Towards global embedding of Fibre inflation

(with the inclusion of higher-derivative α'-corrections)

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Work in progress

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Plan

- Some motivations
- Fibre Inflation
- Global embedding: A list of minimal requirements
- Explicit constructions of concrete examples in which Fibre inflation could be realized:
    - Scheme 1: Winding-corrections with F^4-terms
    - Scheme 2: KK-corrections with F^4-terms
    - Scheme 3: KK+Winding-corrections with F^4-terms
- Summary and outlook

Some General Motivations

Some basic requirements for (semi-)realistic model building in string cosmology

- Moduli stabilization and realizing de-Sitter solution
- Embedding inflationary scenarios (solving η-problem) and consistent realization of cosmological observables

Though recent Planck+BICEP2 paper has diluted the original BICEP2 claim on tensor-to-scalar ratio, $r < 0.11$, nevertheless

- Realizing non-trivial r could still be desirable !

Combining cosmo and pheno requirements ! (local/global effects interplay)

- Technical aspects
  - Moduli stabilization and chirality conflict [Blumenhagen, Moster, Plauschinn]
  - Need to sum over all possible instanton contributions, e.g. rigidifying E3-instantons [Bianchi, Collinucci, Martucci] used for realizing dS [Louis, Rummel, Valandro, Westphal]
  - Tadpole/anomaly cancellations, open string moduli, ...
  - Recent updates on warping effects [Martucci], [de Alwis], ...
  - Chiral global embedding on top of moduli stabilization [Cicoli, Krippendorf, Mayrhofer, Quevedo, Valandro],....
- On top of all: Useful control over (un)known α' and g_s corrections ?

Useful control over (un)known α' and g_s corrections ?

- Type IIB Calabi Yau orientifolds: Moduli stabilization better understood
- Symmetries which allow to perform step-by-step moduli stabilization
- Helps in creating mass hierarchies, useful e.g. for single field inflation, analytic computations, or at least numerical control

In general, K and W can have several corrections induced from various sources,

$$K = K_0 + K_{\alpha'} + K_{g_s} + ..., \qquad W = W_0 + W_{np}^{n=1} + W_{np}^{n=2} + ...$$

- Effects of string loop-corrections [Berg, Haack, Kors], [Cicoli, Conlon, Quevedo].
- Effects of α'-corrections [Becker, Becker, Haack, Louis], [Grimm, Savelli, Weissenbacher] + [Pedro, Rummel, Westphal], [Ciupke, Louis, Westphal]
- F-theory ${\alpha'}^3$-corrections [Minasian, Pugh, Savelli; see Savelli's talk]

V can also have higher derivatives corrections) [Ciupke, Louis, Westphal; Ciupke's talk]
Apart from conventional need, the new corrections shows the importance of having global constructions. History:

- (BBHL) need $\chi(CY) = \int_{CY} c_3(CY)$
- (BHK) need parallel and intersecting stacks of D-branes among $O7$-planes
- Higher derivative F^4 terms: need $\Pi_i(D_i) = \int_{CY} c_2(CY) \wedge D_i$
- $\chi(CY) \to \chi(CY) + 2\int_{CY} D_{O7}^3 = \chi(CY) + 2\chi(D_{O7}) - 2\int_{CY} c_2(CY) \wedge D_{O7}$: F-theory ${\alpha'}^3$-corrections.

Useful control over (un)known α' and g_s corrections and the LVS

- The time evolution about the knowledge of these unknown corrections comes out to be quite uncertain. And issue of viability !
- $\mathbb{E}$xtentions of "No scale structure" [von Gersdorff, Hebecker], [Berg,Haack, Kors], [Cicoli,Conlon,Quevedo], [Pedro, Rummel,Westphal] !

Consider type IIB superstring theory compactified on an orientifold of a Swiss-Cheese CY with $h^{1,1}_+ = 2$, $h^{1,1}_- = 0$ [Balasubramanian+Berglund+Conlon+Quevedo'05].

- Such a CY can be realized as a degree-18 hypersurface inside $\mathbb{WCP}^4[11169]$ with
- $$\mathcal{V} = \frac{1}{9\sqrt{2}}\left(\tau_b^{3/2} - \tau_s^{3/2}\right) = \gamma_b(T_b + \overline{T}_b)^{3/2} - \gamma_s(T_s + \overline{T}_s)^{3/2}.$$

$$K = -2\ln\left(\mathcal{V} + C_{\alpha'}\right), \quad W = W_0 + A_s\, e^{-a_s\, T_s}$$

- The scalar potential $V = e^K\left(K^{i\bar{j}}\,(D_iW)(\overline{D_{\bar{j}}}\,\overline{W}) - 3\,|W|^2\right)$ simplifies into,

$$V(\mathcal{V}, \tau_s) \simeq \frac{2\sqrt{2}\,a_s^2\,A_s^2\,\sqrt{\tau_s}}{3\,\gamma_s\,\mathcal{V}}\,e^{-2\,a_s\,\tau_s} - \frac{4\,a_s\,A_s\,W_0\tau_s}{\mathcal{V}^2}\,e^{-a_s\,\tau_s} + \frac{3\,C_{\alpha'}|W_0|^2}{2\,\mathcal{V}^3}.$$

- LVS minimum: $a_s\tau_s \simeq g_s^{-1}$ and $\mathcal{V} \simeq |W_0|\,e^{a_s\,\tau_s}$.

