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Model building and moduli stabilization with magnetized branes

Outline

- Framework

- Standard Model embedding

- Moduli stabilization

Oblique internal magnetic fields

- Supersymmetry breaking

A new gauge mediation mechanism

General framework

- Type I string theory compactified in 4d on 6d Calabi-Yau

$\Rightarrow$ $N = 2$ SUSY in the bulk, $N = 1$ on branes

- Magnetic fluxes on 2-cycles

$\Rightarrow$ SUSY breaking

Dirac quantization: $H = \frac{m}{nA} \equiv \frac{p}{A}$

H: constant magnetic field

m: units of magnetic flux

n: brane wrapping

A: area of the 2-cycle

Spin-dependent mass shifts for all charged states

$[p_i, p_j] = iqH\epsilon_{ij}$ $\qquad$ q: charge

$\Rightarrow$ Landau spectrum

Exact open string description:

$qH \to \theta = \text{arctan}\, qH\alpha'$ weak field $\Rightarrow$ field theory

T-dual representation: branes at angles

magnetized D9-brane wrapped on T^2

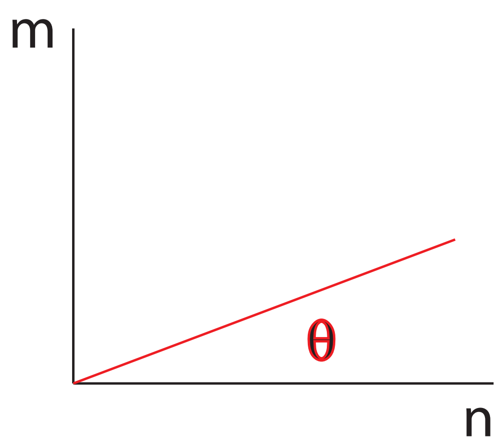
$$H = \frac{m}{n}\frac{1}{R_1 R_2}$$

T-duality: $R_2 \to \alpha'/R_2 \equiv \tilde{R}_2 \Rightarrow$ D8-brane

wrapped around a direction of angle θ in T^2

$$H = \frac{m}{n}\frac{\tilde{R}_2}{R_1} = \tan\theta$$

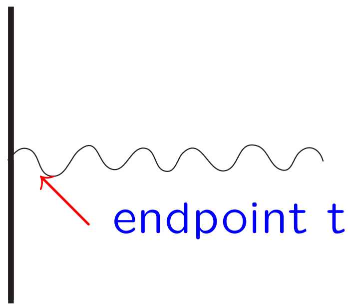
(m, n): wrapping numbers around $(\tilde{R}_2, R_1)$



Generic spectrum

N coincident branes $\Rightarrow U(N)$

a-stack



endpoint transformation: $\mathbf{N}_a$ or $\bar{\mathbf{N}}_a$

$U(1)_a$ charge: $+1$ or -1

$U(1)$: "baryon" number

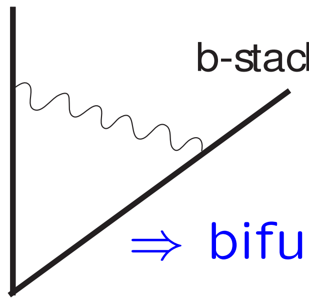
- open strings from the same stack $\Rightarrow$

