Moduli Stabilisation versus Chirality

for MSSM like Type IIB Orientifolds

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Outline

This talk is based on a paper [arXiv:0711.3389] done in collaboration with R. Blumenhagen and S. Moster.

1. Setup, Notation and Motivation
2. Moduli Stabilisation vs. Chirality
3. Example: Large Volume Scenarios
4. Conclusions

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Setup and Notation

An important issue in string phenomenology is moduli stabilisation.

That is, there has to be a minimum in the potential for

- the complex structure moduli U,
- the Kähler moduli T,
- the axio-dilaton S (and further closed and open sector moduli).

More concretely, here we are interested in minima of the potential

- $V_F + V_D$ of the $\mathcal{N} = 1$ SUGRA action in 4D
- originating from type IIB orientifold compactifications

$$\mathbb{R}^{9,1} \rightarrow \mathbb{R}^{3,1} \times \mathcal{X} \qquad \text{with O3-/O7-planes.}$$

Motivation

The potential V_F is expressed in terms of the Kähler potential $\mathcal{K}$ and the superpotential W.

- α'-corrections to $\mathcal{K}$ break the no-scale structure of V_F.

  [Becker et al., hep-th/0204254]

- W receives tree-level and non-perturbative contributions

$$W \quad = \quad W_{\text{GVW}}(U,S) \quad + \quad \sum_I A_I \, e^{-a_I T_I} \, .$$

$W_{\text{GVW}}(U,S)$ $\Downarrow$ leads to a minimum in V_F for all U and S

$\sum_I A_I \, e^{-a_I T_I}$ $\Downarrow$ each term leads to a minimum in V_F for each T_I

[Kachru et al., hep-th/0301240]

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Main assumption: $A_I \sim \mathcal{O}(1)$ for all Kähler moduli T_I.

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E3-Instantons (in Type IIB Orientifolds with O3-/O7-planes)

Non-perturbative effects arise from E3-instantons which are

- pointlike in $\mathbb{R}^4$ and
- wrap 4-cycles $\Xi = m^I D_I$ in $\mathcal{X}$.
- The generated term in the superpotential reads

$$W_{\text{inst.}} = \mathcal{A}\, e^{-2\pi\, m^I T_I} \ .$$

The prefactor $\mathcal{A}$ depends crucially on the instanton zero-modes. For non-vanishing $\mathcal{A}$

universal zero-modes	:	only $4\, x^\mu + 2\, \Theta$	$\Rightarrow$	$O(1)$ instanton
moduli zero-modes	:	none	$\Rightarrow$	rigid cycles
charged zero-modes	:	matter couplings	$\Rightarrow$	$\mathcal{A} = f(U, \Phi)$

[Argurio et al., hep-th/0703236]
[Blumenhagen et al., hep-th/0609191]

Interlude: D7-Branes

Because of the orientifold projection we introduce

- space-time filling D7-branes
- wrapping 4-cycles $\Gamma_a = n_a^I \, D_I$ in $\mathcal{X}$
- with gauge flux $\mathcal{F}_a$.

Chiral matter Φ_{ab} between two D7-branes is counted by

$$I_{ab} = \mathcal{M}_{a,I} \, n_b^I - \mathcal{M}_{b,I} \, n_a^I \; ,$$

where the matrix $\mathcal{M}_{a,I}$ is defined as

$$\mathcal{M}_{a,I} = \int_{\mathcal{X}} \mathrm{ch}_1\big(\mathcal{F}_a\big) \wedge \big[\Gamma_a\big] \wedge \big[D_I\big] \; .$$

Chirality and Charged Zero-Modes

- The chiral zero-modes between E3 and D7$_a$ are counted by

$$Z_a = \mathcal{M}_{a,I}\, m^I \ .$$

- If there is chiral matter between two D7-branes then

$$I_{ab} = \mathcal{M}_{a,I}\, n_b^I - \mathcal{M}_{b,I}\, n_a^I \neq 0 \qquad \Rightarrow \qquad \text{rk}\ \mathcal{M} \neq 0 \ .$$

$\Rightarrow$ There are $(\text{rk}\ \mathcal{M})$ linearly independent instantons such that

$$Z_a = \mathcal{M}_{a,I}\, \widehat{m}^I \neq 0 \qquad \Rightarrow \qquad \widehat{\mathcal{A}} = f(U) \prod_i \Phi_i \ .$$

MSSM Like String Compactifications

Let us assume the MSSM is realised by D7-branes.

- Chirality implies that we have $I_{ab} \neq 0$ for some a, b.