A snapshot of Fiber Inflation [Cicoli+Burgess+Quevedo'08]

The CYs used for this class of models are so-called 'weak' swiss-cheese CYs which have

$$\mathcal{V} = \gamma_b\, \tau_b \sqrt{\tau_f} - \gamma_s\, \tau_s^{3/2};\ K = -2\ln(\mathcal{V} + C_{\alpha'}),\ W = W_0 + A_s\, e^{-a_s\, T_s}.$$

The direction in the $(\tau_b - \tau_f)$-plane orthogonal to the overall volume $\mathcal{V}$ is still flat and is lifted by two-types of string-loop corrections.

- KK-type string-loop corrections: $K_{gs}^{kk} = g_s \sum_i \frac{C_i^{kk}\, t_i^{\perp}}{\mathcal{V}}$
- Winding-type string-loop corrections: $K_{gs}^{w} = \sum_i \frac{C_i^{w}}{\mathcal{V}\, t_i^{\cap}}$

After extended no-scale, the leading order τ_f dependent terms in the scalar potential:

$$V(\tau_f) \simeq \frac{g_s\, |W_0|^2}{\mathcal{V}^2} \left[\frac{A_1}{\tau_f^2} + \frac{A_2}{\mathcal{V}\, \sqrt{\tau_f}} + \frac{A_3\, \tau_f}{\mathcal{V}^2}\right]$$

Features:

- The inflaton is volume of a $K3$ or $\mathbb{T}^4$ divisor fibred over a $\mathbb{P}^1$ base.
- The cosmological parameters $P_s \sim 2.3 \times 10^{-9}$, $n_s \simeq 0.96$ and $N_e \sim 60$ can be successfully realized.
- Moreover, $\epsilon \simeq \frac{3}{2}\eta^2$, $r \sim 6(n_s - 1)^2$, and the best numerical fit can result in r as large as $r \leq 0.007$ (which has improved upto $r \leq 0.01$).

Global embeddings

Global embedding: A list of the minimal requirements

Strategy:

- Searching for some $K3$-fibred CY threefolds with $h^{11} = 3$ and having a shrinkable del-Pezzo divisor (to support LVS).
- Choice of orientifold involutions, tadpole/anomaly cancellations, and fixing a particular Brane-setting.
- Ensuring that the possible brane settings have enough structure (being parallel or intersecting) to generate "appropriate" string-loop corrections.
- Incorporating the effects of recently proposed higher derivative corrections.
- Moduli stabilization and Inflationary dynamics along with the numerics to fit the values without violating the assumptions made.

Searching del-Pezzo divisors: Relevant for LVS

We plan to investigate the CY_3 with $h^{11} = 3$ by considering all the 244 polytopes of the Kreuzer-Skarke list using the recent CY database [Altman, Gray, He, Jejjala, Nelson].

- del-Pezzo surfaces dP_n are realized by blowing up $\mathbb{P}^2$ on eight points,

$$dP_n \equiv . \begin{array}{ccccc} & & 1 & & \\ & 0 & & 0 & \\ 0 & & n+1 & & 0 \\ & 0 & & 0 & \\ & & 1 & & \end{array}, \qquad \forall\, n \in \{0, 1, ...8\} \qquad \text{[see McAllister's talk]}$$

- A necessary condition for the divisor D_s to be del-Pezzo is the fact that the only positive triple intersection is the self-intersection, and all the other intersections are either negative or zero. More concretely it is expressed as under,

$$\int_{\mathcal{C}=D_i \cap D_s} c_1(D_s) = -D_i\, D_s^2 > 0 \qquad \forall\, \mathcal{C} \neq \emptyset \quad \text{and} \quad i \neq s$$

- For shrinkability, we check if there exist a basis of divisors in which the volume form is (block) diagonal. Diagonal del-Pezzo and Non-diagonal del-Pezzo
- For $n > 8$, the four-cycles are rigid but not del Pezzo [Cicoli, Kreuzer, Mayrhofer] and we call them as "NdP$_n$" for notational simplification.

A condition for a $K3$-fibered CY_3

A theorem in [Oguiso' 92] implies that, if a (numerically effective) divisor D appears linearly in the intersection polynomial, then the CY_3 is a ($K3$ or $\mathbb{T}^4$) fibration over a $\mathbb{P}^1$ base.

