Accidental Kähler Moduli Inflation

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A. Maharana, M. Rummel, YS, arXiv: 1504.07202

Stringy inflation models

Some inflation models in string theory

String Scenario	n_s	r
$D3/\overline{D3}$ Inflation	$0.966 \leq n_s \leq 0.972$	$r \leq 10^{-5}$
Inflection Point Inflation	$0.92 \leq n_s \leq 0.93$	$r \leq 10^{-6}$
DBI Inflation	$0.93 \leq n_s \leq 0.93$	$r \leq 10^{-7}$
Wilson Line Inflation	$0.96 \leq n_s \leq 0.97$	$r \leq 10^{-10}$
D3/D7 Inflation	$0.95 \leq n_s \leq 0.97$	$10^{-12} \leq r \leq 10^{-5}$
Racetrack Inflation	$0.95 \leq n_s \leq 0.96$	$r \leq 10^{-8}$
$\mathrm{N-flation}$	$0.93 \leq n_s \leq 0.95$	$r \leq 10^{-3}$
Axion Monodromy	$0.97 \leq n_s \leq 0.98$	$0.04 \leq r \leq 0.07$
Kahler Moduli Inflation	$0.96 \leq n_s \leq 0.967$	$r \leq 10^{-10}$
Fibre Inflation	$0.965 \leq n_s \leq 0.97$	$0.0057 \leq r \leq 0.007$
$\mathrm{Poly-instanton}$ Inflation	$0.95 \leq n_s \leq 0.97$	$r \leq 10^{-5}$

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taken from [Burgess, Cicoli, Quevedo 13]

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Kähler Moduli Inflation

[Conlon, Quevedo, 05]

Advantage:

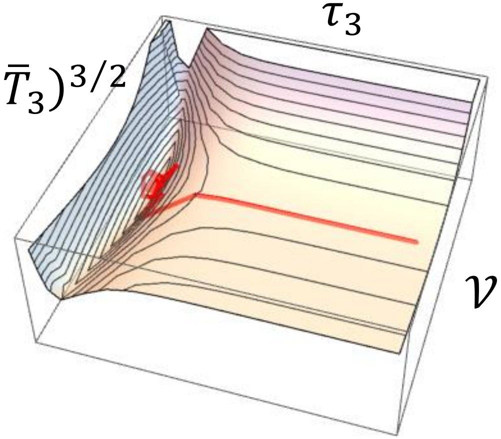
- Simple model with fixed volume in type IIB
- Moduli stabilization well under control in Large Volume Scenario

  Good for physics after inflation ends (reheating etc.)

Model: $V_F = e^K(|DW|^2 - 3|W|^2)$

Swiss-cheese CY: $\mathcal{V} = (T_1 + \bar{T}_1)^{3/2} - (T_2 + \bar{T}_2)^{3/2} - (T_3 + \bar{T}_3)^{3/2}$

$$K = -2\ln\left(\mathcal{V} + \frac{\xi}{2}\right) \qquad W = W_0 + A_2 e^{-a_2 T_2} + A_3 e^{-a_3 T_3}$$



LVS region $V_F \sim \mathcal{O}(\mathcal{V}^{-3})$ and $\mathcal{V} \sim e^{a_i \tau_i}$ $\quad (\tau_i = \mathrm{Re}\, T_i)$

$$V \sim \frac{d}{\mathcal{V}^{4/3}} + \frac{3W_0^2\xi}{4\mathcal{V}^3} + \frac{4a_2 W_0 A_2 \tau_2}{\mathcal{V}^2} e^{-a_2\tau_2} + \frac{2\sqrt{2}a_2^2 A_2^2 \tau_2^{1/2}}{3\mathcal{V}} \mathrm{e}^{-2a_2\tau_2}$$

$$+ \frac{4a_3 W_0 A_3 \tau_3}{\mathcal{V}^2} e^{-a_3\tau_3} + \frac{2\sqrt{2}a_3^2 A_3^2 \tau_3^{1/2}}{3\mathcal{V}} \mathrm{e}^{-2a_3\tau_3}$$

anti brane uplift for dS minimum

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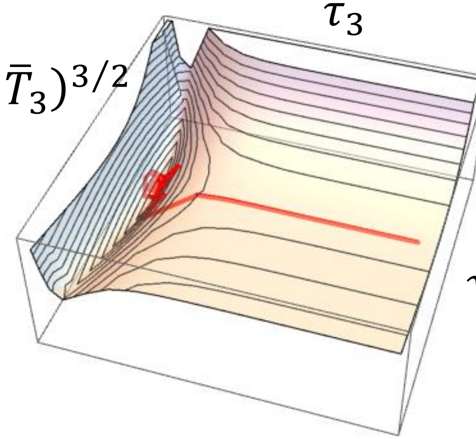

