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Kähler moduli stabilization in magnetized orbifold models

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Collaboration with

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String compactification

- 4D chiral spectrum vs higher dimensional SUSY

Magnetic flux and orbifolding on tori

- Generations of chiral fermions
- Calculable spectrum
- Type IIB superstring theory with D-branes

Moduli stabilization in IIB superstrings

- Dilaton S, Complex structure U and Kähler moduli T
- 3-form fluxes to stabilize S and U
- Additional ingredient for the Kähler moduli stabilization

Kähler moduli stabilization in magnetized orbifolds

- Ratios of the Kähler moduli are stabilized at a SUSY vacuum
- One flat direction remains

E-brane (D-brane instanton)

- Localized at a point in the 4D spacetime
- Non-zero volume in the extra dimensional space

Sequestered : $\sum A_i e^{-a_i T_i}$ → Moduli stabilization

Not sequestered : $\sum A_i e^{-a_i T_i} \Psi_1 \Psi_2 \cdots$

Configuration of sequestered E-branes available ?

Review : magnetized T^2

6D $U(2)$ gauge theories compactified on T^2 with $F_{45} = 2\pi \begin{pmatrix} m & 0 \\ 0 & n \end{pmatrix}$

- Gauge symmetry breaking : $U(2) \to U(1)_a \times U(1)_b$

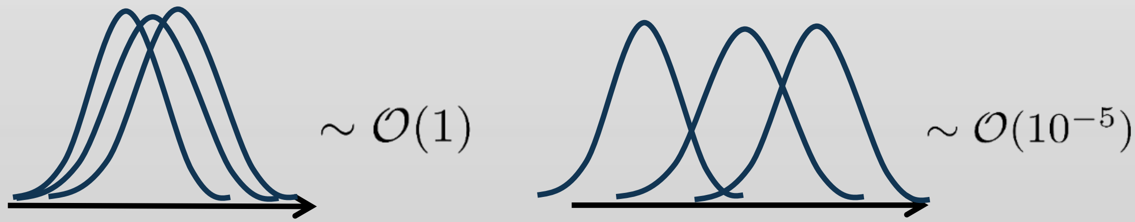
Let us consider a 6D spinor field decomposed into 4D spinors (ψ_+, ψ_-), and assume both of $\psi_\pm$ have the $U(1)$ charges $(+1, -1)$

- Generations of chiral fermion

  For $\mathrm{m} - \mathrm{n} > 0$, ψ_+ has $(\mathrm{m} - \mathrm{n})$ zero-modes, while ψ_- is eliminated

  For $\mathrm{m} - \mathrm{n} < 0$, ψ_- has $(\mathrm{n} - \mathrm{m})$ zero-modes, while ψ_+ is eliminated

- Quasi-localized wavefunctions : hierarchical Yukawa couplings



[C. Bachas ’95]
[D. Cremades, L. E. Ibanez & F. Marchesano ’04]

Review : magnetized T^2/Z_2 Orbifold

- The zero-mode structure is modified, but the spectrum remains calculable

Zero mode degeneracy

M	0	1	2	3	4	5	2n	2n+1
Without Z_2	1	1	2	3	4	5	2n	2n+1
Z_2 Even	1	1	2	2	3	3	n+1	n+1
Z_2 Odd	0	0	0	1	1	2	n-1	n

- # of the degenerate zero-modes is reduced
- useful to eliminate extra field contents

[H. Abe, T. Kobayashi & H. Ohki ’08]

Models of the visible sector

- Toroidal $Z_2 \times Z_2'$ orbifolds with magnetic fluxes
- MSSM(-like) spectrum
- No massless open string moduli and exotic fields
- D9-brane system and D7-branes system

- Possibility of overlapping of the D-branes and the E-branes
- Magnetic fluxes and orbifolding chooses $A_i e^{-a_i T_i}$ or $A_i e^{-a_i T_i} \Psi_1 \Psi_2 \cdots$

E-branes in D9 brane systems

- E1-brane (wrapping a 2-cycle to produce)

$$\mathrm{W} \supset A_i e^{-a_i T_i} \qquad \text{where} \qquad T_i \equiv e^{-\phi}\mathcal{A}_i + i\int_{T^2} C_2$$

$$\begin{array}{c} \mathrm{W} = W_0 + A_i e^{-2\pi T_i} \\ K = \log\left(T_i + \bar{T}_i\right) \end{array} \rightarrow \frac{W_0}{A_i} = -(1 + 4\pi \,\mathrm{Re}\, T_i\,)e^{-2\pi\,\mathrm{Re}\,T_i}$$

$\rightarrow$ a tiny value of W_0, indeed, $\mathrm{Re}\,T_i \sim 1$ implies $\frac{W_0}{A_i} \sim 10^{-2}$

- E5-brane (occupying the whole of the extra space to produce)

$$\mathrm{W} \supset A_S e^{-S} \qquad \text{where} \qquad S \equiv e^{-\phi}\mathcal{A}_1\mathcal{A}_2\mathcal{A}_3 + i\int_{T^6} C_6$$

$\rightarrow A_S e^{-\langle S \rangle}$ (stabilized by 3-form fluxes)