For D being fibre, out of the possibilities $D^3, D^2 D_i$ and $D D_i D_j$, the only terms allowed in the intersection polynomial comes out to be $D D_i D_j$, so two possibilities arise,

$$(i). \qquad I_3 = \sum_{i \neq f} a_i \, D_f \, D_i^2 + \mathcal{P}_1(D_k), \qquad \text{where } k \neq f$$

$$(ii). \qquad I_3 = \sum_{i \neq j \neq f} a_{ij} \, D_f \, D_i \, D_j + \mathcal{P}_2(D_k) \qquad \text{where } k \neq f \, .$$

$\mathcal{P}_i(D_k)$'s are some cubic polynomials depending on all the divisors but the Fibre D_f.

- "Weak" swiss cheese: Minimal case with $h^{11}(CY) = 3$

$$I_3 = a \, D_f \, D_b^2 + b \, D_s^3 \quad \Longrightarrow \mathcal{V} = \frac{a \; t_b^2 \, t_f}{2} + \frac{b \; t_s^3}{6} = \frac{\tau_b \; \sqrt{\tau_f}}{\sqrt{2} \; \sqrt{a}} - \frac{\sqrt{2} \; \tau_s^{3/2}}{3 \; \sqrt{b}}$$

- "Weaker" swiss cheese: Minimal case with $h^{11}(CY) = 4$

$$I_3 = a \, D_f \, D_x \, D_y + b \, D_s^3 \quad \Longrightarrow \mathcal{V} = a \; t_x \, t_y \, t_f + \frac{b \; t_s^3}{6} = \frac{\sqrt{\tau_x \; \tau_y \; \tau_f}}{\sqrt{a}} - \frac{\sqrt{2} \; \tau_s^{3/2}}{3 \; \sqrt{b}}$$

  This type of volume form has been recently motivated in [Cicoli+Burgess+de Alwis+Quevedo].

Minimal global embedding: A concrete example

Let us consider a CY threefold defined by a hypersurface with the following Toric data,

CY Hyp.	x_1	x_2	x_3	x_4	x_5	x_6	x_7
6	0	0	1	1	1	0	3
8	0	1	1	1	0	1	4
8	1	0	1	0	1	1	4
	dP_8	NdP_{10}	$SD2$	NdP_{15}	NdP_{13}	$K3$	$SD1$

$$\text{SR} \quad = \quad \{x_1 x_5,\ x_1 x_6 x_7,\ x_2 x_3 x_4,\ x_2 x_6 x_7,\ x_3 x_4 x_5\}$$

with $(h^{2,1}, h^{1,1}) = (99, 3)$ and Euler number $\chi = -192$. This corresponds to the polytope ID $\#192$ in the CY database [Altman, Gray, He, Jejjala, Nelson].
The package cohomCalg [Blumenhagen, Jurke, Rahn, Roschy] efficiently computes the Hodge numbers of various coordinate divisors.

$$SD1 \equiv \begin{matrix} & & 1 & & \\ & 0 & & 0 & \\ 23 & & 159 & & 23 \\ & 0 & & 0 & \\ & & 1 & & \end{matrix}\ , \qquad SD2 \equiv \begin{matrix} & & 1 & & \\ & 0 & & 0 & \\ 2 & & 29 & & 2 \\ & 0 & & 0 & \\ & & 1 & & \end{matrix}\ ,$$

Canonical version of the volume form

The intersection polynomial with the divisor basis $\{D_1, D_6, D_7\}$ is:

$$I_3 = 18\, D_7^2\, D_6 + 81\, D_7^3 + 9\, D_7^2\, D_1 - 3\, D_7\, D_1^2 + D_1^3$$

which leads to the volume form,

$$\mathcal{V} = \frac{27\, t_7^3}{2} + 9\, t_7^2\, t_6 + \frac{9\, t_7^2\, t_1}{2} - \frac{3\, t_7\, t_1^2}{2} + \frac{t_1^3}{6} = \frac{1}{6}\left(\sqrt{\tau_6}\,(\tau_7 - 2\,\tau_6 + 3\tau_1) - 2\,\sqrt{2}\,\tau_1^{3/2}\right)$$

Switching to the divisor basis $\{D_1, D_6, D_x = D_7 - 2\, D_6 + 3D_1\}$, we have

$$I_3 = D_1^3 + 18\, D_6\, D_x^2$$

Subsequently, the volume form reduces into the minimal canonical version needed for embedding the Fibre inflation scenario,

$$\mathcal{V} = 9\, t_6\, t_x^2 + \frac{t_1^3}{6} = \frac{\tau_x\,\sqrt{\tau_6}}{6} - \frac{\sqrt{2}\,\tau_1^{3/2}}{3}\,,$$

where

$$t_1 = -\sqrt{2}\,\sqrt{\tau_1}, \quad t_6 = \frac{\tau_x}{6\,\sqrt{\tau_6}}, \quad t_x = \frac{\sqrt{\tau_6}}{3}$$

Higher derivative F^4-corrections to the scalar potential

Before looking at the relevant Brane-settings satisfying the tadpoles and generating the correct string-loop corrections to the scalar potential, let us fix the higher-order α' correction for this example.

