Effects of F^4-corrections on String Inflation

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LARGE Volume Scenario

- String Inflation phenomenology $\longrightarrow$ compactification of the extra-dimensions
- 10d Type IIB Superstring theory : Calabi Yau 3-folds
- CY Moduli : axio-dilaton S, complex structure moduli U_α, Kahler moduli T_i
- CY compactifications with superpotential $W_0(S, U)$

$$D_\alpha W_0 = 0 = D_{\overline{\alpha}} \overline{W}_0, \qquad \text{and} \qquad D_S W_0 = 0 = D_{\overline{S}} \overline{W}_0$$

$$W = W_0 + \sum_{i=1}^{n} A_i \, e^{-\mathrm{i}\, a_i \, T_i}$$

- LVS model for Kahler moduli stabilization $T_i = \tau_i + i\theta_i$

$$\tau_i = \frac{1}{2} \int_{\Sigma_i} J \wedge J = \frac{1}{2} \kappa_{ijs} t^i t^s \qquad\qquad \mathcal{V} = \frac{1}{6} \int_X J \wedge J \wedge J = \frac{1}{6} \kappa_{ijs} t^i t^j t^s$$

LARGE Volume Scenario

- Type IIB superstring theory scalar potential

$$V_F = e^K \left(K^{i\bar{j}} (D_i W)(\overline{D}_{\bar{j}} \overline{W}) - 3|W|^2 \right)$$

- Higher derivative F4-corrections [D. Ciupke, J. Louis and A. Westphal]

$$V_{F^4} = -\left(\frac{g_s}{8\pi}\right)^2 \frac{\lambda W_0^4}{g_s^{3/2} \mathcal{V}^4} \sum_{i=1}^{h^{1,1}} \Pi_i t^i = \frac{\gamma}{\mathcal{V}^4} \sum_{i=1}^{h^{1,1}} \Pi_i t^i$$

with topological numbers $\Pi_i = \int_X c_2(X) \wedge \hat{D}_i$

- Need to identify suitable CYs to describe phenomenology [Kreuzer-Skarke database]

$h^{1,1}$	Poly*	Geom* (n_{CY})	$n_{ddP} = 1$	$n_{ddP} = 2$	$n_{ddP} = 3$	$n_{ddP} = 4$	n_{LVS}
1	5	5	0	0	0	0	0
2	36	39	22	0	0	0	22
3	243	305	93	39	0	0	132
4	1185	2000	465	261	24	0	750
5	4897	13494	3128	857	106	13	4104

$$\int_{X_3} D_s^3 = k_{sss} > 0\,,$$

$$\int_{X_3} D_s^2\, D_i \leq 0 \qquad \forall\, i \neq s$$

$$k_{sss}\, k_{sij} = k_{ssi}\, k_{ssj}$$

String Inflation in LVS

- Fix the CY overall volume $\mathcal{V}$

- Search for the expression of the inflationary potential *V*

- Obtain, by derivation of *V*, the slow-roll parameters: $\epsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2 \qquad \eta = \frac{V''}{V}$

- Fix the numer of e-foldings according to the string model

$$N_e(\phi_\star) = \int_{\phi_{end}}^{\phi_\star} \frac{d\phi}{\sqrt{2\epsilon(\phi)}}$$

- Compute, by integration, the value of the inflaton field at the horizon exit

- Estimate the values of phenomenological interest parameters and compare them with observations

Blow-Up Inflation

- CY volume standard form

$$\mathcal{V} = \tau_b - \beta_1 \tau_1 - \beta_2 \tau_2$$

- LVS potential approximation

$$V_{\rm LVS} = \sum_{i=1}^{2} \left(\frac{8(a_i A_i)^2 \sqrt{\tau_i}}{3\mathcal{V}\beta_i} e^{-2a_i\tau_i} - \frac{4a_i A_i W_0 \tau_i}{\mathcal{V}^2} e^{-a_i\tau_i} \right) + \frac{3\hat{\xi} W_0^2}{4\mathcal{V}^3}$$

