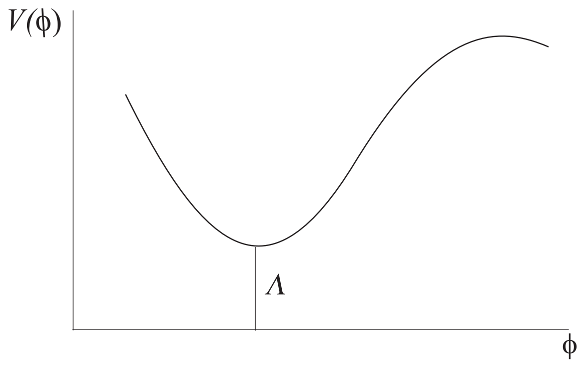
possible link between the two scales?

▲ *Simple Effective Field Theory description:*

with a scalar field, ϕ acquiring

Potential Energy $V(\phi)$

with positive vacuum energy Λ:



▲ de Sitter vacua ▲

...*with some additional requirements*:

$\phi \rightarrow$ inflaton suitable for inflation

The inference from the previous observations and remarks is that a variety of fundamental open questions involving a vast range of scales are **intertwined !**

Thence, it would be desirable to contemplate an effective theory with UV completion where Planck-scale Physics are naturally integrated

Currently, the most successful and robust candidate towards a UV completion is

String Theory

▲ **String Derived Effective Field Theories (EFT)** ▲

Focus of this talk:

EFT from **type II-B/F-theory**

compactified on a Calabi-Yau (CY) Manifold

However

⇊

▲ **Compactifications** characterised by **large numbers** of **massless scalar fields** (moduli)

★ Two basic classes of moduli ★

Recall that a **CY** *is a compact Kähler manifold which admits a Ricci-flat metric g with (closed) (1,1)-Kähler form:*

$$J = g_{i\bar{j}} dz^i \wedge d\bar{z}^{\bar{j}} \ , \ dJ = 0$$

▲ A **CY** can be **deformed** in two ways:

1. Variation of the Kähler structure $\delta g_{i\bar{j}}$ (mixed type), gives $h^{1,1}$ parameters [a], the Kähler moduli T^k, $k = 1, 2, \ldots, h^{1,1}$.
2. Pure type metric variations g_{ij}, $g_{\bar{i}\bar{j}}$ giving rise to $h^{2,1}$ complex structure (CS) parameters z^a, $a = 1, 2, \ldots, h^{2,1}$, associated with:

$$\Omega_{ijk} g^{k\bar{l}} \delta g_{\bar{l}\bar{m}} \, dz^i \wedge dz^j \wedge d\bar{z}^{\bar{m}}$$

where Ω is a holomorphic 3-form.

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[a] $h^{r,s}$ dim. of Dolbeault cohomology $H^{r,s} = \frac{\{\omega^{r,s} | \bar{\partial}\omega^{r,s} = 0\}}{\{\alpha^{r,s} | \alpha^{r,s} = \bar{\partial}\beta^{r,s-1}\}}$

In addition:

$\exists$ *moduli and other fields associated with Type II-B closed string*

spectrum from L- and R-moving open strings with NS and R b.c.

▲ $(\mathrm{NS}_+, \mathrm{NS}_+)$: Graviton, dilaton and Kalb-Ramond (KR)-field

$$g_{\mu\nu},\ \phi,\ B_{\mu\nu} \to B_2, \quad (\mathrm{def}:\ e^{\phi} = g_s)$$

▲ $(\mathrm{R}_-, \mathrm{R}_-)$: Scalar, 2- and 4-index fields (*p-form potentials*)

$$\mathbf{C_0}, C_{\mu\nu}, C_{\kappa\lambda\mu\nu} \to C_p,\ p = 0, 2, 4$$

1. ▲ $C_0,\ \phi \ \to$ *combined to* **axion-dilaton** *modulus:*

$$S = C_0 + i\, e^{-\phi} \equiv C_0 + \frac{i}{g_s}$$

2. ▲ *Field strengths/magnetic fluxes:*

   $F_p := d\, C_{p-1},\ H_3 := d\, B_2,\ \Rightarrow \mathbf{G_3} := F_3 - S H_3$

$\downharpoonleft\downharpoonright$

▲ **we conclude** that: ▲

CY of **Compactifications** and # fluxes $\Rightarrow$

Enormous number of String Vacua

$\Downarrow$

String Landscape

▲ **Long standing Question** ▲

▲ Are there any de Sitter vacua in the **Landscape**?

... even if the answer is Yes... we know that they are...

