Moduli Stabilisation and Axion Inflation with Non-geometric Fluxes

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arXiv:1409.7075 [Ralph Blumenhagen, DH, Erik Plauschinn]
arXiv:1503.xxxxx [Ralph Blumenhagen, Anamaría Font, Michael Fuchs, DH, Erik Plauschinn, Yuta Sekiguchi, Florian Wolf]

Task:

moduli stabilisation scheme behind axion monodromy inflation

see also [Hebecker, Mangat, Rompineve, Witkowski]

- type IIB: fluxes stabilise complex structure moduli and axio-dilaton

  $W = \int \Omega \wedge (SH + F_3)$

- Kähler moduli are stabilised by corrections

  e.g. non-perturbative corrections to superpotential $W \sim e^{-aT}$

- stabilise all saxions, while unstabilised axions are allowed

- axionic inflaton is the lightest state

moduli stabilisation

Procedure: [Blumenhagen, DH, Plauschinn]

1. stabilise complex structure moduli and the axio-dilaton except the axionic inflaton
2. turn on small fluxes to stabilise the inflaton

   tune moduli masses bigger than axion mass

   $$W = \lambda\, W_{mod} + W_{ax}$$

   with $\lambda >> 1$

   axion mass not tunable to be small!
3. stabilise Kähler moduli s.t. $M_T > M_{ax}$

Kähler moduli stabilisation via g_s-, α'- and non-perturbative corrections

$$\Rightarrow M_T < M_{rest}$$

tree level Kähler moduli stabilisation

$$
\begin{aligned}
W = & - \left(\mathfrak{f}_\lambda X^\lambda - \tilde{\mathfrak{f}}^\lambda F_\lambda \right) && \mathfrak{f} \text{ RR-flux} \\
& + i S \left(h_\lambda X^\lambda - \tilde{h}^\lambda F_\lambda \right) && h \text{ H-flux} \\
& - i G^a \left(f_{\lambda a} X^\lambda - \tilde{f}^\lambda{}_a F_\lambda \right) && f \text{ geometric flux} \\
& + i T_\alpha \left(q_\lambda{}^\alpha X^\lambda - \tilde{q}^{\lambda\alpha} F_\lambda \right) && q \text{ non-geometric } Q\text{-flux}
\end{aligned}
$$

[Shelton, Taylor, Wecht], [Grana, Louis, Waldram]

non-geometric fluxes stabilise h^{11}_+ moduli
geometric fluxes stabilise h^{11}_- moduli

[Aldazabal, Camara, Font, Ibanez], [Micu, Palti, Tasinato]

example

Kähler sector of the swiss cheese CY $\mathbb{P}_{1,1,1,6,9}[18]$ with $h^{21} = h^{11}_{-} = 0$ and $h^{11}_{+} = 2$ with Kähler potential

$$K = -\log(S + \overline{S}) - 2\log\Big((T_1 + \overline{T}_1)^{3/2} - (T_2 + \overline{T}_2)^{3/2} \Big) .$$

and superpotential

$$W = i\tilde{\mathfrak{f}} + i\,hS + i\,q_1\,T_1 + i\,q_2\,T_2 ,$$

gives three extrema, of which one is a true minimum:

solution	$(s, \tau_1, \tau_2, \theta)$	susy	tachyons	Λ
1	$\left(-\frac{\tilde{\mathfrak{f}}}{2\,h}, -\frac{3\,\tilde{\mathfrak{f}}\,q_1^2}{2\,(q_1^3+q_2^3)}, -\frac{3\,\tilde{\mathfrak{f}}\,q_2^2}{2\,(q_1^3+q_2^3)}, 0\right)$	yes	2	AdS
2	$\left(\frac{\tilde{\mathfrak{f}}}{8\,h}, \frac{3\,\tilde{\mathfrak{f}}\,q_1^2}{8\,(q_1^3+q_2^3)}, \frac{3\,\tilde{\mathfrak{f}}\,q_2^2}{8\,(q_1^3+q_2^3)}, 0\right)$	no	2	AdS
3	$\left(-\frac{\tilde{\mathfrak{f}}}{h}, -\frac{6\,\tilde{\mathfrak{f}}\,q_1^2}{5\,(q_1^3+q_2^3)}, -\frac{6\,\tilde{\mathfrak{f}}\,q_2^2}{5\,(q_1^3+q_2^3)}, 0\right)$	no	1	AdS

properties of the minimum:

- non-susy AdS
- two axionic combinations unstabilized
- fluxes can be chosen such that

  s is in the perturbative regime

  Kähler moduli in the large volume regime

  complex structure moduli in the large complex structure regime
- masses scale like $M^2_{\mathrm{mod},i} = \mu_i \frac{h(q_1^3+q_2^3)}{\tilde{f}^2} \frac{M_{pl}^2}{4\pi}$

  hierarchy between masses but without parametrical control

  one tachyonic modulus

if stabilised axion lightest state and mass gap large enough

$\Rightarrow$ inflaton candidate

flux scaling vacua

- all terms in the superpotential have the same scaling

$$W = i\tilde{\mathfrak{f}} + i\,h S + i\,q\,T \;= i\left(\tilde{\mathfrak{f}} + \; n_1\,h\,\frac{\tilde{\mathfrak{f}}}{h} + \; n_2\,q\,\frac{\tilde{\mathfrak{f}}}{q}\right)$$

  hence only a subset of the available fluxes is allowed to be turned on
- Mass hierarchy between inflaton and other moduli through

$$W = \lambda\,W_{mod} + \; W_{ax}$$

  possible in some cases, in other cases backreaction not negligible
- Bianchi identities, D_3 and D_7 tadpole and Freed-Witten conditions have to be considered

Problems

- we investigated either the Kähler or the complex structure sector of real Calabi Yau manifolds
- dilute flux limit $\rightarrow$ Ralph Blumenhagen's talk
- hierarchy of masses should be fulfilled

  $M_{\mathrm{Pl}} > M_{\mathrm{s}} > M_{\mathrm{KK}} > M_{\mathrm{mod}} > H_{\mathsf{inf}} > M_{\Theta}$ hard to achieve
- minima AdS $\rightarrow$ uplift
- massless saxions for $h^{11}_{-} > 0$
- tachyons for $h^{21} > 1$ and $h^{11}_{+} > 1$

  $\rightarrow$ uplift for $h^{11}_{+} > 1$

cosmological constant uplift

Minima AdS $\rightarrow$ uplift to dS necessary, e.g. add a term of the form

$$V_{\mathrm{up}} = \frac{\epsilon}{\mathcal{V}^{\alpha}}\,.$$

e.g simple example with axio-dilaton and one Kähler modulus $V \sim \frac{\epsilon}{\tau^{\beta}}$ the minimum gets shifted as

$$V_0 = -\frac{25\,h\,q^3}{216\,\hat{\mathfrak{f}}^2} + \frac{\varepsilon}{16}\left(\frac{5q}{6\hat{\mathfrak{f}}}\right)^{\beta} + O(\varepsilon^2)\,.$$

- uplifted minimum is destabilised for $\beta \gtrsim 1/4$
- therefore an uplift with $\overline{\mathrm{D3}}$-branes does not work
- more complicated scenarios, with e.g. matter field contributions

Tachyon Uplift

D-term of a stack of D7 branes

$$V_D = \frac{M_{\rm Pl}^4}{2{\rm Re}(f)}\xi^2$$

with

ζ the FI-term of U(1) carried by brane

and

f gauge kinetic function

$+$

apply Freed-Witten anomaly cancellation conditions

tachyon uplift - swiss cheese

$$V_D = \frac{k\left(q_2\sqrt{\tau_1} + q_1\sqrt{\tau_2}\right)^2}{(m_1\tau_1 + m_2\tau_2)\left(\tau_1^{3/2} - \tau_2^{3/2}\right)^2}$$

It turns out that $V_D^0 = 0 \Rightarrow$ minimum not changed. Only adds a positive term to the tachyonic Kähler moduli mass:

$$m_{\rm tac}^2 = -\frac{5h(q_1^3 + q_2^3)}{36\tilde{\mathfrak{f}}^2} + \frac{125\,k\,(q_1^3 + q_2^3)^3}{324\tilde{\mathfrak{f}}^3 q_1 q_2 (m_1 q_1^2 + m_2 q_2^2)}\,.$$

Mechanism does not work for complex structure moduli tachyons

$\Rightarrow$ flux scaling vacua work mainly in the small h^{21} regime

Soft SuSy Scale

The gravitino mass is given by

$$M_{\frac{3}{2}}^2 = e^{K_0} |W_0|^2 \,,$$

and the gaugino masses are

$$M_a = \frac{1}{2} (\mathrm{Re} f_a)^{-1} F^i \partial_i f_a \,,$$

with

$$F^i = e^{\frac{K}{2}} K^{i\bar{j}} D_{\bar{j}} \overline{W} \,.$$

- masses of order $\sim M_{mod} \Rightarrow$ quite high
- $F^i = 0$ accidentally possible $\Rightarrow$ vevs through e.g. α' corrections intermediate susy scale

Conclusions

- we considered moduli stabilisation with geometric and non-geometric Q- and P-fluxes on type IIB CYs
- very nice *flux scaling* vacua
- also the mass hierarchies and soft breaking masses are discussed
- good candidates for inflaton

Outlook

- uplift mechanisms needs to be clarified
- dS vacua analytically?