Small W_0 is realized by a reasonable value of $\langle S \rangle$

Specific D9 models based on $\frac{T^2 \times T^2 \times T^2}{Z_2 \times Z_2'}$

- Gauge symmetry : $U(8) \to U(4)_C \times U(2)_L \times U(2)_R$
- A stack of eight D9-branes with

$$F_{45} = \begin{pmatrix} M_{C1} \times \mathbf{1}_4 & 0 & 0 \\ 0 & M_{L1} \times \mathbf{1_2} & 0 \\ 0 & 0 & M_{R1} \times \mathbf{1_2} \end{pmatrix}, F_{67} = \begin{pmatrix} M_{C2} \times \mathbf{1}_4 & 0 & 0 \\ 0 & M_{L2} \times \mathbf{1_2} & 0 \\ 0 & 0 & M_{R2} \times \mathbf{1_2} \end{pmatrix}, F_{89} = \begin{pmatrix} M_{C3} \times \mathbf{1}_4 & 0 & 0 \\ 0 & M_{L3} \times \mathbf{1_2} & 0 \\ 0 & 0 & M_{R3} \times \mathbf{1_2} \end{pmatrix}$$

- Supersymmetric vacuum given by $\frac{F_{45}}{T_1} + \frac{F_{67}}{T_2} + \frac{F_{89}}{T_3} = 0$
- Z_2 parity assignment

$$Z_2 : (z_1, z_2, z_3) \to (-z_1, -z_2, z_3)$$
$$Z_2' : (z_1, z_2, z_3) \to (z_1, -z_2, -z_3)$$

$$P = \begin{pmatrix} \pm\mathbf{1}_4 & 0 & 0 \\ 0 & \pm\mathbf{1_2} & 0 \\ 0 & 0 & \pm\mathbf{1_2} \end{pmatrix}, \quad P' = \begin{pmatrix} \pm\mathbf{1}_4 & 0 & 0 \\ 0 & \pm\mathbf{1_2} & 0 \\ 0 & 0 & \pm\mathbf{1_2} \end{pmatrix}$$

$\longrightarrow$ 16 MSSM-like models

$\longrightarrow$ Only a few models allow
a configuration of the E-branes to get $A_S e^{-\langle S \rangle} + A_i e^{-2\pi T_i}$

E-branes in D7 brane systems

E3-brane

- Wraps a 4-cycle to produce

$$W \supset A_i e^{-a_i T_i} \qquad \text{where} \qquad T_i \equiv e^{-\phi} \mathcal{A}_j \mathcal{A}_k + i \int_{T^4} C_4$$

E(-1)-brane

- Completely localized at a point

$$W \supset A_S e^{-S} \qquad \text{where} \qquad S \equiv e^{-\phi} + i C_0$$

$\rightarrow A_S e^{-\langle S \rangle}$ (stabilized by 3-form fluxes)

These stabilize the moduli in the same way as in the D9 systems

Specific D7 model based on $\frac{T^2 \times T^2 \times T^2}{Z_2 \times Z_2'}$

- Only one viable model with breaking of $U(4)_C$
- Two stacks of four D7-branes : D7**A** /D7**B**
- D7**A** wrapping $T^2 \times T^2 \times T^2$ and D7**B** wrapping $T^2 \times T^2 \times T^2$

$$F_{45}^A = \begin{pmatrix} -5 \times \mathbf{1_3} & 0 \\ 0 & -4 \times \mathbf{1_1} \end{pmatrix}, F_{89}^A = \begin{pmatrix} 5 \times \mathbf{1_3} & 0 \\ 0 & 4 \times \mathbf{1_1} \end{pmatrix}, F_{45}^B = \begin{pmatrix} 0 \times \mathbf{1_2} & 0 \\ 0 & -12 \times \mathbf{1_2} \end{pmatrix}, F_{67}^B = \begin{pmatrix} 0 \times \mathbf{1_2} & 0 \\ 0 & 1 \times \mathbf{1_2} \end{pmatrix}$$

- Supersymmetric vacuum is given by $\frac{T_1}{T_2} = 12$ and $\frac{T_1}{T_3} = 1$
- Gauge symmetry : $U(4)_A \times U(4)_B \to U(3)_C \times \; U(1)_\ell \times U(2)_L \times \; U(2)_R$
- Z_2 parity assignment $\begin{array}{l} Z_2 : (z_1, z_2, z_3) \to (-z_1, -z_2, z_3) \\ Z_2' : (z_1, z_2, z_3) \to (z_1, -z_2, -z_3) \end{array}$

The Z_2 parity assignment is given by $P_A = P_B = P_A' = \mathbf{1}_4$ and $P_B' = -\mathbf{1}_4$

We find a configuration of the E-branes to get $A_S e^{-\langle S \rangle} + A_i e^{-2\pi T_i}$

Summary

- Kähler moduli stabilization in magnetized orbifold D-brane models
- E-branes to produce the moduli potential
- That strongly depends on construction of the visible sector
- Non-trivial even in D7-brane systems

Future prospects

- Other hidden sectors (SUSY breaking etc…)

Thank you very much !!