Aligned Inflation near the Conifold

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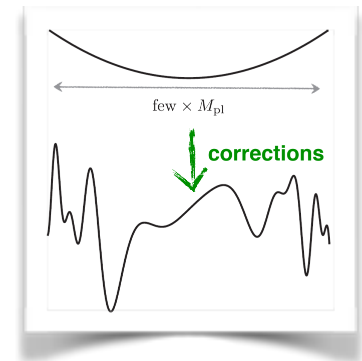
Large-Field Inflation in String Theory

Experiments [BICEP2 '14, Planck '15] motivated to study large-field inflation.

- axions with shift symmetry prevent UV corrections
- axions arise naturally in String Theory as moduli



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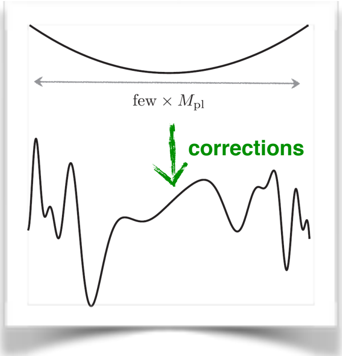

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- 2 axionic moduli with sub-Planckian decay constants for controlled string compactification
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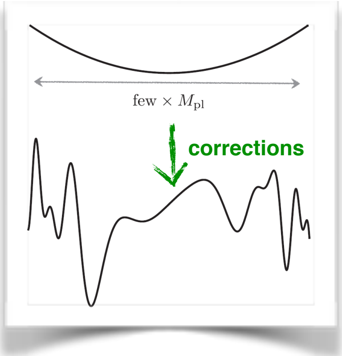

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Difficulty: control **all** effective theories by correct mass hierarchy!

$$M_\Theta < H_{\rm inf} < M_{\rm mod} \sim M_{\rm inf} < M_{\rm KK} < M_{\rm s} < M_{\rm Pl}$$

2 Complex Structure Moduli at Conifold Locus

Based on [JHEP 1608 (2016) 110 by Blumenhagen, Herschmann, FW]

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Mirror manifold of Calabi-Yau threefold $\mathbb{P}_{11226}[12]$ (similar [Conlon, Quevedo '04]):

$$P = z_1^{12} + z_2^{12} + z_3^6 + z_4^6 + z_5^2 - 12\psi\, z_1\, z_2\, z_3\, z_4\, z_5 - 2\phi\, z_1^6\, z_2^6$$

complex structure moduli

$\longrightarrow$ conifold locus at $864\psi^6 + \phi = 1$

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Derive basis of periods solving Picard-Fuchs equations from fundamental period [Candelas, De La Ossa, Font, Katz, Morrison '94]

$$\varpi_f(\psi,\phi) = -\frac{1}{6}\sum_{n=1}^{\infty} \frac{\Gamma\left(\frac{n}{6}\right)(-12\,\psi)^n\, u_{-\frac{n}{6}}(\phi)}{\Gamma(n)\,\Gamma^2\left(1-\frac{n}{6}\right)\,\Gamma\left(1-\frac{n}{2}\right)}$$

with $u_{-\frac{n}{6}}(\phi)$ a polynomial series.

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$\longrightarrow$ transform to symplectic basis and introduce new inhomogeneous coordinates $\{\psi, \phi\} \to \{Z, Y\}$

Final periods for $\mathbb{P}_{11226}[12]$:

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Final per

Periods

$$F_0 = 1\,,$$
$$F_1 = Z\,,$$
$$F_2 = (0.46 + 0.11i) + (1.10 - 2.17i)Y - 0.19\,Z - (7.34 - 14.73i)\,Y^2 + (2.71 + 1.42i)\,YZ + (0.11 - 1.69i)\,Z^2$$

and

$$X^0 = (-0.04 + 0.23i) + (1.10 + 0.06i)Y + 0.17\,Z - (7.34 + 1.83i)\,Y^2 + (0.55 + 1.42i)\,YZ + (0.11 - 0.17i)\,Z^2\,,$$
$$X^1 = -\frac{1}{2\pi i} Z \log Z + 0.18 - 0.42\,Y - 1.43i\,Z + \ldots\,,$$
$$X^2 = 0.09 - 2.19\,Y + 14.67\,Y^2 - 2.84i\,YZ - 0.22\,Z^2$$