- Knowing the second chern class for this CY to be

$$c_2(CY) = -\frac{14}{3} D_3\, D_7 + \frac{2}{3} D_5\, D_7 + \frac{8}{3} D_7^2$$

  the topological quantities Π_i's appearing in the higher derivative F-term corrections are given as under [Ciupke, Louis, Westphal],

$$\Pi_i(D_i) = \int_{CY} c_2(CY) \wedge D_i, \qquad \text{and} \qquad V_{F^4} = \frac{\lambda\, |W_0|^4\, \Pi_i\, t^i}{\mathcal{V}^4}\,.$$

- These Π's have some hierarchy, which is good for inflation [see, Cicoli's talk and Ciupke's talk]

$$\Pi_1 = 10, \quad \Pi_2 = 14, \quad \Pi_3 = 34, \quad \Pi_4 = 24, \quad \Pi_5 = 20, \quad \Pi_6 = 24, \quad \Pi_7 = 126, \quad \Pi_x = 108\,.$$

- Now considering the relevant one Π_1, Π_6 and Π_x results in the following scalar potential contribution,

$$V_{F^4} = \frac{\lambda\, |W_0|^4}{\mathcal{V}^3} \left[\frac{24}{\tau_6} + \frac{8\sqrt{2}\tau_1^{3/2}}{\tau_6\, \mathcal{V}} + \frac{36\sqrt{\tau_6}}{\mathcal{V}} - \frac{10\sqrt{2}\sqrt{\tau_1}}{\mathcal{V}}\right]$$

Curves at the intersection of two divisors on the CY hypersurface

	D_1	D_2	D_3	D_4	D_5	D_6	D_7
D_1	$--$	$\mathbb{T}^2$	$\mathbb{T}^2$	$\mathcal{C}_2$	$\emptyset$	$\emptyset$	$\mathcal{C}_4$
D_2	$\mathbb{T}^2$	$\mathbb{P}^1$	$\mathbb{T}^2$	$2\,\mathbb{P}^1$	$\mathcal{C}_2$	$\emptyset$	$\mathcal{C}_4$
D_3	$\mathbb{T}^2$	$\mathbb{T}^2$	$\mathcal{C}_2$	$\mathbb{P}^1$	$\mathbb{P}^1$	$\mathcal{C}_2$	$\mathcal{C}_{14}$
D_4	$\mathcal{C}_2$	$2\,\mathbb{P}^1$	$\mathbb{P}^1$	$6\,\mathbb{P}^1$	$\mathbb{P}^1$	$\mathcal{C}_2$	$\mathcal{C}_5$
D_5	$\emptyset$	$\mathcal{C}_2$	$\mathbb{P}^1$	$\mathbb{P}^1$	$4\,\mathbb{P}^1$	$\mathcal{C}_2$	$\mathcal{C}_5$
D_6	$\emptyset$	$\emptyset$	$\mathcal{C}_2$	$\mathcal{C}_2$	$\mathcal{C}_2$	$\emptyset$	$\mathcal{C}_{10}$
D_7	$\mathcal{C}_4$	$\mathcal{C}_4$	$\mathcal{C}_{14}$	$\mathcal{C}_5$	$\mathcal{C}_5$	$\mathcal{C}_{10}$	$\mathcal{C}_{82}$

$$t^{\cap}(D_i \cap D_j) \equiv \int_{CY} J \wedge D_i \wedge D_j =$$

$$\begin{array}{ccccccc}
t_1 & -t_1 & -t_1 & -2t_1 & 0 & 0 & -3t_1 \\
-t_1 & t_1 & 6t_x + t_1 & 2\,(3t_x + t_1) & 6t_x & 0 & 3\,(6t_x + t_1) \\
-t_1 & 6t_x + t_1 & 4t_x + t_1 + 2t_6 & 2\,(2t_x + t_1 + t_6) & 2\,(t_6 - t_x) & 6t_x & 3\,(6t_x + t_1 + 2t_6) \\
-2t_1 & 2\,(3t_x + t_1) & 2\,(2t_x + t_1 + t_6) & 2\,(2t_x + 2t_1 + t_6) & 2\,(t_6 - t_x) & 6t_x & 6\,(3t_x + t_1 + t_6) \\
0 & 6t_x & 2\,(t_6 - t_x) & 2\,(t_6 - t_x) & 2\,(t_6 - 4t_x) & 6t_x & 6t_6 \\
0 & 0 & 6t_x & 6t_x & 6t_x & 0 & 18t_x \\
-3t_1 & 3\,(6t_x + t_1) & 3\,(6t_x + t_1 + 2t_6) & 6\,(3t_x + t_1 + t_6) & 6t_6 & 18t_x & 9\,(8t_x + t_1 + 2t_6)
\end{array}$$