$\Rightarrow$ *Certainly Scarce* $\Leftarrow$

Hence

$\mathcal{A}$ $\mathcal{R}$easonable sequence of $\mathcal{T}$asks

in the context of type $\mathcal{IIB}$ theory:

- Provide masses to moduli fields ⇒ **Stabilisation**

- The quest for a *de Sitter* vacuum in String Theory
(if possible... based only on **perturbative** corrections)

- Cosmological implications such as inflation

Implementation

▲▲

▲ Geometry of internal space. Assuming:

i): a factorised $T^6 = T^2 \times T^2 \times T^2$*-torus.*

ii): $3 \times$ *D7 brane-stacks, each one spans 4 compact dimensions while localised at the remaining 2-d.*

D7s	Minkowski				Compact Dimensions					
	0	1	2	3	4	5	6	7	8	9
$D7_a$		*	*	*	*	*	*	*	.	.
$D7_b$		*	*	*	*	*	.	.	*	*
$D7_c$		*	*	*	.	.	*	*	*	*

▲ Context: Type II-B effective Supergravity: *Basic 'ingredients': Superpotential* $\mathcal{W}$ *and Kähler potential* $\mathcal{K}$

▲ The **Superpotential** $\mathcal{W}$ ▲

▲ *A Flux-induced superpotential* has been constructed (*G.V.W. hep-th/9906070*) using $G_3 = F_3 - SH_3$ and $(3,0)$-form $\Omega(z_a)$:

$$\mathcal{W}_0 = \int \mathbf{G_3} \wedge \Omega(z_a) \;\Rightarrow\; \mathcal{W}_0 = \mathcal{W}_0(z_a, S)$$

⇒ does not depend on Kähler moduli T_i. $\mathcal{W}_0$ must satisfy:

▲ **Flatness conditions** ▲

$$\mathcal{D}_{z_a}\mathcal{W} = 0, \quad \mathcal{D}_S\mathcal{W} = 0 \;:$$

⇒ z_a *and* S **stabilised** ⇐

but!

▲ Kähler moduli $\notin \mathcal{W}_0$ ⇒ remain unfixed! ▲

▲ The Kähler potential ▲

$$\mathcal{K}_0 = -\sum_{i=1}^{3} \ln(-i(T_i - \bar{T}_i)) - \ln(-i(S - \bar{S})) - \ln(i \int \Omega \wedge \bar{\Omega}) \cdot$$

▲ The classical scalar potential identically zero: ▲

$$V = e^{\mathcal{K}} (\sum_{I,J} \mathcal{D}_I \mathcal{W}_0 \mathcal{K}^{I\bar{J}} \mathcal{D}_{\bar{J}} \mathcal{W}_0 - 3|\mathcal{W}_0|^2) \equiv 0,$$

due to flatness conditions and the no-scale structure.

⇓

Kähler moduli completely **undetermined**!

⇓

Task: Engineer the appropriate geometric set up and compute:

Kähler moduli-dependent QUANTUM corrections

The Kähler potential $\mathcal{K}$

and

$\mathcal{PERTURBATIVE}$

String Loop Corrections

Two types of expansions in String Theory:

i) Inverse string tension $\propto \alpha'$.

ii) String coupling g_s

▲ α'^3 Corrections

10-d action with α'^3 *(see Becker et al hep-th/0204254):*

$$\mathbf{S} \propto \int d^{10}\sqrt{-g}\, e^{-2\phi}\left(R + 4(\partial\phi)^2 + \alpha'^3\nabla^2\phi Q\right)^{\mathrm{a}}$$

Compactification → redefinition of 4-d dilaton:

$$\begin{aligned} e^{-2\phi_4} &= e^{-2\phi_{10}}(\mathcal{V} + \xi/2) \\ &= e^{-\frac{1}{2}\phi_{10}}(\hat{\mathcal{V}} + \hat{\xi}/2) \quad \text{(Einstein frame)} \end{aligned}$$

where the 6d volume $\hat{\mathcal{V}}$ in Einstein frame are:

$$\hat{\mathcal{V}} = \frac{1}{3!}\kappa_{ijk}\hat{t}^i\hat{t}^j\hat{t}^k$$

with $\hat{t}^i$ defined through:

$$t^k = -\mathrm{Im}(T^k) = \hat{t}^k\left(\frac{S-\bar{S}}{2i}\right)^{-1/2} \equiv \hat{t}^k\, g_s^{1/2}$$

[a] Q → generalisation of 6-d Euler integrand $\int d^6x\sqrt{g}Q = \chi$

ξ is expressed in terms of the Euler characteristic χ of the manifold:

$$\xi \;=\; -\frac{\zeta(3)}{4(2\pi)^3}\chi = \hat{\xi}\left(\frac{S-\bar{S}}{2i}\right)^{-3/2} \equiv \hat{\xi}\, g_s^{3/2}$$

$\hat{\xi}$ is incorporated into the Kähler potential through the **shift** [a]

$$\hat{\mathcal{V}} \to \mathcal{U}_0 = \hat{\mathcal{V}} + \frac{\hat{\xi}}{2} \equiv \hat{\mathcal{V}} + \frac{\xi}{2}\left(\frac{S-\bar{S}}{2i}\right)^{3/2} \equiv \hat{\mathcal{V}} + \frac{\xi}{2}\frac{1}{g_s{}^{3/2}}$$

