Cosmological Models by Compactification in Generalized Varieties

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Introduction

- Flux compactification provides a dependence of all the moduli on the scalar potential.
- de Sitter Vacua is difficult to obtain.
- Negative curvature terms lift the vacua.
- T-duality invariant superpotential does not require non-perturvative effects.
- Neither exotic objects as NS-NS branes are necessary in order to stabilize the moduli.

Objective

- To obtain a de Sitter vacua in a scalar potential by compactification of the Type IIB on a $T^6/\mathbb{Z}_2$ orientifold.
- Stabilize all the moduli.
- Obtain realistic values for the fluxes in the minimum.

- Under T-duality the NS fields changes according to the Buscher rules;

$$
\begin{gathered}
G'_{xx} = \frac{1}{G_{xx}}, \quad G'_{x\mu} = -\frac{B_{x\mu}}{G_{xx}} \\
B'_{x\mu} = \frac{G_{x\mu}}{G_{xx}}, \quad G'_{\mu\nu} = G_{\mu\nu} - \frac{G_{x\mu}G_{x\nu} - B_{x\mu}B_{x\nu}}{G_{xx}} \\
B'_{\mu\nu} = B_{\mu\nu} - \frac{G_{x\mu}B_{x\mu} - B_{x\mu}G_{x\nu}}{G_{xx}}
\end{gathered}
$$

Geometric fluxes

- For a NS-NS 3-form flux on some three cycle, on a T^6 torus;

$$H_{abc} \longrightarrow f^a_{bc} \tag{1}$$

- Applying the Buscher rules, the metric acquires a extra term $(dx^a - f^a_{bc} x^c dx^b)^2$ and the T-dual B-field vanishes.

Nongeometric fluxes

- Performing another T-duality in the b direction;

$$H_{abc} \to f^{a}_{bc} \to Q^{ab}_{c} \tag{2}$$

So T-duality invariance leads to additional nongeometric fluxes required so that superpotentials in type IIA and type IIB orientifolds match.

Compactification

- Compactification on a $T^6/\mathbb{Z}_2$.
- Where $T^6 = T^2 \times T^2 \times T^2$ and all the 2-tori are identical.
- The Kähler potential is given by;
  $K = -3ln(-i(\tau - \bar{\tau})) - 3ln(-i(U - \bar{U})) - ln(-i(S - \bar{S}))$.
- And a scalar potential $V = e^K \left(K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2 \right)$.

- Without nongeometric fluxes the superpotential is given by;

$$W = \int G_3 \wedge \Omega = \int F_3 - SH_3 \wedge \Omega = P_1(\tau) + SP_2(\tau)$$

- After the T-duality chain...

$$W = \int (F_3 + SH_3 + Q \cdot U) \wedge \Omega = P_1(\tau) + SP_2(\tau) + UP_3(\tau)$$

Invariant superpotential

- $W = \int (F_3 + SH_3 + Q\cdot U) \wedge \Omega$ (Gerardo Aldazabal et al. JHEP05(2006)070)

Term	IIB Flux	integer Flux
1	$\bar{F}_{ijk}$	a_0
τ	$\bar{F}_{ij\gamma}$	a_1
τ^2	$\bar{F}_{i\beta\gamma}$	a_2
τ^3	$\bar{F}_{\alpha\beta\gamma}$	a_3
S	$\bar{H}_{ijk}$	b_0
U	$\bar{Q}_k^{\alpha\beta}$	c_0
$S\tau$	$\bar{H}_{\alpha jk}$	b_1
$U\tau$	$\bar{Q}_k^{\alpha j}, \bar{Q}_k^{i\beta}, \bar{Q}_\alpha^{\beta\gamma}$	$\check{c}_1, \hat{c}_1, \tilde{c}_1$
$S\tau^2$	$\bar{H}_{i\beta\gamma}$	b_2
$U\tau^2$	$\bar{Q}_\gamma^{i\beta}, \bar{Q}_\beta^{\gamma i}, \bar{Q}_k^{ij}$	$\check{c}_2, \hat{c}_2, \tilde{c}_2$
$S\tau^3$	$\bar{H}_{\alpha\beta\gamma}$	b_3
$U\tau^3$	$\bar{Q}_\gamma^{ij}$	c_3

