Moduli Stabilization 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.

Outline

Setup and Notation

An important issue in string phenomenology is moduli stabilization.

That is, there has to be a minimum in the scalar 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, Becker, Haack, Louis; 2002]
- W receives tree-level and non-perturbative contributions
  [Gukov, Vafa, Witten; 1999]
  [Witten; 1996]

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

$W_{\text{flux}}(U,S)$ $\Rightarrow$ generically stabilizes all U and S

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

[Kachru, Kallosh, Linde, Trivedi; 2003]

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

Outline

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, Bertolini, Franco, Kachru; 2007]
[Blumenhagen, Cvetič, Weigand; 2006]

Interlude: D7-Branes

In order to cancel the C_8 tadpole 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 (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 realized 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 stabilized in V_F.

Main Statement of this Talk

If	the MSSM is realized by D-branes,
then	not all Kähler moduli can be stabilized by D-instantons.

D-Term Potential

Besides V_F, there is always the D-term potential

- $$V_D = \sum_a \frac{1}{\text{Re } f_a} \left(Q_a^b \left|\Phi_b^{\text{MSSM}}\right|^2 + Q_a^\beta \left|\Phi_\beta^{\text{add.}}\right|^2 - \xi_a \right)^2$$
- with $\Phi_\beta^{\text{add.}}$ possible additional fields charged under some $U(1)$ orthogonal to the MSSM gauge group,
- and minimum $$Q_a^b \left|\Phi_b^{\text{MSSM}}\right|^2 + Q_a^\beta \left|\Phi_\beta^{\text{add.}}\right|^2 - \xi_a = 0 \ .$$

Assumption: If $\Phi_\beta^{\text{add.}}$ and Φ_b^{MSSM} originate from the same open string sector, then

$$\langle \Phi_b^{\text{MSSM}} \rangle = 0 \quad \Longleftrightarrow \quad \langle \Phi_\beta^{\text{add.}} \rangle = 0 \ .$$

Fayet–Iliopoulos Terms

With this assumption, the minimum of V_D is given by

$$Q_a^b \left|\Phi_b^{\mathrm{MSSM}}\right|^2 + Q_a^\beta \left|\Phi_\beta^{\mathrm{add.}}\right|^2 - \xi_a = 0$$

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

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

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

Without the assumption above, the Kähler moduli can be stabilized by string-loop corrections to $\mathcal{K}$.

[Cicoli, Conlon, Quevedo; 2008]

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 stabilize $(\text{def}\ \mathcal{M})$ Kähler moduli $T = m^I T_I$.

The vanishing of the D-term potential V_D

- provides $(\text{rk}\ \mathcal{M})$ equations for $t^I \leftrightarrow (\text{Re}\ T_J)$
- which allow to stabilize the remaining Kähler moduli.

Outline

LARGE Volume Scenarios

LARGE Volume Scenarios have very appealing features for string phenomenology and cosmology.

[Balasubramanian, Berglund; 2004]
[Balasubramanian, Berglund, Conlon, Quevedo; 2005]
[Conlon, Quevedo et al.; . . .]

LVS can be realized on manifolds

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

[Cicoli, Conlon, Quevedo; 2008]

Constraint on $h^{1,1}_{+}$

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

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

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

$\Rightarrow$ At least 3 Kähler moduli are needed.

$T_1 \sim \mathcal{V}^{2/3}$	stabilized perturbatively
T_2	stabilized non-perturbatively

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

An Explicit Example

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

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

We constructed an explicit model where

- the Kähler moduli are stabilized by $V_F + V_D$ at $\mathcal{V} \simeq 10^{16}$
- and the D7- and D3-tadpoles are cancelled.
- A subtle issue related to the D3-tadpole matching in type IIB and F-theory has now been corrected.

[Aluffi, Esole; 2007]
[Collinucci, Denef, Esole; 2008]

An Explicit Example cont'd

- Configuration of D7-branes, O7-plane and E3-instanton

Cycles	N	Gauge Flux
$D_A = D_5 + D_6$	2	$c_1(\mathcal{L}_A) = 5\,D_5 + 2\,D_6$
$D_B = D_5$	2	
$D_C = 3\,D_5 + 2\,D_6 + D_7$	2	
$D_D = D_5 + D_6 + D_7$	2	
$D_{O7} = 3\,D_5 + 2\,D_6 + D_7$		
$D_{E3} = 2\,D_5 + D_6$		

- The chiral spectrum is computed as

	$U(2)$	$\times\; Sp(4)$	$\times\; Sp(4)$	$\times\; U(2)$
$10\times$	$(\overline{A},$	$1,$	$1,$	$1)$
$10\times$	$(\overline{S},$	$1,$	$1,$	$1)$
$10\times$	$(\square,$	$\square,$	$1,$	$1)$

Outline

Conclusions

The goal of this talk was to illustrate that

- stabilization of closed string moduli depends on the open string sector.
- If the MSSM is realized by D-branes, not all Kähler moduli can be stabilized by D-instantons.
- With plausible assumptions, the D-term potential allows to stabilize the remaining Kähler moduli.

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

- we explicitly constructed a LVS with D-brane sector
- where the arguments above have been taken into account
- and model building constraints are satisfied.