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$$+ \frac{4a_3 W_0 A_3 \tau_3}{\mathcal{V}^2} e^{-a_3\tau_3} + \frac{2\sqrt{2}a_3^2 A_3^2 \tau_3^{1/2}}{3\mathcal{V}} \mathrm{e}^{-2a_3\tau_3}$$ inflation (τ_3)

anti brane uplift for dS minimum

Concern of loops

String-loop corrections to supergravity may spoil inflation.

$$K = -2\ln\left(\mathcal{V} + \frac{\xi}{2}\right) + \delta K_{g_s}^{KK} \qquad \delta K_{g_s}^{KK} \sim c_3^{KK} g_s \frac{\tau_3^{1/2}}{\mathcal{V}}$$

$$\Rightarrow \quad \delta V_{\text{loop}} \sim (c_3^{KK})^2 g_s^2 W_0^2 \frac{1}{\sqrt{\tau_3}\,\mathcal{V}^3}$$

while inflation potential: $V \sim V_0 + 4a_3 W_0 A_3 \frac{\tau_3}{\mathcal{V}^2} e^{-a_3\tau_3}$

Then, slow roll cond. for sufficient e-folds $N_e \sim 60$

$$\epsilon \sim \mathcal{V}^3 \tau_3^{5/2} e^{-2a_3\tau_3} \ll 1, \qquad |\eta| \sim \mathcal{V}^2 \tau_3^{3/2} e^{-a_3\tau_3} \ll 1$$

$$\Rightarrow \quad e^{-a_3\tau_3^{(60)}} \sim 3.1 \times 10^{-12} \quad \text{for } {\mathcal{V}^{(60)}}^{-1} \sim 3.7 \times 10^{-5}$$

Hence, the loop correction becomes dominant if present (D7 setups).

Note: LVS 'minimum' suggests $e^{-a_3\tau_3^{(min)}} \sim {\mathcal{V}^{(min)}}^{-1}$.

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Concern of gauge group ranks

Necessary to have a hierarchy to control moduli stabilization

$V = V_{stab} + V_{inf}\,, \qquad V_{stab} \gg V_{inf}$ and stabilization at minimum

Realized by D7 gauge group ranks generating non-perturbative terms

$W = W_0 + A_2 e^{-a_{stab} T_2} + A_3 e^{-a_{inf} T_3}, \quad a_i = 2\pi/N_i$ for $SU(N_i)$

When $\xi \sim 760, A_2/W_0 = -1, A_3/W_0 = -1$, and appropriate uplift,

$$\frac{a_{inf}}{a_{stab}} = \frac{N_{stab}}{N_{inf}} \gtrsim \; 15.5$$ e.g. $N_{inf} = 2,\; N_{stab} = 30$

However, tadpole cancellation and holomorphicity suggest maximal gauge group ranks: [Collinucci, Denef, Esole, 08], [Cicoli, Mayhofer, Valandro, 11], [Louis, Rummel, Valandro, Westphal, 12]

$h^{1,1}$	1	2	3	4	5	6	7	8	9
N_{max}	14	26	36	44	54	62	62	72	98

Visible matter branes give further restriction on tadpole.

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D-term generated racetrack

[Rummel, YS, 14]

Multi-Kähler moduli model

$$K = -2\ln\left(\mathcal{V} + \frac{\xi}{2}\right),\ \mathcal{V} = (T_1 + \bar{T}_1)^{\frac{3}{2}} - \sum_{i=2}^{5}(T_i + \bar{T}_i)^{\frac{3}{2}}$$

$$W = W_0 + \sum_{i=2}^{5} A_i e^{-a_i T_i}$$

Magnetized D7-branes generate D-term:

$$V_D = \frac{1}{\mathrm{Re}(f_D)}\xi_D^2 \qquad \text{with FI term } \xi_D = \frac{1}{\mathcal{V}}\int_{X_3} D_D \wedge J \wedge \mathcal{F}_D$$

a choice

$$\Rightarrow \quad V_{D_4} \propto \frac{1}{\mathrm{Re}(f_{D_4})}\frac{1}{\mathcal{V}^2}\left(\sqrt{\tau_4} - \sqrt{\tau_3}\right)^2, V_{D_5} \propto \frac{1}{\mathrm{Re}(f_{D_5})}\frac{1}{\mathcal{V}^2}\left(\sqrt{\tau_5} - \sqrt{\tau_3}\right)^2$$

As $V_D \gg V_F \sim \mathcal{O}(\mathcal{V}^{-3})$, D-term give a constraint: $T_4 = T_3,\ T_5 = T_3$.