- $W = P_1(\tau) + SP_2(\tau) + UP_3(\tau)$

R-R tadpole and Bianchi constraints

$$\bar{F}_{[abc}\bar{H}_{def]} = 0 \qquad (3)$$

$$\bar{F}_{x[abc}f^{x}_{de]} - \bar{F}_{[ab}\bar{H}_{cde]} = 0 \qquad (4)$$

$$\bar{F}_{xy[abc}Q^{xy}_{d]} - 3\bar{F}_{x[ab}f^{x}_{cd]} - 2\bar{F}_{[a}\bar{H}_{bcd]} = 0 \qquad (5)$$

$$\bar{F}_{xyz[abc]}R^{xyz} - 9\bar{F}_{xy[ab}Q^{xy}_{c]} - 18\bar{F}_{x[a}f^{x}_{bc]} + 6F^{(0)}\bar{H}_{[abc]} = 0 \qquad (6)$$

$$\bar{F}_{xyz[ab]}R^{xyz} + 6\bar{F}_{xy[a}Q^{xy}_{b]} - 6\bar{F}_{x}f^{x}_{[ab]} = 0 \qquad (7)$$

R-R tadpole and Bianchi constraints

$$a_0 b_3 - 3a_1 b_2 + 3a_2 b_1 - a_3 b_0 = 0 \qquad (8)$$

$$a_0 c_3 + a_1(\check{c}_2 + \hat{c}_2 - \tilde{c}_2) - a_2(\check{c}_1 + \hat{c}_1 - \tilde{c}_1) - a_3 c_0 \qquad (9)$$

NS-NS Bianchi identity constraints

$$\bar{H}_{x[ab}f^{x}_{cd]} = 0 \qquad (10)$$

$$f^{a}_{x[b}f^{x}_{cd]} + \bar{H}_{x[bc}Q^{ax}_{d]} = 0 \qquad (11)$$

$$Q^{[ab]}_{x}f^{x}_{[cd]} - 4f^{[a}_{x[c}Q^{b]x}_{d]} + \bar{H}_{x[cd]}R^{[ab]x} = 0 \qquad (12)$$

$$Q^{[ab}_{x}Q^{c]x}_{d} + f^{[a}_{xd}R^{bc]x} = 0 \qquad (13)$$

$$Q^{[ab}_{x}R^{cd]x} = 0 \qquad (14)$$

NS-NS Bianchi identity constraints

$$c_0 b_2 - \tilde{c}_1 b_1 + \hat{c}_1 b_1 - \check{c}_2 b_0 = 0 \tag{15}$$

$$\check{c}_1 b_3 - \hat{c}_2 b_2 + \tilde{c}_2 b_2 - c_3 b_1 = 0 \tag{16}$$

$$c_0 b_3 - \tilde{c}_1 b_2 + \hat{c}_1 b_2 - \check{c}_2 b_1 = 0 \tag{17}$$

$$\check{c}_1 b_2 - \hat{c}_2 b_1 + \tilde{c}_2 b_1 - c_3 b_0 = 0 \tag{18}$$

$$c_0 \tilde{c}_2 - \check{c}_1^2 + \tilde{c}_1 \hat{c}_1 - \hat{c}_2 c_0 = 0 \tag{19}$$

$$c_3 \tilde{c}_1 - \check{c}_2^2 + \tilde{c}_2 \hat{c}_2 - \hat{c}_1 c_3 = 0 \tag{20}$$

$$c_3 c_0 - \check{c}_2 \hat{c}_1 + \tilde{c}_2 \check{c}_1 - \hat{c}_1 \tilde{c}_2 = 0 \tag{21}$$

Solutions

- SUSY is broken through the complex structure moduli.
- We take the solution of the constraints when $b_2 = 0$, $b_0 = 0$, $b_1 = 0$, $c_0 = 0$, $c_3 = 0$, $\hat{c}_1 = \check{c}_1 = 0$, $\hat{c}_2 = \check{c}_2 = 0, a_0 = 0$, $a_1 = (a_2 \tilde{c}_1)/\tilde{c}_2$.