${\alpha'}^3$*-modified Kähler potential:*

$$\boxed{\mathcal{K}_0 \to \mathcal{K} = -\log(-i(S-\bar{S})) - 2\log \mathcal{U}_0 + \mathcal{K}_{cs}}$$

$$(\textit{where: } \mathcal{K}_{cs} = -\ln(i\textstyle\int \Omega \wedge \bar{\Omega}))$$

[a] ξ in the prepotential $F = \frac{i}{3!}k_{abc}\frac{X^aX^bX^c}{X^0} + \xi X_0$, Candelas et al, NPB (91)

▲ Loop **Corrections** ▲

▲ *Previous* α'^3 *corrections at "tree-level" w.r.t. string-loop series.*

▲ **Hypothesis:** ▲

▲ Generic type of **one-loop correction** is captured by

$$\mathcal{U}_1 = \left(\frac{S-\bar{S}}{2i}\right)^{-1/2} f(\hat{\mathcal{V}}) \equiv {g_s}^{1/2} f(\hat{\mathcal{V}})$$

▲ *These are included by another shift:*

$$\hat{\mathcal{V}} \to \mathcal{U}_0 \to \boxed{\mathcal{U} \equiv \hat{\mathcal{V}} + \frac{\xi}{2}\frac{1}{{g_s}^{3/2}} + {g_s}^{1/2} f(\hat{\mathcal{V}})}$$

So, the final form of the corresponding Kähler potential is

$$\boxed{\mathcal{K} = -\log(-i(S-\bar{S})) - 2\log\mathcal{U} + \mathcal{K}_{cs}}$$

Evidence: recall that type IIB string theory admits $SL(2,\mathbb{Z})$
This implies invariance of the resulting EFT under some subgroup
$\Gamma_s \subset SL(2,\mathbb{Z})$.

$\Downarrow$

Motivation to look for a $SL(2,\mathbb{Z})$ completion.
Consider the non-holomorphic Eisenstein series: $\mathcal{E}_{\frac{3}{2}} \equiv E_{\frac{3}{2}}(S,\overline{S})$:

$$\mathcal{E}_{\frac{3}{2}} = 2\zeta(3)\underbrace{\left(\frac{S-\bar{S}}{2i}\right)^{\frac{3}{2}}}_{\alpha'^3-\text{part}} + 4\zeta(2)\underbrace{\left(\frac{S-\bar{S}}{2i}\right)^{-\frac{1}{2}}}_{\text{loop}-\text{part}} + \underbrace{\left(\frac{S-\bar{S}}{2i}\right)^{\frac{1}{2}}}_{\text{non}-\text{pert.part}} \mathcal{O}(e^{-2\pi \mathrm{Re} S})$$

Observation:
first and second terms are associated with α'^3 and loop corrections.

▲ The form of $f(\mathcal{V})$ ▲

(*Antoniadis, Chen, GKL, 1803.08941*, EPJC-2019)

Consider the set up :

▲ Configuration of Three intersecting D7-brane stacks

▲▲ A 4-d Einstein-Hilbert ($\mathcal{EH}$) term $\mathcal{R}_4$ in the **bulk**, generated from higher derivative terms in the 10-d string action (*Antoniadis et al hep-th/9707013, etc.*)

⇓⇓⇓

$$\boxed{f(\hat{\mathcal{V}}) = \sigma + \eta \log(\hat{\mathcal{V}})}$$

The coefficients η and σ are expressed in terms of $\xi \ \propto \chi$ (*Antoniadis, Chen, GKL*, JHEP-2020):

$$\sigma = -\eta = \frac{\zeta(2)}{\zeta(3)}\xi,$$

The following ratio is of particular interest:

$$\frac{\hat{\xi}}{\hat{\eta}} = -\frac{\zeta(3)}{\zeta(2)}\frac{1}{g_s^2}$$

with

$$\hat{\xi} = \xi g_s^{-3/2} \ ; \ \ \hat{\eta} = g_s^{1/2}\eta$$

Kähler moduli

STABILISATION

within a concrete Global Model:

(*GKL & Pramod Shukla* **2203.03362** *; JHEP-2022*)

Kreuzer-Skarke (KS) in hep-th/0002240 introduced toric methods to construct Calabi-Yau manifolds in terms of

Reflexive Polyhedra

...exploring the KS dataset ...⇒

Explicit CY_3 Manifold

$$h^{1,1} = 3,\ h^{2,1} = 115,\ \chi \equiv 2(h^{1,1} - h^{2,1}) = -224$$

Assuming a basis of smooth divisors D_1, D_2, D_3, the Kähler form is

$$J = 2\sum_{k=1}^{3} t^k D_k$$

and the case under consideration gives intersection polynomial with only one non-zero intersection:

$$I_3 = 2D_1 D_2 D_3$$

The 6d-volume :

$$\mathcal{V} = 2\, t^1 t^2 t^3 = \frac{1}{\sqrt{2}}\sqrt{\tau_1 \tau_2 \tau_3}$$

($t^i \to$ 2-cycle, $\tau_i \to$ 4-cycle moduli, subject to $\tau_i = 2\, t^j t^k$)

▲ Kähler potential including α' and loop corrections:

$$\mathcal{K}(T_i, S, z_a) = -\log\{-i(S-\bar{S})\} - 2\ln\mathcal{U} + K_{cs}(z_a) \qquad (1)$$

$$\mathcal{U}(T_i, S) = \mathcal{V} + \frac{\hat{\xi}}{2} + \mathcal{U}_1 \qquad (2)$$

Assuming generic $\mathcal{U}_1(S, T^i)$ incorporating any loop corrections.