Scheme 1: Fibre inflation with winding-type and F^4-terms

From the curve analysis, we choose the involution $\sigma : x_3 \to -x_3$.

$$D7 \text{ tadpole}: \quad 8\,[O7] \equiv 8\,[D_3] = 8\,[D_5] + 8\,[D_2], \quad \text{D7 not on top of O7}$$

$$D3 \text{ tadpole}: \quad N_{D3} + \frac{N_{\rm flux}}{2} + N_{\rm gauge} = \frac{N_{O3}}{4} + \frac{\chi(O7)}{12} + \sum_a \frac{N_a\,(\chi(D_a) + \chi(D'_a))}{48}$$

$$= \frac{5}{4} + \frac{35}{12} + \frac{8(16+13)}{48} = 9\,.$$

- The relevant intersections to look at are:
  $O7 \cap (D7_a \equiv D_5) = \mathbb{P}^1$, $\quad O7 \cap (D7_b \equiv D_2) = \mathbb{T}^2$, $\quad D_a \cap D_b = \mathcal{C}_2$.
- The scalar potential is

$$V_{g_s}^{(w)} = \sum_i \frac{|W_0|^2\,\mathcal{A}_i^w}{\mathcal{V}^3\;t_i^{\cap}} = \frac{|W_0|^2}{\mathcal{V}^3}\left[\frac{\mathcal{A}_1^w}{6\,t_x} + \frac{\mathcal{A}_2^w}{(t_1 + 6\,t_x)} + \frac{\mathcal{A}_3^w}{2\,(t_6 - t_x)}\right]$$

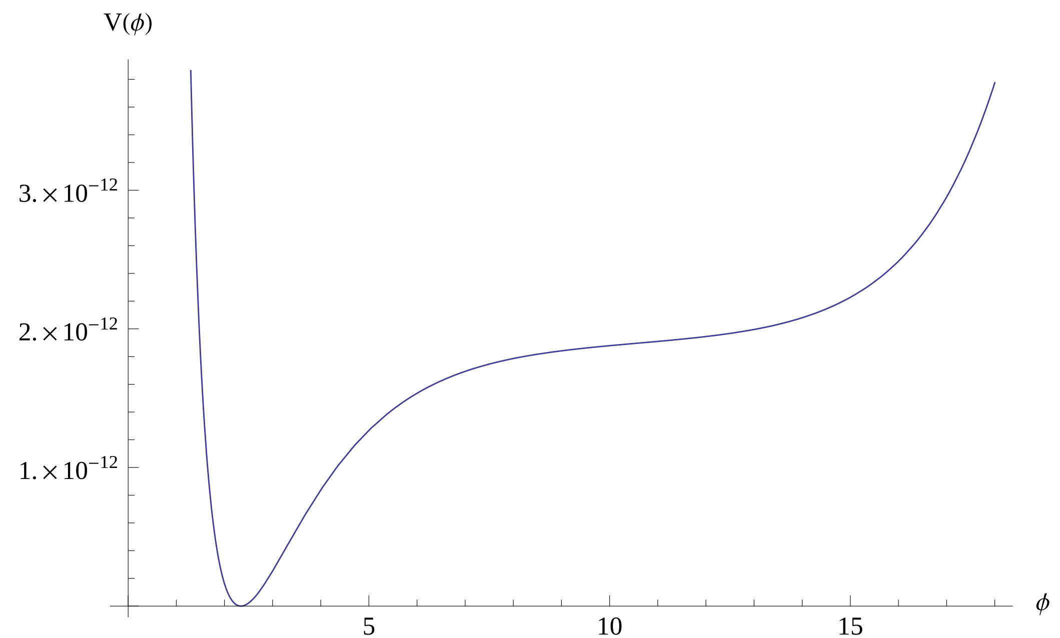
Recalling that $t_6 = \frac{\tau_x}{6\sqrt{\tau_6}}$, $t_1 = -\sqrt{2}\sqrt{\tau_1}$, $t_x = \frac{\sqrt{\tau_6}}{3}$, therefore

$$V_{g_s}^{(w)} = \frac{|W_0|^2}{\mathcal{V}^3}\left[\frac{\mathcal{A}_1^w}{2\sqrt{\tau_6}} + \frac{\mathcal{A}_2^w}{2\sqrt{\tau_6} - \sqrt{2}\sqrt{\tau_1}}\right]$$