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Kähler potential:

$$\begin{aligned} K_{\mathrm{cs}} &= -\log\left[-i\left(X^\Lambda \bar{F}_\Lambda - \bar{X}^\Lambda F_\Lambda\right)\right] \\ &= -\log\left[\frac{1}{2\pi}|Z|^2 \log\left(|Z|^2\right) + A + \mathrm{Re}Y + B\left(\mathrm{Re}Y\right)^2 + C\,|Z|^2 \ldots\right] \end{aligned}$$

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- can change (e.g. linear term in Z) due to possible $Sp(6;\mathbb{Z})$ transf. of periods
- obeys shift symmetries: [Etxebarria, Grimm, Valenzuela '14]

$\mathrm{Im}(Y) \to \mathrm{Im}(Y) + \varphi$ axionic sym.

$Z \to e^{i\theta} Z$ broken by higher orders to discrete sym. $\theta \to \theta + 2\pi$

Moduli Stabilisation I

Consider more flexible models inspired by periods and Kähler potential of $\mathbb{P}_{11226}[12]$.

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General flux-induced superpotential [Gukov, Vafa, Witten '99]

$$W_{\rm GVW} = -\left(\mathfrak{f}_\Lambda X^\Lambda - \tilde{\mathfrak{f}}^\Lambda F_\Lambda\right) + iS\left(h_\Lambda X^\Lambda - \tilde{h}^\Lambda F_\Lambda\right)$$

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Turn on fluxes to generate a superpotential of the form
(similar [Giddings, Kachru, Polchinski '01])

$$W \sim f\left(-\frac{1}{2\pi i} Z \log Z + 0.18 - 0.42Y - 1.43iZ + \dots\right) + i\,(hS + \hat{f}Y)\,Z - ih'S - i\hat{f}'\underbrace{Y}_{\text{complex structure modulus } Y = y + i\,\zeta} + \dots$$

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complex structure modulus $Y = y + i\,\zeta$

Moduli Stabilisation II

Conic modulus Z is stabilised via F-term condition $F_Z = 0$:

$$Z \sim \exp\left(-\frac{2\pi}{f}(hS + \hat{f}Y)\right)$$

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$$W_{\text{eff}} \sim i(f + h'S + \hat{f}'Y) + \cancel{Z} + \ldots$$

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- assume Kähler potential $K_{\text{eff}} = -2\log\mathcal{V} - \log(S+\bar{S}) - \log\left(A + \kappa\,\text{Re}Y - (\text{Re}Y)^2\right)$

Minkowski minimum:

- axion $\Sigma = \hat{f}'\zeta - h'C_0$ and saxions stabilised by fluxes
- axionic moduli combination $\Theta = \hat{f}\zeta - hC_0$ remains unstabilised

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The inflaton potential in the regime $f/\hat{f}' \gg 1$, $h/h' \gg 1$ and $\kappa = 0$ reads

$$V_{\text{eff}} \sim \frac{4|Z|^2}{A\mathcal{V}^2}\,\frac{fh^2}{h'}\,\Big(1 - \cos\big(\tfrac{2\pi}{f}\Theta\big)\Big)$$

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$\longrightarrow$ alignment mechanism for $(h\hat{f}' - h'\hat{f}) < h'$

Mass Hierarchy

- assume Kähler moduli are stabilised via LVS

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Summary of moduli masses and scales:

Scale	$(\text{Mass})^2$ in M_{Pl}^2
string scale M_s^2	$\frac{1}{f^{1/2}\,\mathcal{V}}$
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conic c.s. modulus M_Z^2	$\frac{f}{\mathcal{V}^2\|Z\|^2}$
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$$\frac{M_{\text{mod}}^2}{M_{\tilde{\Theta}}^2} \sim \frac{f^2}{|Z|^2} > 1$$

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$$\frac{M_{\tilde{\Theta}}^2}{M_{\tau_b}^2} \sim \frac{\mathcal{V}|Z|^2}{f^{7/2}}$$

difficult to arrange: $M_{\tilde{\Theta}} < M_{\tau_b}$

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correct hierarchy in principle possible!