$$V_F = e^K(|DW|^2 - 3|W|^2)$$

$$\sim V_{stab} + \underbrace{\frac{4a_3 W_0 A_3 \tau_3}{\mathcal{V}^2}e^{-a_3\tau_3} + \frac{4a_4 W_0 A_4 \tau_3}{\mathcal{V}^2}e^{-a_4\tau_3} + \frac{4a_5 W_0 A_5 \tau_3}{\mathcal{V}^2}e^{-a_5\tau_3}}_{\text{racetrack structure}} + \cdots$$

LVS $\mathcal{O}(\mathcal{V}^{-3})$

racetrack structure

Accidental Kähler Moduli Inflation

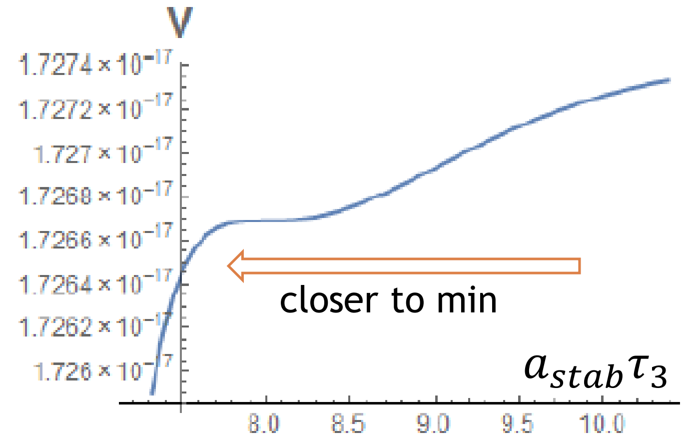
Using the same parameter set: $\xi \sim 760, A_2/W_0 = -1, A_3/W_0 = -1$

an inflection/accidental point is generated by

$$A_4/W_0 \sim 0.99, \qquad A_5/W_0 \sim -0.25$$

$$\frac{a_3}{a_{stab}} = 2.2, \qquad \frac{a_4}{a_{stab}} = 2.1, \qquad \frac{a_5}{a_{stab}} = 2$$

and $\epsilon_{acc} \sim 2.1 \times 10^{-11},\ \eta_{acc} \sim 7.6 \times 10^{-6}$

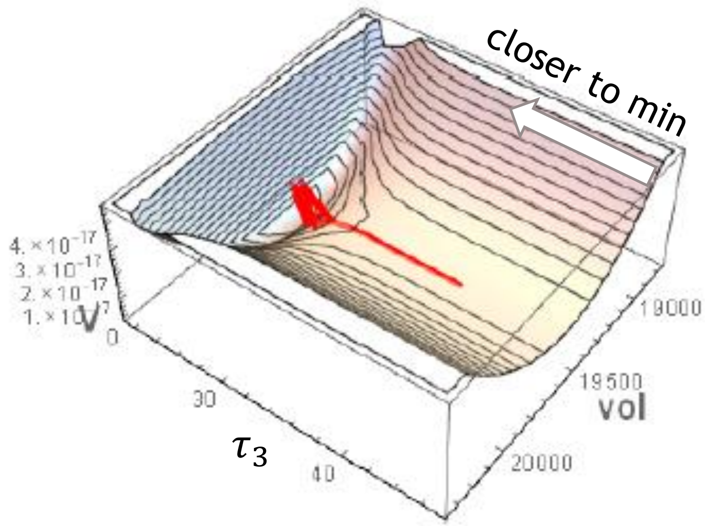


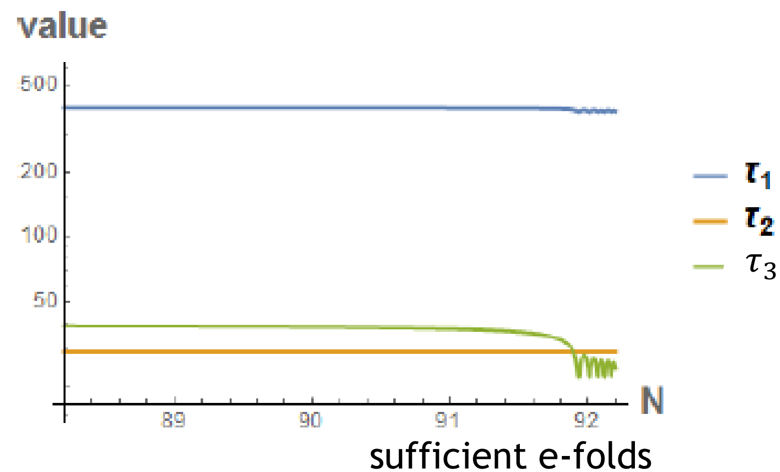
in full moduli space

- Sufficient slow-roll parameters even near minimum
- Gauge group rank hierarchy is quite relaxed. (remind $a_{KMI}/a_{stab} \gtrsim 15.5$)
- Parameters are reasonable.
- Axionic directions ($\mathrm{Im}\, T_i$) are well stabilized.