Scheme 1: Fibre inflation with winding-type and F^4-terms

The scalar potential takes the form: $V = V_{up} + V_{LVS} + V_{g_s}^{(w)} + V_{F^4} + \ldots$

$$V(\tau_6) \simeq \frac{|W_0|^2}{\mathcal{V}^3}\left[\frac{\mathcal{A}_1^w}{2\sqrt{\tau_6}} + \frac{\mathcal{A}_2^w}{2\sqrt{\tau_6}-\sqrt{2}\sqrt{\tau_1}}\right] + \frac{\lambda\,|W_0|^4}{\mathcal{V}^3}\left[\frac{24}{\tau_6} + \frac{36\sqrt{\tau_6}}{\mathcal{V}}\right]$$



e.g. $$V \simeq V_{up} + \frac{\beta_1}{2\sqrt{\tau_6}} + \frac{\beta_2}{2\sqrt{\tau_6}-\sqrt{2}\sqrt{\tau_1}} + \frac{\beta_3\sqrt{\tau_6}}{\mathcal{V}};\quad \tau_6 = e^{2\phi/\sqrt{3}},$$

Plotted for $\beta_1 = -5,\ \beta_2 = 2, \beta_3 = 0.001, \tau_1 = 4, \mathcal{V} = 5000\,.$

For details on Fibre inflation with "Windings + F^4 ", [see, Cicoli's talk].

Scheme 2: Fibre inflation with KK-type and F^4 -terms

From the curve analysis, we choose the involution $\sigma : x_6 \to -x_6$.

$$D7 \text{ tadpole}: \quad 8\,[O7] \equiv 8\,[D_6] = 8\,[D_2] + 8\,[D_1], \qquad \text{D7 not on top of O7}$$

$$D3 \text{ tadpole}: \quad N_{D3} + \frac{N_{\rm flux}}{2} + N_{\rm gauge} = \frac{N_{O3}}{4} + \frac{\chi(O7)}{12} + \sum_a \frac{N_a\,(\chi(D_a) + \chi(D'_a))}{48}$$

$$= \frac{12}{4} + \frac{24}{12} + \frac{8(13+11)}{48} = 9\,.$$

- The relevant intersections are: $O7 \cap (D7_a \equiv D_2) = \emptyset, \quad O7 \cap (D7_b \equiv D_1) = \emptyset,$ $D_a \cap D_b = \mathbb{T}^2$ but $t^{\cap}(D_a \cap D_b) = -t_1$ implying no winding-type corrections !
- The string-loop corrections of KK-type are,

$$V_{g_s}^{(kk)} \simeq \frac{|W_0|^2}{\mathcal{V}^2}\left[\frac{g_s^2\,\mathcal{B}_6^{kk}}{\tau_6^2} + \frac{g_s^2\,\mathcal{B}_x^{kk}\,\tau_6}{3\,\mathcal{V}^2}\right]$$

Collecting everything $\quad\Longrightarrow\quad V = V_{up} + V_{LVS} + V_{g_s}^{(kk)} + V_{F^4} + \ldots\ldots$

$$V(\tau_6) = \frac{|W_0|^2}{\mathcal{V}^2}\left[\frac{g_s^2\,\mathcal{B}_2^{kk}}{\tau_6^2} + \frac{g_s^2\,\mathcal{B}_x^{kk}\,\tau_6}{3\,\mathcal{V}^2}\right] + \frac{\lambda\,|W_0|^4}{\mathcal{V}^3}\left[\frac{24}{\tau_6} + \frac{36\,\sqrt{\tau_6}}{\mathcal{V}}\right]$$

For Fibre inflation with "$KK + F^4$ " [Broy, Ciupke, Pedro, Westphal], [see also, Ciupke's talk]. We do not find suitable brane settings "just" enough to have standard Fibre inflation (i.e. KK and Winding both).

Scheme 3: Standard Fibre inflation with F^4 -terms

Let us consider the Calabi Yau threefold defined by the following Toric data,

	x_1	x_2	x_3	x_4	x_5	x_6	x_7
6	0	0	1	1	0	3	1
8	0	1	1	1	1	4	0
12	1	0	2	2	1	6	0
	NdP$_{11}$	dP_7	$SD2$	$SD2$	$K3$	$SD1$	W

$$\mathrm{SR} \quad = \quad \{x_1 x_5, x_2 x_5, x_1 x_3 x_4, x_2 x_6 x_7, x_3 x_4 x_6 x_7\}$$

with Hodge numbers $(h^{2,1}, h^{1,1}) = (111, 3)$ and Euler number $\chi = -216$. This CY corresponds to polytope ID $\#228$ in the database [Altman, Gray, He, Jejjala, Nelson]. The intersection polynomial in the basis of smooth divisors $\{D_2, D_5, D_7\}$, which is subsequently given as under,

$$I_3 = 2D_2^3 + 2D_5\, D_7^2 - 8D_7^3 \qquad \Longrightarrow \mathcal{V} = \frac{t_2^3}{3} + t_5\, t_7^2 - \frac{4\, t_7^3}{3} = \frac{1}{6}\left(\sqrt{\tau_5}\,(3\tau_7 + 4\tau_5) - 2\,\tau_2^{3/2}\right)$$