But generic mass hierarchy is given by

$$M_{\tau_b} < M_{\tilde{\Theta}} < M_{\text{mod}} < M_{\text{inf}} \sim M_Z < M_{\text{KK}} < M_{\text{s}} < M_{\text{Pl}}$$

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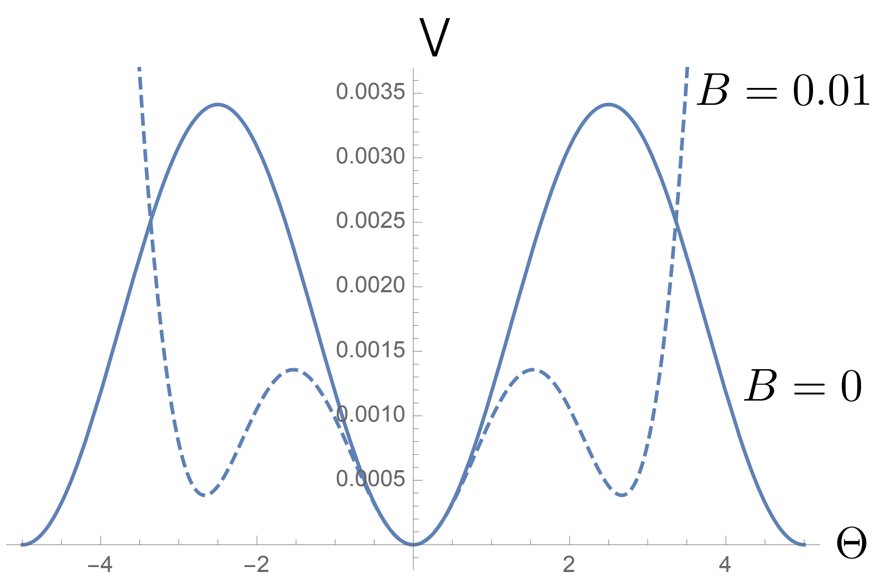
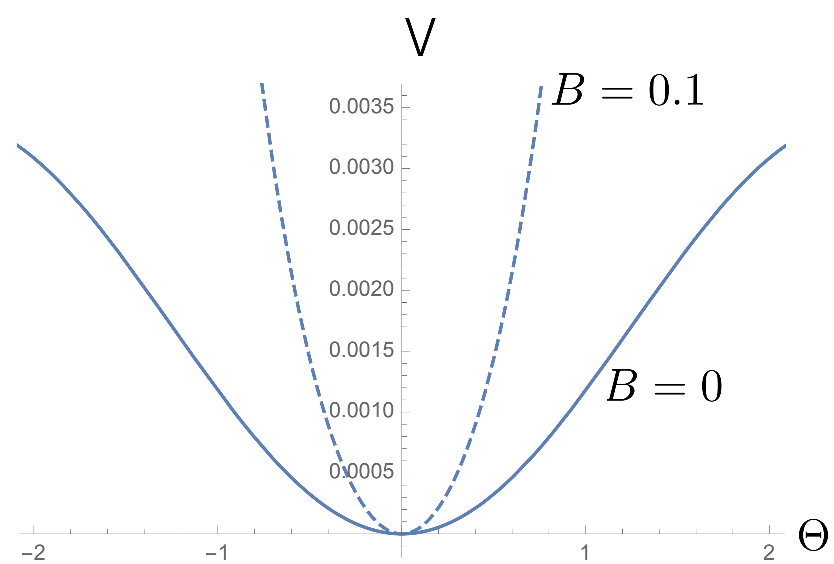


Inflation works ✔



Inflation works not ✗

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Loop-Hole to fulfill mild WGC:

[Brown, Cottrell, Shiu, Soler '15, Hebecker, Mangat, Rompineve, Witkowski '15]

- add second instanton $\mathcal{S}^{(2)}_{\rm inst}$ (e.g. $D(-1)$) with $\mathcal{S}_{\rm inst} < \mathcal{S}^{(2)}_{\rm inst}$

$$V \sim e^{-2\,S_{\rm inst}} \left(1 - \cos\left(\frac{\tilde{\Theta}}{f_{\tilde{\Theta}}}\right)\right) + e^{-2\,S^{(2)}_{\rm inst}} \left(1 - \cos\left(\frac{k\,\tilde{\Theta}}{f_{\tilde{\Theta}}}\right)\right)$$

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large-field inflation

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sub-Planckian decay constant for proper k

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large-field inflation

satisfies WGC

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- further analysis of conifold locus [Bizet, Loaiza-Brito, Zavala '16]
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