Fibre inflation models and moduli-space sizes

David Ciupke

University of Bologna, INFN-Bologna

Based on
∗ Cicoli, D.C., Diaz, Guidetti, Muia, Shukla [1709.01518]
∗ Cicoli, D.C., Shukla to appear

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Outline

Motivation/ Introduction

Global Chiral Embedding of Fibre Inflation

Moduli Spaces of LVS Vacua

Motivation: String-Inflation

String embedding of inflation faces many challenges:

1. Desired range: $10^{-3} \leq r \leq 10^{-2} \Rightarrow \Delta\phi > 1 M_p$
2. Consistent moduli stabilization
3. String vacuum with explicit compactification
4. Possibly global embedding with chiral matter

Meeting the Challenges

- Experience of model-builders (mostly for axions) so far: $1 + 2$ very hard to achieve
- Inflation from flat directions of LVS [Balasubramanian et al '05], Example Kähler modulus inflation [Conlon, Quevedo '05]. Here: Fibre Inflation [Burgess, Cicoli, Quevedo '08]
- Challenges 1-3 for Fibre Inflation assessed in [Cicoli, Muia, Shukla '16]
- Global embeddings [Cicoli, Garcia-Etxebarria, Klevers, Krippendorf, Mayrhofer, Quevedo, Shukla, Valandro]

Outline

Large Volume Scenario

[Balasubramanian et al '05]

- Starting point: [Kachru, Giddings, Polchinski '01]
- Requirement: Special CY of 'Swiss-Cheese'-type $h^{1,1} \geq 2$
- $\mathcal{V} = f(\tau_1, \ldots, \tau_{h^{1,1}-1}) - \tau_{h^{1,1}}^{3/2}$
- If D_n shrinkable rigid divisor $\Rightarrow$ del Pezzo surface $\Rightarrow$ Can support e.g. an $ED3$-instanton
- Moduli stabilization: W_{np} from instanton and $\delta K_{\alpha'^3}$, the 'BBHL-term' [Becker, Becker, Haack, Louis '02]

Result:

Stabilization of τ_n and $\mathcal{V}$ exponentially large. Trustworthy EFT with $h^{1,1} - 2$ flat directions

Fibre Inflation in a Nutshell

[Burgess, Cicoli, Quevedo '08]

- $h^{1,1} = 3$: LVS vacua with one flat direction, lifted by sub-leading corrections
- Consider LVS for CY with K3-fibration

$$\mathcal{V} = \sqrt{\tau_f}\tau_b - \tau_3^{3/2}$$

- Inclusion of g_s-corrections
  [Berg, Haack, Kang, Körs, Pajer, Sjörs '05 -'17]
- Plateau-type potentials with $10^{-3} \leq r \leq 10^{-2}$ and $\Delta\phi \sim$ a few M_p

Contributions to Scalar Potential

- $V = V_{LVS} + V_{g_s,KK} + V_{g_s,W} + V_{F^4} + V_D$
- $V_{g_s,KK}$: arise from KK-exchange between parallel D3/D7-branes or O3/O7-planes
- $V_{g_s,W}$: arise when intersecting D7-branes/O7-planes have non-trivial 1-cycles in their intersection
- V_{F^4}: F^4-terms which arise generically from the supersymmetric completion of higher derivative $(\alpha')^3$-corrections to T_i [DC, Louis, Westphal '15]
- V_D: D-term from wrapped D7-branes with worldvolume fluxes

Plethora of terms gives rise to many scenarios
[Broy, DC, Pedro, Westphal '15],[Cicoli, DC, de Alwis, Muia '16]

Requirements for Global Embedding

1. Chiral matter from wrapped D7-branes with worldvolume fluxes $\Rightarrow$ Minimal setup $h^{1,1} = 4$
2. A CY with $K3$-fibration and shrinkable dP
3. Choice of orientifolding and brane-setup with D7-gauge fluxes and tadpoles cancelled
4. Choice of gauge-fluxes such that Freed-Witten anomalies [Freed, Witten '99] are cancelled and only a single FI-term is generated
5. Absence of dangerous chiral intersections between visible sector and dP [Blumenhagen et al '07]
6. Moduli stabilization and inflation should take place well-inside the Kähler cone and the EFT approximation trustworthy. In particular, $m_{inf} < H < m_{3/2} < M_{KK}^{(i)} < M_s < M_p$

A triple $K3$-fibred CY

- GLSM data:

x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
0	0	0	1	1	0	0	2
0	0	1	0	0	1	0	2
0	1	0	0	0	0	1	2
1	0	0	1	0	1	1	4
dP_7			K3		K3	K3	

- $(h^{1,1} = 4, h^{2,1} = 98)$

- $$\boxed{\mathcal{V} \sim t_4\, t_6\, t_7 + t_1^3 \sim \sqrt{\tau_4 \tau_6 \tau_7} + \tau_1^{3/2}}$$