For the divisor basis $\{D_2, D_5, D_x = (4\,D_5 + 3\,D_7)\}$, the volume simples into,

$$\mathcal{V} = 9\, t_5\, t_x^2 + \frac{t_2^3}{3} = \frac{\tau_x\,\sqrt{\tau_5}}{6} - \frac{\tau_2^{3/2}}{3}, \quad \text{where} \quad t_2 = -\sqrt{\tau_2}, \quad t_5 = \frac{\tau_x}{6\sqrt{\tau_5}}, \quad t_x = \frac{\sqrt{\tau_5}}{3}$$

Scheme 3: Standard Fibre inflation with F^4 -terms

	D_1	D_2	D_3	D_4	D_5	D_6	D_7
D_1	$--$	$\mathbb{T}^2$	$\mathbb{P}^1$	$\mathbb{P}^1$	$\emptyset$	$\mathcal{C}_4$	$\mathcal{C}_2$
D_2	$\mathbb{T}^2$	$--$	$\mathbb{T}^2$	$\mathbb{T}^2$	$\emptyset$	$\mathcal{C}_3$	$\emptyset$
D_3	$\mathbb{P}^1$	$\mathbb{T}^2$	$\mathcal{C}_3$	$\mathcal{C}_3$	$\mathcal{C}_2$	$\mathcal{C}_{19}$	$2\,\mathbb{P}^1$
D_4	$\mathbb{P}^1$	$\mathbb{T}^2$	$\mathcal{C}_3$	$\mathcal{C}_3$	$\mathcal{C}_2$	$\mathcal{C}_{19}$	$2\,\mathbb{P}^1$
D_5	$\emptyset$	$\emptyset$	$\mathcal{C}_2$	$\mathcal{C}_2$	$\emptyset$	$\mathcal{C}_{10}$	$\mathcal{C}_2$
D_6	$\mathcal{C}_4$	$\mathcal{C}_3$	$\mathcal{C}_{19}$	$\mathcal{C}_{19}$	$\mathcal{C}_{10}$	$\mathcal{C}_{93}$	$6\,\mathbb{P}^1$
D_7	$\mathcal{C}_2$	$\emptyset$	$2\,\mathbb{P}^1$	$2\,\mathbb{P}^1$	$\mathcal{C}_2$	$6\,\mathbb{P}^1$	$--$

$$t^{\cap}(D_i \cap D_j) \equiv \int_{CY} J \wedge D_i \wedge D_j =$$

$2t_2$	$-2t_2$	$2\,(t_2+3t_x)$	$2\,(t_2+3t_x)$	0	$4t_2+18t_x$	$6t_x$
$-2t_2$	$2t_2$	$-2t_2$	$-2t_2$	0	$-4t_2$	0
$2\,(t_2+3t_x)$	$-2t_2$	$2\,(t_2+t_5+4t_x)$	$2\,(t_2+t_5+4t_x)$	$6t_x$	$4t_2+6\,(t_5+4t_x)$	$2\,(t_5-2t_x)$
$2\,(t_2+3t_x)$	$-2t_2$	$2\,(t_2+t_5+4t_x)$	$2\,(t_2+t_5+4t_x)$	$6t_x$	$4t_2+6\,(t_5+4t_x)$	$2\,(t_5-2t_x)$
0	0	$6t_x$	$6t_x$	0	$18t_x$	$6t_x$
$4t_2+18t_x$	$-4t_2$	$4t_2+6\,(t_5+4t_x)$	$4t_2+6\,(t_5+4t_x)$	$18t_x$	$8t_2+18\,(t_5+4t_x)$	$6\,(t_5-2t_x)$
$6t_x$	0	$2\,(t_5-2t_x)$	$2\,(t_5-2t_x)$	$6t_x$	$6\,(t_5-2t_x)$	$2\,(t_5-8t_x)$

Scheme 3: Standard Fibre inflation with F^4 -terms

From the curve analysis, we choose the involution $\sigma : x_4 \to -x_4$.

$$D7 \text{ tadpole}: \quad 8\,[O7] \equiv 8\,[D_4] = 8\,[D_5] + 8\,[D_1] + 8\,[D_7], \quad \text{D7 not on top of O7}$$

$$D3 \text{ tadpole}: \quad N_{D3} + \frac{N_{\rm flux}}{2} + N_{\rm gauge} = \frac{N_{O3}}{4} + \frac{\chi(O7)}{12} + \sum_a \frac{N_a\,(\chi(D_a) + \chi(D'_a))}{48}$$

$$= \frac{2}{4} + \frac{46}{12} + \frac{8(24+14-4)}{48} = 10\,.$$

- The string-loop corrections of KK-as well as winding-type are,

$$V_{g_s}^{(kk)} \simeq \frac{|W_0|^2}{\mathcal{V}^2}\left[\frac{g_s^2\,\mathcal{B}_5^{kk}}{\tau_5^2} + \frac{g_s^2\,\mathcal{B}_x^{kk}\,\tau_5}{3\,\mathcal{V}^2}\right], \quad V_{g_s}^{(w)} = \frac{|W_0|^2}{\mathcal{V}^3}\left[\frac{\mathcal{A}_1^w}{6\,t_x}\right] = \frac{|W_0|^2}{\mathcal{V}^3}\left[\frac{\mathcal{A}_1^w}{2\sqrt{\tau_5}}\right]$$