The effective potential

Identities to compute $K_j = \frac{\partial K}{\partial T_j}$, $K_{ij} = \frac{\partial^2 K}{\partial T_i \partial T_j}$, $K_{Sj} = \frac{\partial^2 K}{\partial S \partial T_j}$ *etc:*

$$\tau_i = \frac{\partial \mathcal{V}}{\partial t_i} = \frac{1}{2}\kappa_{ijk} t^j t^k, \quad A_{ij} t^i t^j = 6\mathcal{V}, \quad A^{ij}\tau_i\tau_j = 3\mathcal{V}/2$$

with A_{ij} *the second derivatives of* $\mathcal{V}$ *and their inverse:*

$$A_{ij} = \frac{\partial \mathcal{V}}{\partial t_i \partial t_j} = \kappa_{ijk} t^k, \quad A^{ij} = \left(\kappa_{ijk} t^k\right)^{-1}, \; A_{ik} A^{kj} = \delta_i^j \qquad (3)$$

Computing the inverse Kähler metric $K^{\bar{C}B}$ *using* $K_{A\bar{C}}K^{\bar{C}B} = \delta_A^B$:

$$
\begin{aligned}
K_{S\bar{S}}K^{\bar{S}S} + K_{S\bar{T}_j}K^{\bar{T}_j S} &= 1 \\
K_{S\bar{S}}K^{\bar{S}T_j} + K_{S\bar{T}_i}K^{\bar{T}_i T_j} &= 0 \\
K_{T_i\bar{S}}K^{\bar{S}T_j} + K_{T_i\bar{T}_k}K^{\bar{T}_k T_j} &= \delta_i^j \ .
\end{aligned}
\tag{4}
$$

These lead to a simple analytic form in the basis S, T^i, z^a:

$$
\mathcal{K}^{A\bar{B}} = \begin{pmatrix} \tilde{\mathcal{P}}_1 & k_\alpha \tilde{\mathcal{P}}_2 & \mathcal{O} \\ k_\alpha \tilde{\mathcal{P}}_2 & k_\alpha\, k_\beta\, \tilde{\mathcal{P}}_3 - k_{\alpha\beta}\, \tilde{\mathcal{P}}_4 & \mathcal{O} \\ \mathcal{O} & \mathcal{O} & K_{cs}^{i\bar{j}} \end{pmatrix}
\tag{5}
$$

$\Rightarrow$ *block-diagonal for* $K_{cs}^{i\bar{j}}$ *but* S *and* T_i $(\mathcal{V}\ )$ *mix :* $\tilde{\mathcal{P}}_I = \tilde{\mathcal{P}}_I(\mathcal{V}, S)$.

Master formula for F-term potential

(*for generic* $\mathcal{U}_1$ loop corrections)

⇓

$$V_{\alpha'+\text{generic}} = e^{\mathcal{K}} \left(\frac{3\mathcal{V}}{2\mathcal{U}^2} \left(1 + \frac{\partial \mathcal{U}_1}{\partial \mathcal{V}}\right)^2 \frac{4\mathcal{V}^2 + \mathcal{V}\hat{\xi} + 4\hat{\xi}^2}{\mathcal{V} - \hat{\xi}} - 3 \right) |W_0|^2$$

▲▲ For α' and logarithmic corrections: $\mathcal{U}_1 = -\hat{\eta} + \hat{\eta} \log \mathcal{V}$:

$$V_{\alpha'+\log} = 12 g_s e^{K_{cs}} |W_0|^2 \, \underbrace{\hat{\xi} \frac{\mathcal{V}^2 + 7\hat{\xi}\mathcal{V} + \hat{\xi}^2}{\left(\mathcal{V} - \hat{\xi}\right)\left(2\mathcal{V} + \hat{\xi}\right)^4}}_{\alpha'^3 - corrections}$$

$$- \frac{3\kappa}{2} |W_0|^2 \underbrace{\frac{2\hat{\eta} - \hat{\eta} \log \mathcal{V}}{2\mathcal{V}^3}}_{logarithmic} + \cdots$$

Large Volume Limit

$$V_F \approx C \frac{\hat{\xi} - 4\hat{\eta} + 2\hat{\eta}\log(\mathcal{V})}{\mathcal{V}^3}$$