- Precise Kähler cone of this CY:

$$-t_1 > 0\ , \quad t_4 + t_1 > 0\ , \quad t_6 + t_1 > 0\ , \quad t_7 + t_1 > 0$$

Choice of Sources and Orientifolding

- Choice of involution: $\sigma : x_8 \to -x_8$
  $\Rightarrow$ one $O7$ wrapping D_8, $N_{O3} = 0$

- D7-tadpole cancelled by (D3-tadpole ✓):

$$8[O_7] \equiv 8[D_8] = 8([D_2] + [D_4] + [D_6]) + \sigma - \text{image}$$

- $D_2 \cap D_4, D_2 \cap D_6, D_4 \cap D_6 \sim \mathbb{T}^2 \Rightarrow V_{g_s,W}$ generated

- Choose $N_{D3} = 0 \Rightarrow V_{g_s,KK} = 0$

Gauge Fluxes and Chirality

- $\mathcal{F}_i = \sum_{j=1}^{h^{1,1}} f_{ij} \hat{D}_j - \frac{1}{2} c_1(D_i) - i^*_{D_i}(B)$
- 8 D7-branes on D_2 yield $Sp(16) \to U(8)$
- Moduli-dependent FI-term: $\xi = \frac{1}{4\pi\mathcal{V}} \int \hat{D}_2 \wedge J \wedge \mathcal{F}_2$
- Supersymmetric minimum: $\xi = 0 \Rightarrow \boxed{t_4 = \alpha t_6}$

Inflationary Potential

- After LVS + D-terms: Fibre inflation setup $\tau_f = \tau_7$

$$V = V_{F^4} + V_{g_s,W}$$

$$V_{F^4} \sim -\frac{\lambda W_0^4}{g_s^{3/2}\mathcal{V}^3}\left(\frac{1}{\tau_f} + \frac{1+\alpha}{\sqrt{\alpha}}\frac{\sqrt{\tau_f}}{\mathcal{V}}\right)$$

$$V_{g_s,W} \sim \frac{W_0^2}{\mathcal{V}^3}\left(\frac{C_w}{\sqrt{\tau_f}} - C_w'\frac{\tau_7}{\mathcal{V}}\right)$$

- **Kähler cone:** $2\alpha\langle\tau_1\rangle < \tau_f < \frac{\mathcal{V}}{\langle\tau_1\rangle}$

- Canonical normalization: $\tau_f \sim \mathrm{e}^{\phi} \Rightarrow \Delta\phi \lesssim \ln(\mathcal{V})$

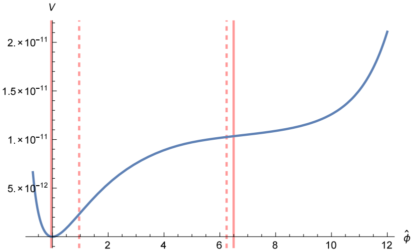
Tension and Explicit Example

General tension in satisfying all:

$$
\begin{aligned}
(1):&\qquad V_{inf} \ll V_{LVS}\\
(2):&\qquad \Delta\phi \sim \mathcal{O}(\text{few})\, M_p\\
(3):&\qquad V_{F^4} \quad \text{not destroying flatness}
\end{aligned}
$$

Example without (1) (single-field approximation invalid):
$\alpha = 1\ , \quad g_s \sim 0.1\ , \quad \mathcal{V} = 10^4\ , \quad W_0 = 80\ , \quad |\lambda| = 10^{-3}\ , \ldots$

$$r \sim 10^{-2}$$

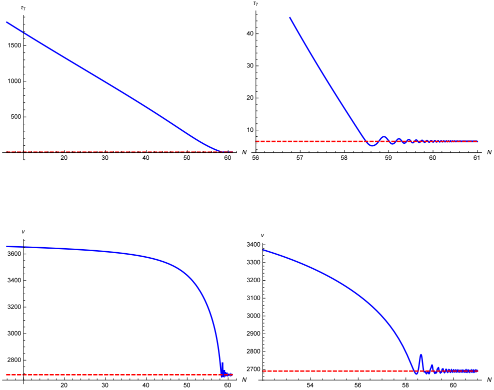


Example with Multifield-Evolution

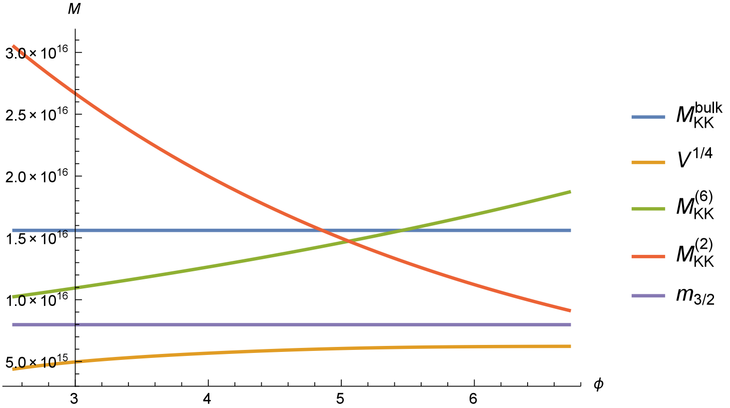
An example satisfying (1) for $\lambda \sim 10^{-6}$ with simple multifield-dynamics:

$$\alpha = 1 \; , \quad g_s \sim 0.25 \; , \quad \mathcal{V} \sim 2600 \; , \quad W_0 = 50 \; , \quad |\lambda| = 10^{-6} \; , \ldots$$

$$r \sim 10^{-3}$$



Hierarchy of Scales



Outline

Motivation

- This example motivates conjecture: Moduli space of LVS flat direction compact with size