  adjoint gauge multiplets of $U(N_a)$

- stretched between two stacks

a-stack in p dims

b-stack in p' dims



$\Rightarrow$ bifundamentals of $U(N_a) \times U(N_b)$

in $p \cap p'$ dims

Non oriented strings $\Rightarrow$ orientifold planes

where closed strings change orientation

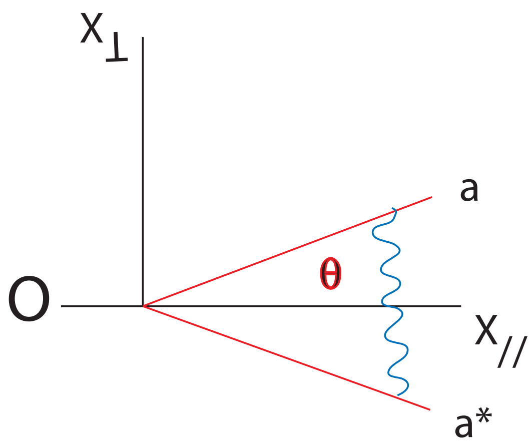
$\Rightarrow$ mirror branes

identified with branes under orientifold action

- strings stretched between two mirror stacks

Orientifold $\rightarrow$

$X_\perp \rightarrow -X_\perp$



$\Rightarrow$ antisymmetric or symmetric of $U(N_a)$

Minimal Standard Model embedding

- oriented strings $\Rightarrow$

  need at least 4 brane-stacks

- also for non-oriented strings

  with Baryon and Lepton number symmetries

I.A.-Kiritsis-Tomaras '00

I.A.-Kiritsis-Rizos-Tomaras '02

- General analysis using 3 brane stacks

  $\Rightarrow \; U(3) \times U(2) \times U(1)$

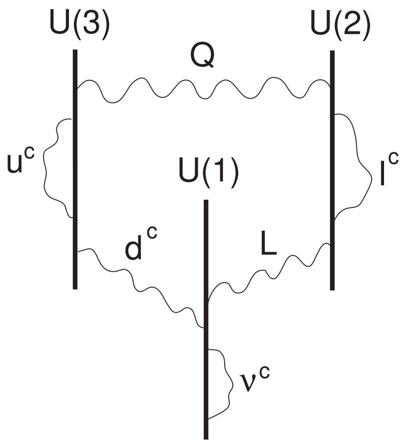
antiquarks u^c, d^c $(\bar{3}, 1)$:

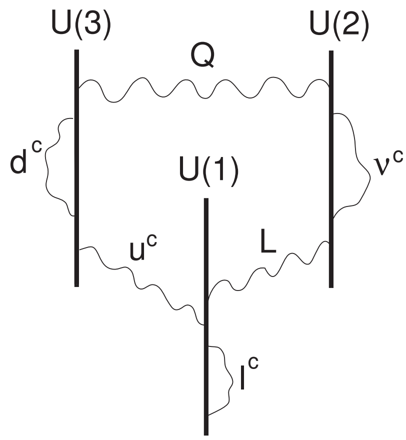
antisymmetric of $U(3)$ or

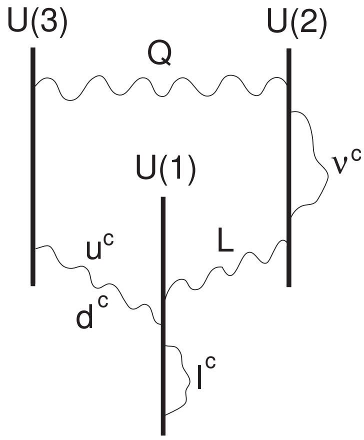
bifundamental $U(3) \leftrightarrow U(1)$

$\Rightarrow$ 3 models: antisymmetric is u^c, d^c or none

I.A.-Dimopoulos '04







	Model A	**Model B**	**Model C**
Q	$(\mathbf{3},\mathbf{2};1,1,0)_{1/6}$	$(\mathbf{3},\mathbf{2};1,\varepsilon_Q,0)_{1/6}$	$(\mathbf{3},\mathbf{2};1,\varepsilon_Q,0)_{1/6}$
u^c	$(\bar{\mathbf{3}},\mathbf{1};2,0,0)_{-2/3}$	$(\bar{\mathbf{3}},\mathbf{1};-1,0,1)_{-2/3}$	$(\bar{\mathbf{3}},\mathbf{1};-1,0,1)_{-2/3}$
d^c	$(\bar{\mathbf{3}},\mathbf{1};-1,0,\varepsilon_d)_{1/3}$	$(\bar{\mathbf{3}},\mathbf{1};2,0,0)_{1/3}$	$(\bar{\mathbf{3}},\mathbf{1};-1,0,-1)_{1/3}$
L	$(\mathbf{1},\mathbf{2};0,-1,\varepsilon_L)_{-1/2}$	$(\mathbf{1},\mathbf{2};0,\varepsilon_L,1)_{-1/2}$	$(\mathbf{1},\mathbf{2};0,\varepsilon_L,1)_{-1/2}$
l^c	$(\mathbf{1},\mathbf{1};0,2,0)_{1}$	$(\mathbf{1},\mathbf{1};0,0,-2)_{1}$	$(\mathbf{1},\mathbf{1};0,0,-2)_{1}$
ν^c	$(\mathbf{1},\mathbf{1};0,0,2\varepsilon_\nu)_{0}$	$(\mathbf{1},\mathbf{1};0,2\varepsilon_\nu,0)_{0}$	$(\mathbf{1},\mathbf{1};0,2\varepsilon_\nu,0)_{0}$

$$Y_A = -\frac{1}{3}Q_3 + \frac{1}{2}Q_2 \qquad\qquad Y_{B,C} = \frac{1}{6}Q_3 - \frac{1}{2}Q_1$$

Model A : $\sin^2\theta_W = \left.\frac{1}{2+2\alpha_2/3\alpha_3}\right|_{\alpha_2=\alpha_3} = \frac{3}{8}$

