De Sitter Uplift and Axion Inflation with non-geometric fluxes

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arXiv:1510.01522, Blumenhagen, Damian, Font, Herschmann, RS

Backgrounds

- de Sitter vacua

  [Kallosh, Quevedo, Wrase, Junghans, Retolaza and Dierigl's talk; Conclon, Kachru, Luest, Linde, Mcallister, Shiu, Trivedi, Urange, Westphal, et al.]

- non-geometric flux-scaling vacua

  [Blumenhagen, Fuchs, Herschmann, Plauschinn, Sekiguchi, Wolf '15]

- F-term axion monodromy inflation

  [Marchesano, Shiu, Uranga, Blumenhagen, Plauschinn, Hebecker, Witkowski, Silverstein, Westphal, McAllister, et al]

- D-term containing geometric and non-geometric fluxes

  [Blumenhagen, Font, Plauschinn]

- Fluxes under T-duality: $H_{abc} \to F^{a}{}_{bc} \to Q_{c}{}^{ab} \to R^{abc}$

  [Dabholkar, Hull, Shelton, Taylor, Wecht, Hohm, Ki Kwak, Siegel, Zwiebach, Aldazabal, Marques, Nunez, Lüst, Blumenhagen, Berman, Thompson, et al]

Outline

- Type IIB superstring
  $\Rightarrow$ Orientifolds compactification on Calabi-Yau three-folds
  with non-vanishing (non-)geometric fluxes

- Uplift to Minkowski and de Sitter:
  by adding an $\overline{\mathrm{D3}}$-brane and a D-term (geo & non-geo)

- Axion monodromy inflation:
  self-consistently admitting values of the fluxes
  with mass hierarchy satisfied

Type IIB Orientifold compactifications

- Tree-level cubic prepotential of the CY three-fold

$$F = \frac{1}{6} d_{ijk} X^i X^j X^k / X^0$$

- The flux-induced superpotential can be evaluated as

$$W = -\left(\mathfrak{f}_\lambda X^\lambda - \tilde{\mathfrak{f}}^\lambda F_\lambda\right) + iS\left(h_\lambda X^\lambda - \tilde{h}^\lambda F_\lambda\right)$$
$$+ \mathrm{i}G^a\left(f_{\lambda a} X^\lambda - \tilde{f}^\lambda{}_a F_\lambda\right) - iT_\alpha\left(q_\lambda{}^\alpha X^\lambda - \tilde{q}^{\lambda\alpha} F_\lambda\right)$$

  Holomorphic 3-form $\Omega = X^\lambda \alpha_\lambda - F_\lambda \beta^\lambda$

- Resulting from Kähler potential and superpotential
  $\Rightarrow$ the F-term scalar potential

$$V_F = \frac{M_{\rm Pl}^4}{4\pi}\; e^K \left(K^{I\bar{J}} D_I W D_{\bar{J}} \overline{W} - 3\left|W\right|^2\right)$$

Uplift Example by adding $\overline{\mathrm{D3}}$-brane

- The common mechanism to uplift AdS vacua [KKLMMT]

  $\Rightarrow$ introduce an $\overline{\mathrm{D3}}$-brane at a warped throat

$$\mathrm{V}_{\mathrm{up}} = \frac{A}{\mathcal{V}^{4/3}} \frac{M_{\mathrm{Pl}}^4}{4\pi}$$

- CY manifold with moduli T_α, U^i and S

  $$K = -\log(S+\overline{S}) - 3\log(T+\overline{T}) - 3\log(U+\overline{U})$$

- Superpotential

$$W = -\,i\,f\,U + i\,h_0 S - 3ihSU^2 - iqT$$

- Moduli Stablization $\Rightarrow$ AdS vacuum
- With $\overline{\mathrm{D3}}$-brane contribution $\Rightarrow$ Minkowski vacuum

  $s = \frac{1}{3^{3/4}} \frac{f}{(hh_0)^{1/2}}$, $v = \frac{1}{3^{1/4}} \left(\frac{h_0}{h}\right)^{1/2}$, $\tau = \frac{f}{3^{1/4}q} \left(\frac{h_0}{h}\right)^{1/2}$

  The warp factor $A = \frac{3^{1/4}}{2} \frac{qh^{3/2}}{h_0^{1/2}}$
- Increase A, expand solution in $\Lambda \Rightarrow$ de Sitter vacuum

  $s = \frac{1}{3^{3/4}} \frac{f}{(hh_0)^{1/2}} + \frac{2^4 \cdot 7}{3^{5/2}} \frac{f^3 h_0}{q^3 h^3} \Lambda + \mathcal{O}(\Lambda^2)$

  $v = \frac{1}{3^{1/4}} \left(\frac{h_0}{h}\right)^{1/2} - \frac{2^4}{3^2} \frac{f^2 h_0^2}{q^3 h^3} \Lambda + \mathcal{O}(\Lambda^2)$