- We have Π_i's as $\Pi_1 = 140$, $\Pi_2 = 44$, $\Pi_3 = 44$, $\Pi_4 = 8$, $\Pi_5 = 24$, $\Pi_6 = 16$, $\Pi_7 = 4$, $\Pi_x = 108$ which gives $V_{F^4} \simeq \frac{\lambda\,|W_0|^4}{\mathcal{V}^3}\left[\frac{24}{\tau_5} + \frac{8\,\tau_2^{3/2}}{\tau_5\,\mathcal{V}} + \frac{36\,\sqrt{\tau_5}}{\mathcal{V}} - \frac{8\,\sqrt{\tau_2}}{\mathcal{V}}\right]$

- Collecting things together as: $V = V_{up} + V_{LVS} + V_{g_s}^{(kk)} + V_{g_s}^{(w)} + V_{F^4} + \ldots\ldots$

$$V(\tau_2) = \frac{|W_0|^2}{\mathcal{V}^2}\left[\frac{g_s^2\,\mathcal{B}_5^{kk}}{\tau_5^2} + \frac{\mathcal{A}_1^w}{2\,\mathcal{V}\,\sqrt{\tau_5}} + \frac{g_s^2\,\mathcal{B}_x^{kk}\,\tau_5}{3\,\mathcal{V}^2}\right] + \frac{\lambda\,|W_0|^4}{\mathcal{V}^3}\left[\frac{24}{\tau_5} + \frac{36\,\sqrt{\tau_5}}{\mathcal{V}}\right]$$

This is the standard Fibre inflation potential (with F^4-terms added).

A concrete example of the "weaker" swiss-cheese

Let us consider the following toric data for a Calabi Yau threefold which produces a volume form of kind $\mathcal{V} = \gamma_1 \sqrt{\tau_1 \, \tau_2 \, \tau_3} - \gamma_2 \, \tau_s^{3/2}$,

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
4	0	0	0	1	1	0	0	2
4	0	0	1	0	0	1	0	2
4	0	1	0	0	0	0	1	2
8	1	0	0	1	0	1	1	4
	dP_7	NdP$_{11}$	NdP$_{11}$	$K3$	NdP$_{11}$	$K3$	$K3$	

$$\mathrm{SR} \quad = \quad \{x_1 x_4,\, x_1 x_6,\, x_1 x_7,\, x_2 x_7,\, x_3 x_6,\, x_4 x_5 x_8,\, x_2 x_3 x_5 x_8\}$$

with $(h^{2,1}, h^{1,1}) = (98, 4)$ and Euler number $\chi = -188$. This corresponds to polytope ID $\#1206$ in the database of [Altman, Gray, He, Jejjala, Nelson].

- The Intersection Polynomial:

  $I_3 = 2\, D_1^3 + 2\, D_4\, D_6\, D_7 \qquad \Longrightarrow \mathcal{V} = \frac{t_1^3}{3} + 2\, t_4\, t_6\, t_7.$

- Subsequently, the overall volume of the CY:

$$\mathcal{V} = \frac{\sqrt{\tau_4\, \tau_6\, \tau_7}}{\sqrt{2}} - \frac{1}{3}\, \tau_1^{3/2}\,.$$

This form can be useful for chiral global embedding of Fibre inflation, work in progress.

Summary and outlook

- Some explicit CY orientifold constructions for (possibly) realizing the standard as well as the modified versions of the Fibre inflation potentials have been presented.
- The recently proposed higher derivative corrections have been investigated for specific models, especialy the values of parameters $\Pi)i$,s.
- We presented 3 schemes with Brane-settings satisfying the tadpole cancellations
  - Scheme 1: Winding-corrections with F^4-terms
  - Scheme 2: KK-corrections with F^4-terms
  - Scheme 3: KK+Winding-corrections with F^4-terms
- On the lines of recent interest proposed in [Cicoli, Burgess, de Alwis, Quevedo], an explicit CY example having the volume form to be of a 'weaker' swiss-type (which is analogous to the blow-up added version of the toroidal case, e.g. $\mathbb{T}^6/(\mathbb{Z}_2 \times \mathbb{Z}_2)$) has been presented.
- Our aim is to scan the full Calabi Yau database with $h^{11} = 3$ and $h^{11} = 4$ to look for K3-fibrations with a 'shrinkable' del-Pezzo divisor to list all the such weak/weaker swiss-cheese volume forms.
- To understand the KK string-loop corrections better?? and to look for chiral global embedding.