- High derivative F^4-corrections

$$V_{F^4} = \frac{\gamma}{\mathcal{V}^4} \left[\Pi_b \left(\mathcal{V} - \sum_{i=1}^{2} \beta_i \tau_i^{3/2} \right)^{1/3} - 3 \sum_{i=1}^{2} \Pi_i \beta_i \sqrt{\tau_i} \right]$$

$h^{1,1}$	Poly*	Geom* (n_{CY})	$n_{ddP} = 1$	$n_{ddP} = 2$	$n_{ddP} = 3$	$n_{ddP} = 4$	$n_{\rm LVS}$	Blowup infln.
1	5	5	0	0	0	0	0	0
2	36	39	22	0	0	0	22	0
3	243	305	93	39	0	0	132	39
4	1185	2000	465	261	24	0	750	285
5	4897	13494	3128	857	106	13	4104	976

Blow-Up Inflation

Number of e-foldings:

The number of e-foldings for inflation depends on the early history of universe evolution and, in particular, on the decay of the longest living particle.

1). If the inflaton is the longest living particle:

- Decay in the visible sector

$$\Gamma_{\tau_2} = \frac{1}{\mathcal{V}} \frac{m_{\tau_2}^3}{M_P^2} \sim \frac{M_P}{\mathcal{V}^4} \longrightarrow N_e = 57 + \frac{1}{4} \ln r - \frac{1}{4} N_{\tau_2} = 50 - \frac{5}{12} \ln \mathcal{V}$$

2). If the volume is the longest living particle:

- Decay in the visible sector

- Decay into Higgs [Hebecker]

$$\Gamma_{\tau_B} \sim c_{\text{loop}}^2 \left(\frac{m_{3/2}}{m_{\tau_B}} \right)^4 \frac{m_{\tau_B}^3}{M_P^2} \sim c_{\text{loop}}^2 \frac{M_P}{\mathcal{V}^{5/2}} \longrightarrow N_e = 50 - \frac{1}{6} \ln \mathcal{V}$$

Blow-Up Inflation

- Explicit example with parameter choice

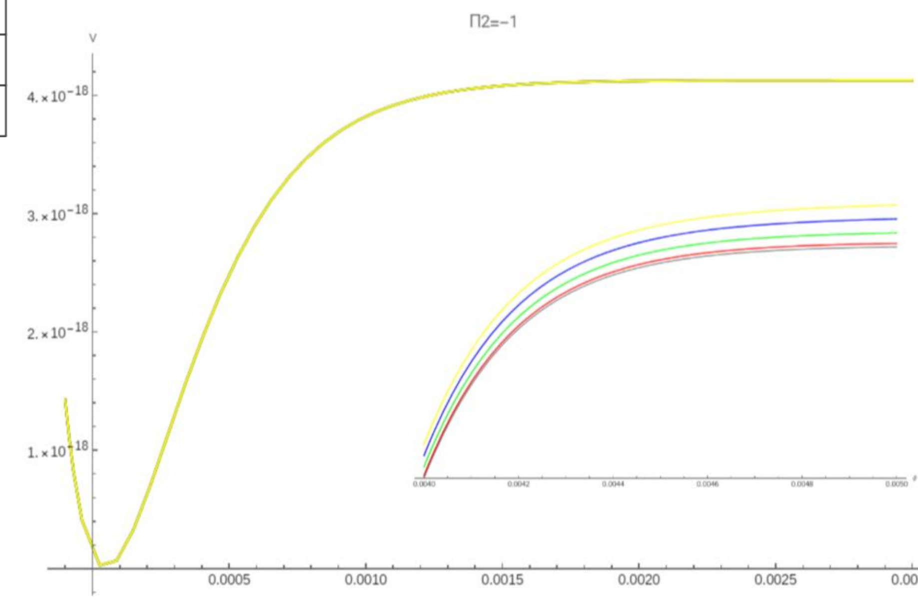
W_0	g_s	a_1	a_2	A_1	A_2	β_1	β_2
0.1	0.13	2π	2π	0.2	3.4×10^{-7}	0.4725	0.01