Properties

- Minimum exists for $\hat{\eta} < 0$.
- Stabilisation at **large** volume (*in weak coupling* g_s *regime*):

$$\mathcal{V}_{\min} = e^{\frac{7}{3} + \frac{\hat{\xi}}{2|\hat{\eta}|}} \sim e^{\frac{1}{g_s^2}}$$

- For F-term potential, AdS-minimum

$$(V_F)_{\min} \propto \frac{\hat{\eta}}{\mathcal{V}^3} < 0$$

- *New contributions required to* **uplift** *to* **dS** *vacuum*

▲ **Uplift** to dS occurs through $\mathcal{D}$**-terms**
(*Lüst et al hep-th/0609211; Antoniadis,Chen, GKL 1803.08941*)
associated with universal $U(1)$'s of D7-stacks:

$$V_{\mathcal{D}} = \frac{g^2_{D7_i}}{2}\left(Q_i \partial_{T_i} K + \sum_j q_j |\Phi_j|^2\right)^2 \,,\quad \frac{1}{{g_{D7_i}}^2} = \mathrm{Re} T_i + \cdots$$

Minimising the total potential:

$$V_{\rm eff} = V_F + V_{\mathcal{D}}$$

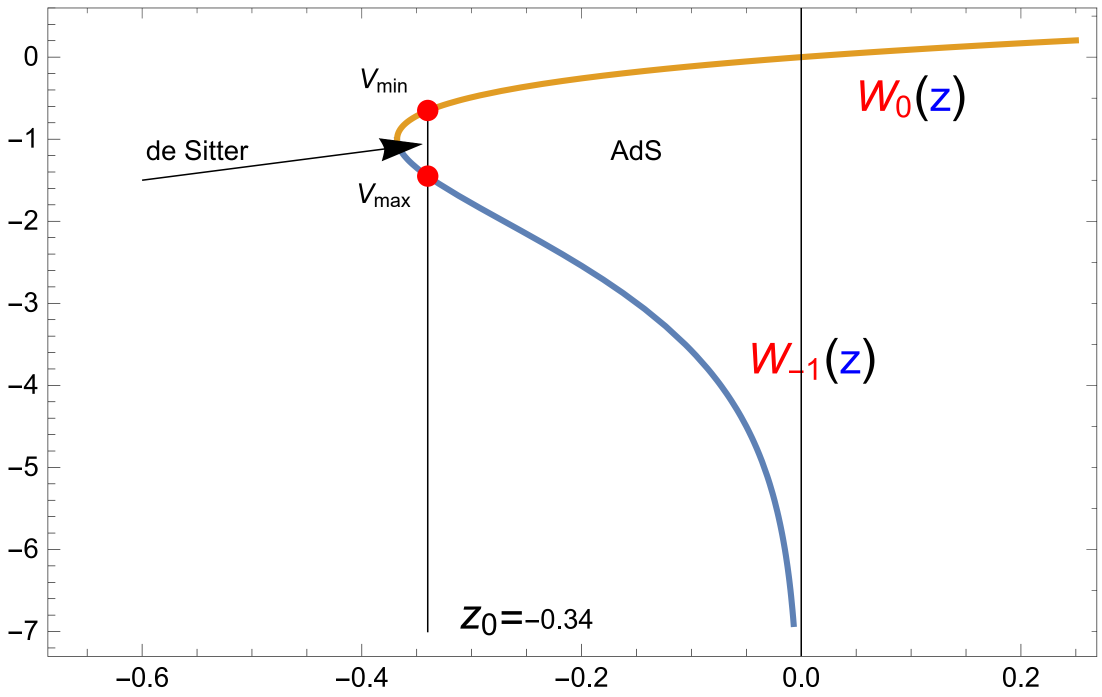
$\Rightarrow$ a minimum and a maximum defined by the
double-valued **Lambert** W-function (i.e., solution of $\mathbf{W}e^{\mathbf{W}} = z$):

$$\boxed{\mathcal{V}_{\rm min} = \frac{\hat{n}}{d}\mathbf{W_{0/-1}}\left(\frac{d}{\hat{n}} e^{\frac{7}{3} - \frac{\hat{\xi}}{2\hat{n}}}\right)}$$

▲ de Sitter vacua ▲

minimum $V_{\rm eff} = V_F + V_{\mathcal{D}}$ *at* $\mathcal{V}_0$ *must be positive:*

$$V_{\rm eff}^{\rm min} = \frac{c}{\mathcal{V}_0^3} + \frac{d}{\mathcal{V}_0^2} > 0$$