$\Rightarrow$ We find (rk $\mathcal{M}$) terms in the superpotential of the form

$$\widehat{W}_{\text{inst.}} = f(U) \prod_i \Phi_i^{\text{MSSM}} \; e^{-2\pi \, \widehat{m}^I T_I} \; .$$

For unbroken MSSM gauge symmetries

- the VEVs of the fields have to vanish: $\langle \Phi^{\text{MSSM}} \rangle = 0 \, .$

$\Rightarrow$ In the vacuum, $\widehat{W}_{\text{inst.}}$ vanishes.

$\Rightarrow$ (rk $\mathcal{M}$) Kähler moduli will not be stabilised in V_F.

D-Term Potential

In addition to V_F there is the D-term potential

$$V_D = \sum_a \frac{1}{\text{Re } f_a} \Big(\sum_b Q_b^{(a)} \big|\Phi_b\big|^2 - \xi_a \Big)^2 .$$

The minimum is where $$\sum_b Q_b^{(a)} \big|\Phi_b\big|^2 - \xi_a = 0$$

$$\xrightarrow{\langle \Phi^{\text{MSSM}} \rangle = 0} \qquad \xi_a = \frac{1}{\mathcal{V}} \mathcal{M}_{a,I}\, t^I = 0 .$$

These are (rk $\mathcal{M}$) non-trivial equations for $t^I \leftrightarrow$ (Re T_J)

- with solution $t^I = 0$ for $t^I \notin$ ker $\mathcal{M}$.

$\Rightarrow$ Some 4-cycle volumes (Re T_I) approach zero.

- The corresponding (rk $\mathcal{M}$) axions (Im T_I) are absorbed into massive $U(1)$'s.

Summary

If there is chiral (MSSM) matter present then

$$I_{ab} = \mathcal{M}_{a,I}\, n_b^I - \mathcal{M}_{b,I}\, n_a^I \neq 0 \qquad \Rightarrow \qquad \text{rk}\ \mathcal{M} \neq 0\,.$$

In V_F only rigid $O(1)$ instantons

- with $Z_a = \mathcal{M}_{a,I}\, m^I = 0$
- can stabilise (def $\mathcal{M}$) Kähler moduli $T = m^I T_I$.

The vanishing of the D-term potential

- provides (rk $\mathcal{M}$) equations for $t^I \leftrightarrow$ (Re T_J)
- which together with massive $U(1)$'s
- allow to stabilise the remaining Kähler moduli.

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Large Volume Scenarios

Large Volume Scenarios have very interesting features for string phenomenology.

[Balasubramanian et al., hep-th/0502058]
[Conlon et al., hep-th/0505076]
...

LVS can be realised on manifolds

- with one Kähler modulus controlling the volume $\mathcal{V}$ of $\mathcal{X}$.
- $\mathcal{V}$ can be stabilized perturbatively at large values
- if there is (at least) one instanton contribution to W.

$T_1 \sim \mathcal{V}^{2/3}$	stabilized perturbatively	
T_2	stabilized by inst./D-terms	realise the MSSM
T_3	stabilized by inst./D-terms	on $D_2, D_3, \ldots$
$\vdots$	$\vdots$	via D7-branes

An Explicit Example

In a LVS with 2 Kähler moduli, the MSSM cannot be realised.

- D-branes with gauge flux only on D_2.
- Instantons on $D_2 \leftrightarrow T_2$ always have charged zero-modes.

$\Rightarrow$ T_2 will not be stabilised by instantons.

One needs a LVS with at least 3 Kähler moduli.

- We found $\mathbb{P}_{[1,3,3,3,5]}[15]$ with volume

$$\mathcal{V} = \sqrt{\tfrac{2}{45}}\left((5\tau_5 + 3\tau_6 + \tau_7)^{\frac{3}{2}} - \tfrac{1}{3}(5\tau_5 + 3\tau_6)^{\frac{3}{2}} - \tfrac{\sqrt{5}}{3}(\tau_5)^{\frac{3}{2}} \right).$$

- We constructed an explicit (non-realistic) model with the constraints above satisfied.

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Conclusions

The goal of this talk was to illustrate that

- stabilisation of closed string moduli depends on the open string sector.
- If the MSSM is realised by D-branes, not all Kähler moduli can be stabilised by D-instantons.
- In principle, the D-term potential together with massive $U(1)$'s allow to stabilise the remaining Kähler moduli.

In the second part of the paper [arXiv:0711.3389]

- we constructed an explicit example of a LVS
- with the arguments above taken into account.