- Divisor topology with $\Pi_1 = \Pi_b = 0$

$\lvert\lambda\rvert$	$\phi_\star$	n_s	A_s
0	4.494899×10^{-3}	0.956386	2.11146×10^{-9}
1.0×10^{-4}	4.95668×10^{-3}	0.958164	1.94664×10^{-9}
4.0×10^{-4}	4.98039×10^{-3}	0.963219	1.53505×10^{-9}
8.0×10^{-4}	5.01349×10^{-3}	0.969316	1.13485×10^{-9}
1.2×10^{-3}	5.04829×10^{-3}	0.974691	8.53024×10^{-10}

$$n_s = 0.9649 \pm 0.0042 \qquad (68\%\ \mathrm{CL})$$

$$|\lambda|_{max} = 1.1 \times 10^{-3}$$



Blow-Up Inflation

- Explicit example with parameter choice

W_0	g_s	a_1	a_2	A_1	A_2	β_1	β_2
0.1	0.13	2π	$2\pi/N$	0.19	3.4×10^{-7}	$\simeq 0.5$	0.01

- Divisor topology with $\Pi_1 = \Pi_b = 0$

N	$\lvert\lambda\rvert$	$\phi_\star$	n_s	A_s
$N=2$	0	8.55743×10^{-3}	0.957692	2.20009×10^{-9}
	1.0×10^{-3}	8.59968×10^{-3}	0.962656	1.73612×10^{-9}
	2.0×10^{-3}	8.64364×10^{-3}	0.967233	1.38248×10^{-9}
	3.0×10^{-3}	8.68932×10^{-3}	0.971425	1.11088×10^{-9}
	4.0×10^{-3}	8.73669×10^{-3}	0.975239	9.00672×10^{-10}
$N=3$	0	1.22049×10^{-2}	0.957679	2.28554×10^{-9}
	2.0×10^{-3}	1.22649×10^{-2}	0.96252	1.81483×10^{-9}
	4.0×10^{-3}	1.23273×10^{-2}	0.966995	1.45345×10^{-9}
	6.0×10^{-2}	1.23921×10^{-2}	0.971106	1.174×10^{-9}
	8.0×10^{-3}	1.24593×10^{-2}	0.97486	9.56344×10^{-10}
$N=5$	0	1.78617×10^{-2}	0.957678	2.14345×10^{-9}
	5.0×10^{-3}	1.7953×10^{-2}	0.962446	1.70842×10^{-9}
	1.0×10^{-2}	1.80479×10^{-2}	0.966862	1.37293×10^{-9}
	1.5×10^{-2}	1.81464×10^{-3}	0.970927	1.11241×10^{-9}
	2.0×10^{-2}	1.82484×10^{-2}	0.974647	9.08706×10^{-10}

	$N=2$	$N=3$	$N=5$
$\lvert\lambda\rvert_{max}$	3.48×10^{-3}	7.15×10^{-3}	1.82×10^{-2}

Fiber Inflation

- CY volume standard form

$$\mathcal{V} = \frac{1}{6}\left(k_{111}(t^1)^3 + 3k_{233}t^2(t^3)^2\right) = \alpha\left(\tau_3\sqrt{\tau_2} - \tau_1^{3/2}\right)$$

- LVS potential approximation

$$V(\mathcal{V},\tau_1) = a_1^2 A_1^2 \frac{\sqrt{\tau_1}}{\mathcal{V}} e^{-2a_1\tau_1} - a_1 A_1 W_0 \frac{\tau_1}{\mathcal{V}} e^{-a_1\tau_1} + \frac{\xi W_0^2}{g_s^{3/2}\mathcal{V}^3}$$

- Inflationary potential + F^4-corrections

$$V_{inf}(\hat{\phi}) = V_0\left[e^{-4\hat{\phi}/\sqrt{3}} - 4e^{-\hat{\phi}/\sqrt{3}} + 3 + R(e^{2\hat{\phi}/\sqrt{3}} - 1) - R_1 e^{\hat{\phi}/\sqrt{3}} - R_2 e^{-2\hat{\phi}/\sqrt{3}}\right]$$