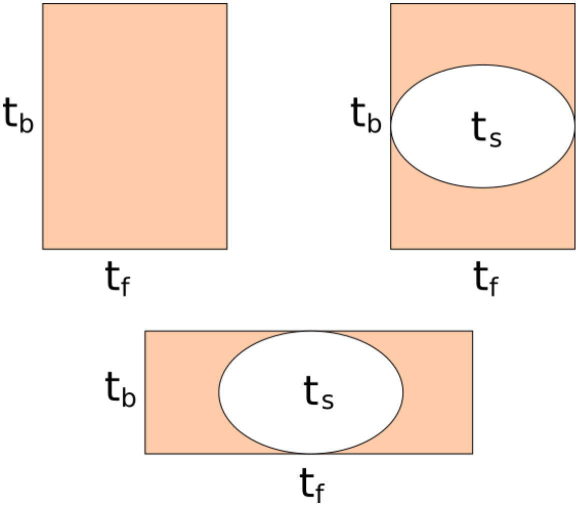
$$\Delta \lesssim \mathrm{Log}(\mathcal{V}) \sim \mathrm{Log}(1/\Lambda)$$

- Fits with 'Moduli space size conjecture' [Palti '17], [Hebecker et al '17]
- Any 'large' flat direction of LVS may admit Plateau inflation ⇒ are there other models?

Goal:

Collect evidence for this conjecture from $h^{1,1} = 3$ Kreuzer-Skarke list

Why is the moduli space compact?



Setup

First step: Scan for LVS vacua, Requirements:

1. CY favorable and trivial fundamental group
2. For LVS: CY with 'diagonal' dP $:= \exists$ a basis of smooth div. where dP only intersects with itself

Assumption: Sufficient to scan for coordinate divisors

Advantage: Scan for divisor topology simpler than other approaches such as [Altman et al '17]

Tools: database [Altman et al '14], divisor topology from 'cohomcalg' [Blumenhagen et al '10/'11]

Setup 2

Second step: Divide LVS vacua into classes:

1. K3-fibrations: $\mathcal{V} \sim \sqrt{\tau_f}\tau_b - \tau_{dP}^{3/2}$
2. CY with 2 diagonal dP: $\mathcal{V} \sim \tau_b^{3/2} - \tau_{dP}^{3/2} - \tau_{dP'}^{3/2}$
3. 'Strong Swiss-Cheese': $\mathcal{V} \sim \tau_b^{3/2} - \underbrace{(\sum_i \tau_i)^{3/2}}_{\text{i.g. not smooth}} - \tau_{dP}^{3/2}$
4. 'Exotic': $\mathcal{V} \sim f(\tau_1, \tau_2) - \tau_{dP}^{3/2}$, $\quad f$ cannot be simplified

Results of Scan of CY Geometries

Results for LVS vacua:

$h^{1,1}$	Total #	Σ of LVS	$K3$-Fib.	2 dP	1 dP SSC	Exotic
2	37	21	–	–	21	–
3	300	132	43	39	36	14

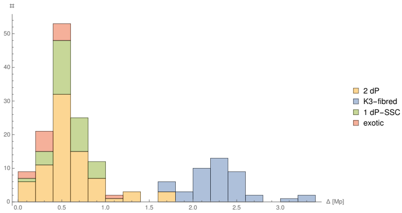
≥ 25 new LVS vacua which were not found in [Altman et al '17].

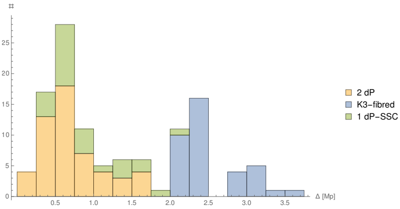
Results for average moduli space size ($g_s = 0.1$, $\mathcal{V} = 10^3$):

	$K3$-Fib.	2 dP	1 dP SSC	Exotic
Δ	$2.28\,M_p$	$0.59\,M_p$	$0.59\,M_p$	$0.39\,M_p$

The conjectured upper bound $\Delta \lesssim \mathrm{Log}(\mathcal{V})$ holds in all cases!

Distribution of Moduli space sizes





Reference histogram of $\Delta(\mathcal{A})$ for $\mathcal{V} = 10^3$.

Thanks for your attention!