Solutions

- For these conditions the following minima are obtained

Fluxes	$Re\tau$	$Re(S)Im(U)+Im(S)Re(U)$	V_{min}
$\tilde{c}_1 = b_3 = 0$	0	$\frac{-3a_2 Im(S)}{\tilde{c}_2}$	$\frac{(3a_3 Im(\tau) - 4\tilde{c}_2 Im(U))^2}{128 Im(S)^3 Im(\tau) Im(U)^3}$
$\tilde{c}_1 = a_2 = 0$	0	0	$\frac{(3a_3 Im(\tau) - 4\tilde{c}_2 ImU)^2}{128 Im(S) Im(\tau) Im(U)^3}$
$\tilde{c}_1 = a_3 = 0$	0	$-\frac{3a_2 Im(S)}{\tilde{c}_2}$	$\frac{\tilde{c}_2^2}{(8 Im(S) Im(\tau) Im(U))}$
$a_2 = a_3 = 0$	$\frac{\tilde{c}_1}{2\tilde{c}_2}$	0	$\frac{\tilde{c}_2^2}{(8 Im(S) Im(\tau) Im(U))}$
$b_3 = a_3 = 0$	$\frac{\tilde{c}_1}{2\tilde{c}_2}$	$-\frac{3a_2 Im(S)}{\tilde{c}_2}$	$\frac{9a_2^2 + \tilde{c}_2^2 Im(U)^2}{8 Im(S) Im(\tau) Im(U)^3}$
$b_3 = a_2 = 0$	$\frac{\tilde{c}_1}{2\tilde{c}_2}$	$\frac{3a_3 \tilde{c}_1 Im(S)}{2\tilde{c}_2}$	Ec. (22)
$\tilde{c}_1 = b_3 = a_3 = 0$	0	$-\frac{3a_2 Im(S)}{\tilde{c}_2}$	$\frac{\tilde{c}_2^2}{(8 Im(S) Im(\tau) Im(U))}$
$a_2 = b_3 = a_3 = 0$	$\frac{\tilde{c}_1}{2\tilde{c}_2}$	0	$\frac{\tilde{c}_2^2}{(8 Im(S) Im(\tau) Im(U))}$
$\tilde{c}_1 = a_2 = a_3 = 0$	0	0	$\frac{\tilde{c}_2^2}{(8 Im(S) Im(\tau) Im(U))}$
$\tilde{c}_1 = b_3 = a_2 = 0$	0	0	Ec.(15)
$\tilde{c}_1 = b_3 = a_2 = a_3 = 0$	0	0	$\frac{\tilde{c}_2^2}{(8 Im(S) Im(\tau) Im(U))}$

Solutions

- For the fluxes asumed to be $b_3 = 0$, $a_2 = 0$. We obtain the following scalar potential;

$$V_{min} = \frac{\left[3a_3(\tilde{c}_1^2 - 4\tilde{c}_2^2 Im(\tau)^2) + 16\tilde{c}_2^3 Im(\tau) Im(U))\right]^2}{2048\tilde{c}_2^4 Im(S) Im(\tau)^3 Im(U)^3} \tag{23}$$

Results

- From the $b_3 = a_2 = 0$ solution;

$$Re(\tau) = \frac{\tilde{c}_1}{2\tilde{c}_2}, \quad Re(S) = \frac{3a_3\tilde{c}_1 Im(S)}{2\tilde{c}_2^2 Im(U)} - \frac{Im(S)Re(U)}{Im(U)}$$

This implies that $Re(U) < \frac{3\tilde{c}_1 a_3}{2\tilde{c}_2^2}$

Conclusions

- The nongeometric fluxes yields to de Sitter potentials.
- Only three of the six moduli are stabilized, the remaining modulis play the role of the Polonyi fields.
- When two of the nongeometric fluxes are turned on, the real parts of the moduli may obtain realistic values.
- As a further work, a solution for these moduli based in the Randall and Thomas propose is considered.
- A detailed analysis of these solutions are left to a forthcoming work.

Questions