Accidental Kähler Moduli Inflation

When inflation starts at the accidental point,





At $N_e = 60$ from the end of inflation,

$$n_s^{(60)} \sim 0.963, \qquad r^{(60)} \sim 5.40 \times 10^{-10}$$

and then moduli field values:

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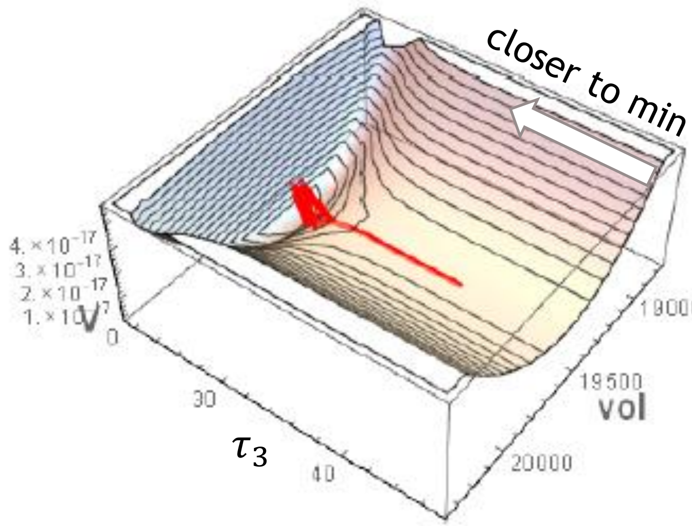

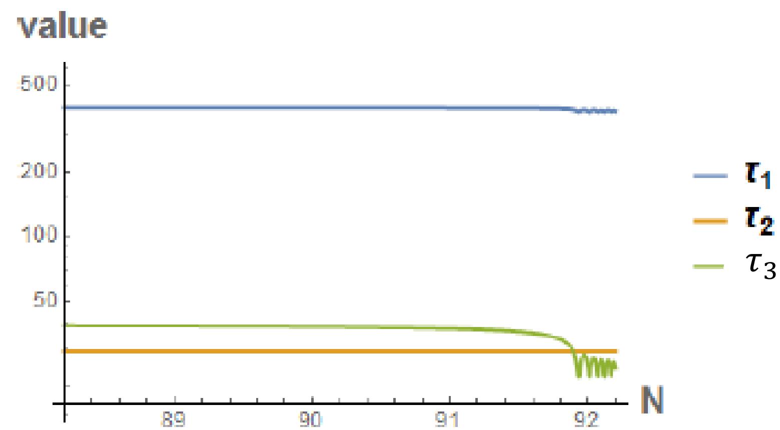

sufficient e-folds

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and then moduli field values:

$$e^{-a_5 \tau_3^{(60)}} \sim 1.2 \times 10^{-7}, \qquad \mathcal{V}^{(60)^{-1}} \sim 5.1 \times 10^{-5}$$

significant improvement owing to accidental point near minimum!

Loop corrections

$$V = V_0 + \frac{4a_5 W_0 A_5 \tau_3}{\mathcal{V}^2} e^{-a_5\tau_3} + \cdots \sim V_0 - 4.8 \times 10^{-15} W_0^2 + (\text{same order})$$

$$\delta V_{\text{loop}} \sim (c_3^{KK})^2 g_s^2 W_0^2 \frac{1}{\sqrt{\tau_3}\,\mathcal{V}^3} \sim 2.1 \times 10^{-14} (c_3^{KK})^2 g_s^2 W_0^2$$

Not difficult to realize $c_3^{KK}(U,\bar{U}) < 1,\ g_s < 1$, not necessary too small

Kähler Moduli Inflation

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Kähler Moduli Inflation

significant, no way of absorption

Accidental Kähler Moduli Inflation

negligible, absorbed into slight shift

The best place to hide a leaf is in a forest.

Summary

- Concern of string-loop corrections is well alleviated.

  String-loop corrections can be sub-leading order.

  Hence Kähler Moduli Inflation can be realized in a variety of setups.

- Hierarchy of gauge group ranks is also relaxed.

  Moduli stabilization is well under control.

  $a_{inf}/a_{stab} \sim \mathcal{O}(10)$ ⇨ $a_{inf}/a_{stab} \sim \mathcal{O}(1)$

  significant in D-term generated racetrack

  The same works in ordinary racetrack of superpotential, but with slightly larger a_{inf}/a_{stab}.

- Reasonable coefficients of non-perturbative terms

  $A_3/W_0 = -1,\ A_4/W_0 \sim 0.99,\ A_5/W_0 \sim -0.25$: same order

  Naturally realized after complex structure moduli stabilization