  $\tau = \frac{f}{3^{1/4}q} \left(\frac{h_0}{h}\right)^{1/2} + \frac{2^4 \cdot 13}{3^2} \frac{f^3 h_0^2}{q^4 h^3} \Lambda + \mathcal{O}(\Lambda^2)$

  The warp factor $A = \frac{3^{1/4}}{2} \frac{qh^{3/2}}{h_0^{1/2}} + \frac{2^2}{3^{1/2}} \frac{f^2 h_0}{q^2 h} \Lambda + \mathcal{O}(\Lambda^2)$

Example with $\overline{\mathrm{D3}}$-brane

- The upshot: for small $|\Lambda|$ one can continuously interpolate from AdS to a dS
- The saxions vev and moduli masses with expansion of $|\Lambda|$ e.g. the normalized masses corrected at linear order in Λ as $M^2_{\mathrm{mod}} = \left(\mu_i \frac{q^3 h^{5/2}}{f^2 h_0^{3/2}} - \tilde{\mu}_i \Lambda + \mathcal{O}(\Lambda^2)\right) \frac{M^2_{\mathrm{Pl}}}{4\pi}$
- Lightest states: Saxions $\not\Longrightarrow$ Axion Inflation: left space for further searching

F-term + D-term

- Double Field Theory action
  $\Rightarrow$ Orientifolds compactification on Calabi-Yau three-folds *with* non-vanishing (non-)geometric fluxes

  $\Rightarrow$ Scalar potential splits into $V = V_F + V_D + V_{\rm tad}^{\rm NS}$

- V_D as additional D-term potential in Einstein frame

$$\mathrm{V}_D = -\frac{M_{\rm Pl}^4}{2}\left[(\mathrm{Im}\,\mathcal{N})^{-1}\right]^{\hat{\lambda}\hat{\sigma}} D_{\hat{\lambda}} D_{\hat{\sigma}}$$

$$D_{\hat{\lambda}} = \frac{1}{\mathcal{V}}\left[-r_{\hat{\lambda}}\left(e^{\phi}\mathcal{V} - \frac{1}{2}\kappa_{\alpha ab}t^{\alpha}b^a b^b\right) - q_{\hat{\lambda}}{}^{a}\,\kappa_{a\alpha b}t^{\alpha}b^b + f_{\hat{\lambda}\alpha}t^{\alpha}\right]$$

with $\tilde{r}^{\hat{\lambda}} = \tilde{q}^{\hat{\lambda}a} = \tilde{f}^{\hat{\lambda}}{}_{\alpha} = 0$

[Blumenhagen, Font, Plauschinn '15]

Ex with D-term

- The superpotential

  $W_0 = ifU + i\tilde{f}U^3 - ihS + iqT$

- For concreteness, Hodge numbers

  $h_+^{2,1} = 1$, $h_-^{2,1} = 1$, $h_+^{1,1} = 1$ and $h_-^{1,1} = 0$.

- The total scalar potential $V = V_F + V_D$

- The explicit form of the corresponding D-term potential

  $$V_D = \frac{\delta}{v\tau^2}\left(g - \frac{r\tau}{3s}\right)^2$$

  where $r = f_{\hat{1}0}, g = f_{\hat{1}1}$, and δ is a positive constant parameter

- Moduli Stablization $\Rightarrow$ stable Minkowski vacuum

$$Re : \Theta = q\rho - hc = 0, \quad u = 0$$

$$s \sim \frac{f^{3/2}}{h\tilde{f}^{1/2}},\ \tau \sim \frac{f^{3/2}}{q\tilde{f}^{1/2}},\ v \sim \left(\frac{f}{\tilde{f}}\right)^{1/2},\ \delta \sim \frac{hq\tilde{f}}{fg^2}$$

- The ratio of the KK and string scale is

$$\frac{M_{\rm s}^2}{M_{\rm KK}^2} = 178\,\frac{h^{1/2}}{q^{1/2}}\,, \qquad \frac{M_{\rm KK}^2}{M_{\rm mod}^2} = \frac{0.1}{\mu_i}\,\frac{1}{hq}\frac{{}^{3/2}}{\tilde{}\,{}^{3/2}}$$

- Parametrically matching mass ratios

  with additional one massless axion

  $\Rightarrow$ good for F-term axion monodromy inflation

Axion Inflation

- Scaling Scenario: superpotential

$$W = \lambda W_0 - ip\, S\, T\, U$$

with $W_0 = ifU + i\tilde{f}\,U^3 - ihS + iqT$

- Taking axion inflaton $\theta = c$, integrating out the heavy moduli:

The effective quartic potential

$$V_{\rm eff} = B_1\,\theta^2 + B_2\,\theta^4$$

with $B_1 \sim \frac{\lambda\, p\, h^2\, q^2\, \tilde{f}^{5/2}}{f^{11/2}}\,, \quad B_2 \sim \frac{p^2\, h^3\, q\, \tilde{f}^{5/2}}{f^{13/2}}$

- $\frac{M_{\rm KK}^2}{M_{\rm mod}^2} \sim \frac{f^{3/2}}{\lambda^2\, h\, q\, \tilde{f}^{3/2}}\,, \quad \frac{M_{\rm mod}^2}{M_\theta^2} \sim \frac{\lambda\, h\, q\, \tilde{f}}{p\, f^2}$

$$\Rightarrow \frac{M_{\rm KK}^2}{M_{\rm mod}^2}\,\frac{M_{\rm mod}^2}{M_\theta^2} \sim \frac{1}{\lambda\, p\, f^{1/2}\, \tilde{f}^{1/2}}$$

Rational shift required

Backreaction

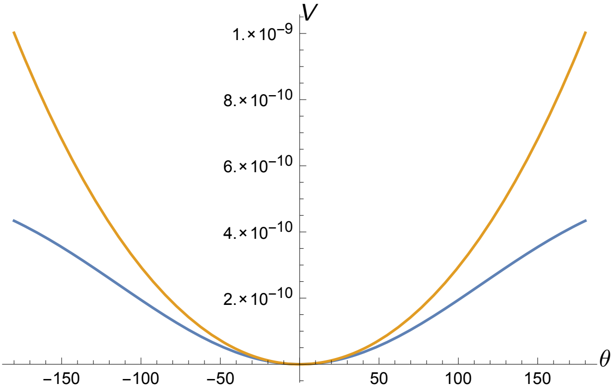

Figure: Backreacted (blue line) and quadratic potential in units $\frac{M_{\rm Pl}^4}{4\pi}$ for $h = 1/220$, $\tilde{f} = 1/1810$, $f = 6/49$, $q = 1/8$, $g = 1/10$, $p = 1/10000$ and $\lambda = 10$.

Parameter	Value
Δc	$93\, M_{\mathrm{Pl}}$
N_e	61
r	0.0980
n_s	0.9667
$\mathcal{P}$	$2.14 \cdot 10^{-9}$
M_{s}	$1.04 \cdot 10^{17}$ GeV
M_{KK}	$1.49 \cdot 10^{16}$ GeV
M_{inf}	$4.89 \cdot 10^{15}$ GeV
M_{mod}	$\{11.99, 4.81, 2.38, 6.81, 2.47\} \cdot 10^{14}$ GeV
H_{inf}	$7.82 \cdot 10^{13}$ GeV
M_θ	$1.70 \cdot 10^{13}$ GeV

Table: Summary of inflationary parameters for $\lambda = 10$.

For $9.44 < \theta < 104$ one collects 60-efoldings. Matches mass hierarchy $\mathrm{M}_{\mathrm{Pl}} > M_{\mathrm{s}} > M_{\mathrm{KK}} > M_{\mathrm{inf}} > M_{\mathrm{mod}} > H_{\mathrm{inf}} > M_\theta$

Rational Shift

- The prepotential, in the large complex structure limit

  $\widetilde{F} = F + \frac{1}{2} a_{ij} X^i X^j + b_i X^i X^0 + \frac{1}{2} i\gamma \left(X^0\right)^2 + F_{\text{inst.}}$

  with the usual cubic term $F = \frac{1}{6} d_{ijk} X^i X^j X^k / X^0$.

  Constants a_{ij} and b_i are rational numbers, while γ is real

- Holomorphic 3-form $\Omega = X^\lambda \alpha_\lambda - F_\lambda \beta^\lambda$

- The flux-induced superpotential can be evaluated as

$$W = -\left(\mathfrak{f}_\lambda X^\lambda - \tilde{\mathfrak{f}}^\lambda F_\lambda\right) + iS\left(h_\lambda X^\lambda - \tilde{h}^\lambda F_\lambda\right)$$

$$+\mathrm{i}\mathrm{G}^a\left(f_{\lambda a} X^\lambda - \tilde{f}^\lambda{}_a F_\lambda\right) - iT_\alpha\left(q_\lambda{}^\alpha X^\lambda - \tilde{q}^{\lambda\alpha} F_\lambda\right)$$

Conclusion & Outlook

- Uplift to Minkowski and de Sitter:
  by adding an $\overline{\mathrm{D3}}$-brane and a D-term (geo & non-geo)
- Axion monodromy inflation:
  self-consistently admitting values of the fluxes
  with mass hierarchy satisfied
- Open questions related to $\overline{\mathrm{D3}}$-brane
- Non-geometric flux phenomenology