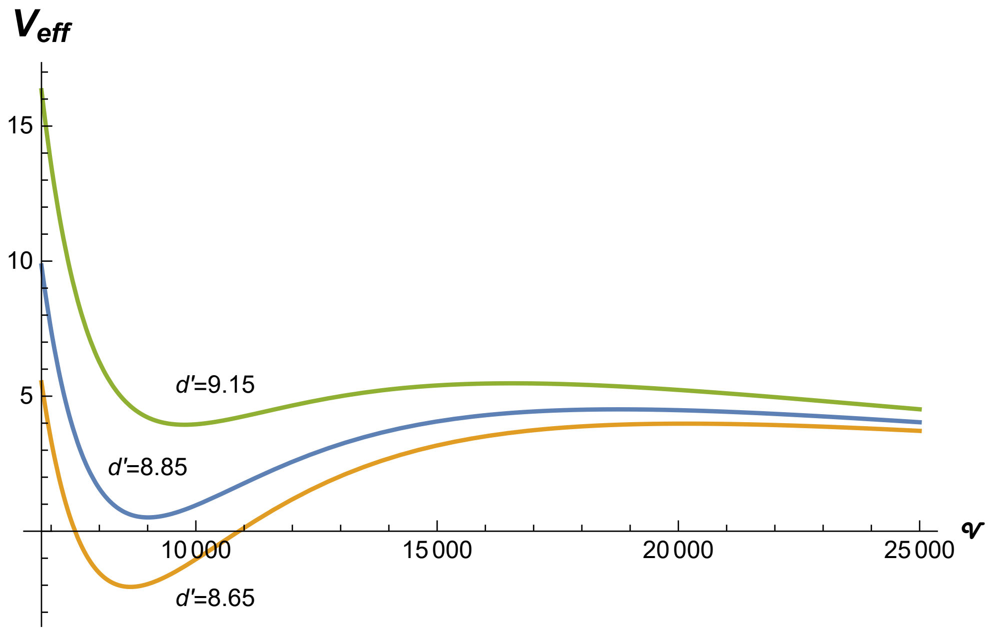
This dramatically constrains acceptable string vacua (fluxes etc)

de Sitter

Plot of $V_{\rm eff}$ vs $\mathcal{V}$ for $d' = 10^4 d = \{8.65, 8.85, 9.15\}$.

The lower curve corresponds to AdS vacuum.

At large volume, the potential vanishes asymptotically



Inflation

Hybrid scenario can be realised with **open string states** χ *at D7-brane intersections playing the role of waterfall fields (Antoniadis, Lacombe, GKL, 2109.03243, JHEP 2022)*

Shape of V_{total} in the presence of χ at large $\mathcal{V}$ regime:

$$V_{total} = C\frac{\hat{\xi} - 4\hat{\eta} + 2\hat{\eta}\log(\mathcal{V})}{\mathcal{V}^3} + \frac{d}{\mathcal{V}^2} + V_\chi$$

with V_χ the waterfall field potential:

$$V_\chi = \sim m^2(\mathcal{V})\chi^2 + \lambda(\mathcal{V})\chi^4$$

▲ The volume modulus can play the role of Inflaton field

$$\phi \propto \log \mathcal{V}$$

▲ *We find that inflation can be realised with most of the 60 efolds collected near the metastable local mimimum* $V_{total}(\mathcal{V}_{min})$.

▲ Inflation ends and false vacuum decays to *Global minimum* through a

$$\textbf{waterfall field } \chi\text{:} \;\; V_\chi \sim m^2(\mathcal{V})\chi^2 + \lambda(\mathcal{V})\chi^4 \; .$$

For $m^2 > 0$ minimum in the χ-field direction is at the origin

$$m^2 > 0 \; \to \; \langle\chi\rangle = 0$$

When the mass of χ becomes tachyonic, a phase transition occurs and the new vacuum is obtained at a non-vanishing $\langle\chi\rangle$:

$$m^2 < 0 \; \to \; \langle\chi\rangle \neq 0$$

A configuration to realise the hybrid scenario in our D7 set-up

	$\mathcal{T}^2_{(45)}$	$\mathcal{T}^2_{(67)}$	$\mathcal{T}^2_{(89)}$
$D7_1$	$\cdot$	$\otimes$	$\times_{\mathcal{A}_1}$
$D7_2$	$\times$	$\cdot_{\pm\mathbf{x_2}}$	$\otimes$
$D7_3$	$\otimes$	$\times_{\mathcal{A}_3}$	$\cdot$

▲ A circled cross shows magnetic field on specific $D7$ and $\mathcal{T}^2$.

▲ $\mathcal{A}_{1,3}$ denote Wilson lines

▲ $\pm\mathbf{x_2}$ brane separations (uplifting tachyons)

$\Rightarrow$ only one tachyonic state playing the role of waterfall field:

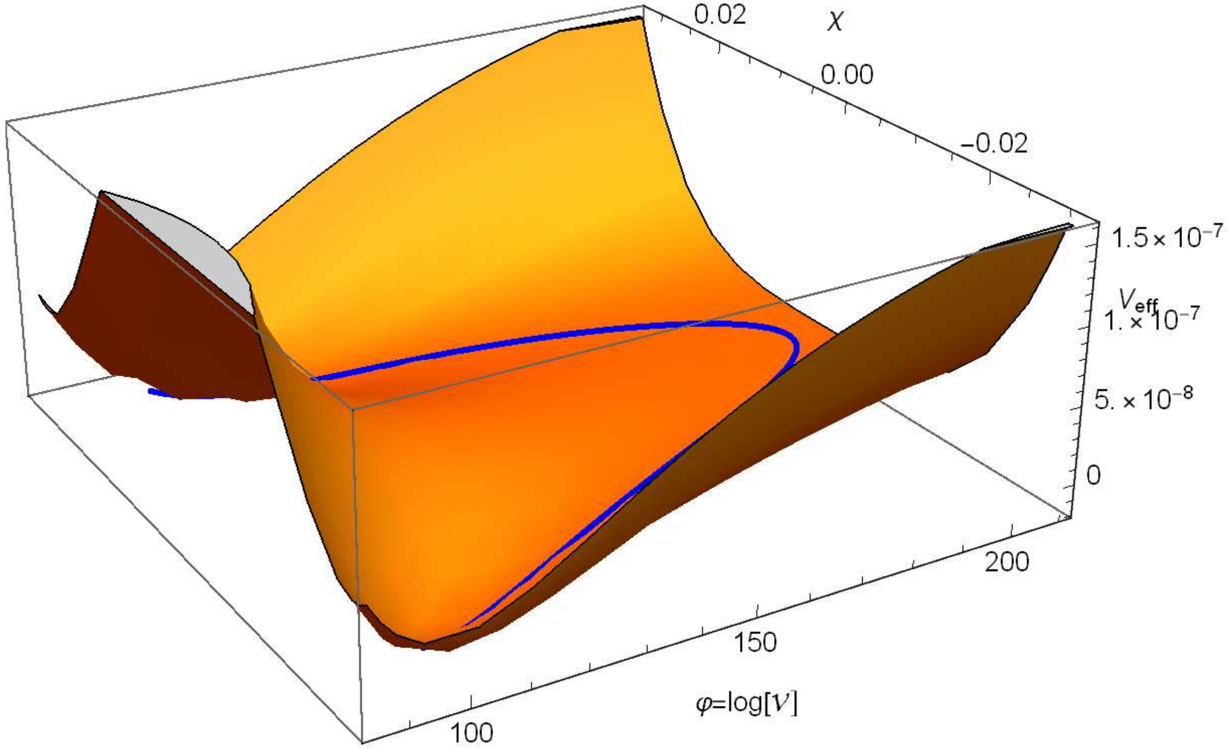
$$\alpha' {m_{22}}^2 \approx -\frac{A}{\mathcal{V}^{1/3}} + B\mathcal{V}^{1/3}, \;\; (A, B) \rightarrow \textit{positive constants}$$

$\langle\chi\rangle \neq 0$ for

$$\mathcal{V} \; < \; \mathcal{V}_{\text{critical}} = \left(\frac{A}{B}\right)^{\frac{3}{2}}$$

▲ Hybrid scenario: Inflaton: $\phi \propto \log \mathcal{V}$

▲ Blue curve: waterfall field χ trajectory



★ Conclusions ★

★ *IIB/F-theory:*

• Stabilisation of Kähler Moduli possible with

Perturbative corrections only:

$$\mathcal{K} = -2\ln\left(\mathcal{V} + \hat{\xi}/2 + \hat{\eta}\ln\mathcal{V}\right) + \cdots$$

Origin of log-corrections:

Induced Einstein-Hilbert terms from R^4-couplings in 10-d theory.

This $\mathcal{EH}$-term $\exists$ in $4d$ only!

$\Downarrow$

★ *induced* $\mathcal{EH}$–term ... indispensable element for a:

$4d$ de Sitter Universe

★ Hybrid Inflation with inflaton $\phi \sim \log\mathcal{V}$ and

waterfall fields open string states attached on $D7$'s.

APPENDIX

▲▲

D7-branes and Logarithmic corrections

Two ingredients needed for log*-corrections:*

▲▲

$\mathcal{A}$) Intersecting **D7-brane configuration**:

D7s	Minkowski				Compact Dimensions					
	0	1	2	3	4	5	6	7	8	9
$D7_a$		*	*	*	*	*	*	*		
$D7_b$		*	*	*	*	*			*	*
$D7_c$		*	*	*			*	*	*	*

$\mathcal{B}$) **Higher derivative couplings in curvature**

(generated by multigraviton scattering)

(see hep-th/9704145; 9707013; 9707018)