$h^{1,1}$	Poly*	Geom* (n_{CY})	$n_{\rm LVS}$	$K3$ fibred CY	$n_{\rm LVS}$ with $K3$-fib. (Fibre inflation)	$n_{\rm LVS}$ with $K3$-fib. & D_Π
1	5	5	0	0	0	0
2	36	39	22	10	0	0
3	243	305	132	136	43	0
4	1185	2000	750	865	171	32
5	4897	13494	4104	5970	951	161+ 37

Fiber Inflation

- Explicit example with a parameter choice such that [M. Cicoli, E. Di Valentino]

$R = 4.8 \times 10^{-6}$ ⟶ $R_1 = 8.8 \times 10^{-3} \lambda \Pi_1$ $R_2 = 1.8 \times 10^{-1} \lambda \Pi_2$

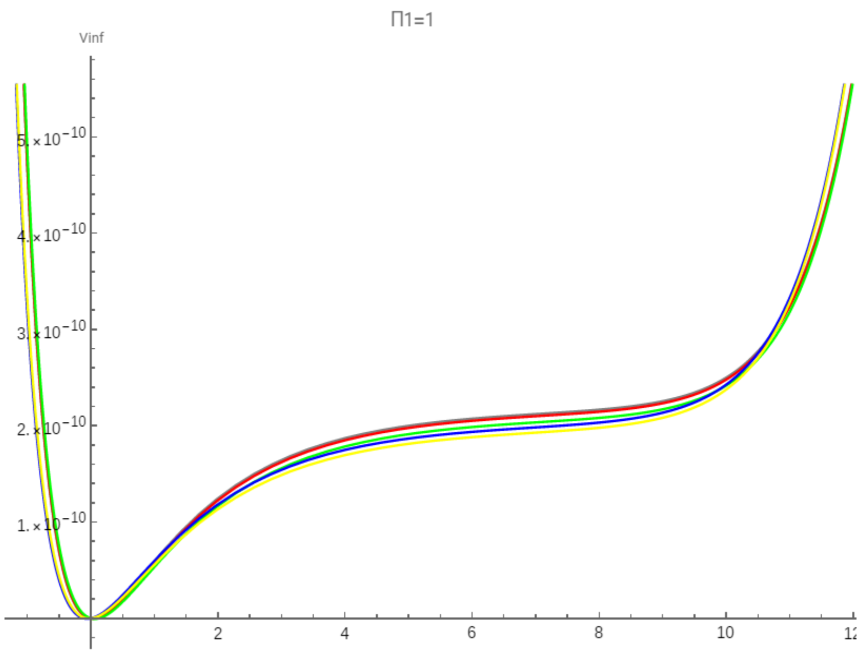
- Divisor topology with $\Pi_2 = 24$

$$\frac{\Gamma_{\phi\to hh}}{\Gamma_{\phi\to\gamma\gamma}} \sim \frac{c_{loop}^2}{\mathcal{V}^{2/3}} \left(\frac{\mathcal{V}^{5/3}}{\mathcal{V}}\right)^4 = (c_{loop}\mathcal{V})^2 \gg 1$$

$\lvert\lambda\rvert$	$\phi_\star$	n_s	A_s
0	5.91328	0.97049	2.13082×10^{-9}
0.1×10^{-3}	5.93005	0.970657	2.09702×10^{-9}
0.4×10^{-3}	5.98203	0.971207	1.99576×10^{-9}
0.7×10^{-3}	5.88793	0.97178	1.90293×10^{-9}
1.0×10^{-3}	5.93552	0.972399	1.81416×10^{-9}

$$n_s = 0.9696^{+0.0010}_{-0.0026}$$

$$\lvert\lambda\rvert_{max} = 6.1 \times 10^{-4}$$



Conclusions and Outlooks

- Not all the possible CY topologies support LVS
- High derivative corrections to the scalar potential affect the inflation dynamics
- There is an upper bound on the correction factors in order to preserve the correct inflation
- In some situations corrections are desirable
- Study other string-built models for inflations
- Analyze the effects of such corrections on other cosmological problems