Leading correction term in type II-B action:

proportional to the fourth power of curvature:

$$\boxed{\propto R^4}$$

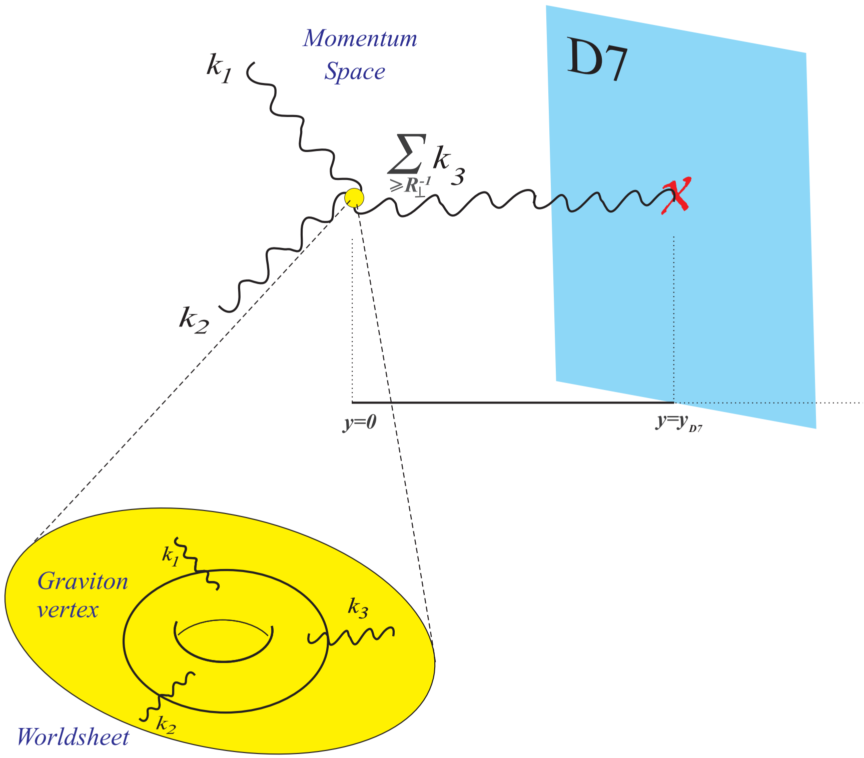
After reduction on $\mathcal{M}_4 \times \mathcal{X}_6$, (with $\mathcal{M}_4$ 4-d Minkowski) R^4 induces a **novel** Einstein-Hilbert term $\mathcal{R}_{(4)} \propto$ by the Euler characteristic χ:

$$\propto \quad \underbrace{\chi \int_{M_4} (\zeta(2) - \zeta(3) e^{-2\phi}) \mathcal{R}_{(4)}}_{\text{induced } \mathcal{EH} \text{ term}},$$

▲▲ *this $\mathcal{EH}$ term possible in 4-dimensions only*!

▲▲ New $\mathcal{EH}$-term localised at points with $\chi \neq 0$▲▲

KK-exchange between graviton vertex and a $D7$-brane



Corrections

$$\propto \zeta(2)\chi \int_{M_4} (1 + \sum_{i=1,2,3} e^{2\phi} \mathcal{T}_i \log(R^i_\perp) \mathcal{R}_{(4)} \ ,$$

▲ $\mathcal{T}_i$: D7-brane tension ($= g_s T_0$)

▲ $R^i_\perp$: D7-transverse 2-dimension

Kähler potential :

$\mathcal{K} = -\log(-i(S - \bar{S})) - 2\log(\mathcal{V} + \xi/2 + \eta \log \mathcal{V}) + K_{cs}$

$$\eta = -\frac{1}{2} g_s T_0 \xi \ \ ; \ \ \xi = -\frac{\chi}{4} \times \begin{cases} \frac{\pi^2}{3} g_s^2 & \text{for orbifolds} \\ \zeta(3) & \text{for smooth CY} \end{cases} \qquad (6)$$

Details of the Specific CY manifold

The analysis of the divisor topologies using *cohomCalg* shows that divisors are of $K3$ and SD types and can be represented by the following Hodge diamonds:

$$K3 \equiv \begin{matrix} & & 1 & & \\ & 0 & & 0 & \\ 1 & & 20 & & 1 \\ & 0 & & 0 & \\ & & 1 & & \end{matrix}\,, \qquad \mathrm{SD} \equiv \begin{matrix} & & 1 & & \\ & 0 & & 0 & \\ 27 & & 184 & & 27 \\ & 0 & & 0 & \\ & & 1 & & \end{matrix}\,.$$

Cancellation of all D7-charges

Introduce N_a D7-branes wrapped around divisors D_a and orientifold images D'_a (*0811.2936*)

$$\sum_k N_k \left([D_k + D'_k]\right) = 8[O7]$$

D7-branes and O7-planes also give rise to D3-tadpoles which receive contributions also from background 3-form fluxes

Assuming simple case:
$D7$-tadpoles are cancelled by placing 4 $D7 + D7'$-branes on top of $O7$-plane:

$$N_{D3} + \frac{1}{2} N_{\text{flux}} + N_{\text{gauge}} = \frac{1}{4}\left(O3 + \chi(O7)\right)$$

Example

Specific brane setting involving 2 stacks of $D7$-branes wrapping the divisors D_1, D_6 in the basis,

$$8[O7] = 4\left([D_1 + D_1']\right) + 4\left([D_6 + D_6']\right)$$

$D3$ tadpole condition

$$N_{D3} + \frac{1}{2}N_{flux} + N_{gauge} = 12$$

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