Model B, C : $\sin^2\theta_W = \left.\frac{1}{1+\alpha_2/2\alpha_1+\alpha_2/6\alpha_3}\right|_{\alpha_2=\alpha_3} = \frac{6}{7+3\alpha_2/\alpha_1}$

- Higgs can be easily implemented

massless $\Rightarrow$ susy intersection

$H_1, H_2 \,:\; U(2) \leftrightarrow U(1)$ like L

	Model A	**Model B, C**
H_1	$(\mathbf{1},\mathbf{2};0,-1,\varepsilon_{H_1})_{-1/2}$	$(\mathbf{1},\mathbf{2};0,\varepsilon_{H_1},1)_{-1/2}$
H_2	$(\mathbf{1},\mathbf{2};0,1,\varepsilon_{H_2})_{1/2}$	$(\mathbf{1},\mathbf{2};0,\varepsilon_{H_2},-1)_{1/2}$

- 2 extra $U(1)$'s

\- One combination can be $B-L$

$(\varepsilon_d = \varepsilon_L = \varepsilon_\nu = -\varepsilon_{H_1} = \varepsilon_{H_2})$

$$B-L = -\tfrac{1}{6}Q_3 + \tfrac{1}{2}Q_2 - \tfrac{\varepsilon_d}{2}Q_1$$

broken by a SM singlet VEV at high scale

or survive at low energies

\- The other/both is/are anomalous

Moduli stabilization with 3-form fluxes:
significant progress but

- no exact string description
  low energy SUGRA approximation

- fix only complex structure

Type I with internal magnetic fluxes:
alternative/complementary approach

- exact string description

- Kähler class stabilization
  T^6: all geometric moduli fixed

- natural implementation in intersecting
  D-brane models

Magnetic fluxes can be used to stabilize moduli

I.A.-Maillard '04, I.A.-Kumar-Maillard '05, '06

e.g. T^6: 36 moduli (geometric deformations)

internal metric: $6 \times 7/2 = 21 = 9 + 2 \times 6$

type IIB RR 2-form: $6 \times 5/2 = 15 = 9 + 2 \times 3$

$$\text{complexification} \Rightarrow \begin{cases} \text{Kähler class} & J \\ \text{complex structure} & \tau \end{cases}$$

9 complex moduli for each

magnetic flux: 6×6 antisymmetric matrix F

complexification $\Rightarrow$

$F_{(2,0)}$ on holomorphic 2-cycles: potential for τ

$F_{(1,1)}$ on mixed (1,1)-cycles: potential for J

T^6 parametrization/complexification

$x^i \equiv x^i + 1 \quad y_i \equiv y_i + 1 \quad i = 1, 2, 3$

$z^i = x^i + \tau^{ij} y_i$

τ: 3×3 complex structure matrix

$\delta g_{i\bar{j}}$: Kähler deformations

$\rightarrow J = \delta g_{i\bar{j}} i dz_i \wedge d\bar{z}_j$

W : covering map

of the brane world-volume over T^6

$N = 1$ SUSY conditions:

1. $F_{(2,0)} = 0 \quad \Rightarrow \tau \quad \tau^{\mathsf{T}} p_{xx} \tau - (\tau^{\mathsf{T}} p_{xy} + p_{yx} \tau) + p_{yy} = 0$

2. $J \wedge J \wedge F_{(1,1)} = F_{(1,1)} \wedge F_{(1,1)} \wedge F_{(1,1)} \quad \Rightarrow J$

3. action positivity: $\det W (J \wedge J \wedge J - J \wedge F \wedge F) > 0$

Appropriate choice of magnetic fluxes F^a

in several abelian directions $U(1)_a \Rightarrow$

all moduli vanish except the 6 radii of T^6

which are fixed in terms of the quantized fluxes

$T^6 = \prod_{I=1}^{3} T_I^2 \leftarrow$ orthogonal 2-torus

$$\tau_I = \frac{R_I}{R_I'} \qquad J_I = R_I R_I' \qquad H_I^a = \frac{F_I^a}{J_I}$$

(1) fixes the ratios τ_I

(2) fixes the sizes J_I

$$H_1 + H_2 + H_3 = H_1 H_2 H_3 \Leftrightarrow \theta_1 + \theta_2 + \theta_3 = 0$$

Main ingredients for moduli stabilization

- "oblique" magnetic fields $\Rightarrow$

  fix off-diagonal components of the metric

- Non linear DBI action $\Rightarrow$ fix overall volume

  not valid in six dimensions

- (2) $\Leftrightarrow$ vanishing of a Fayet-Iliopoulos term

  $\xi \sim F \wedge F \wedge F - J \wedge J \wedge F$

Stabilization of RR moduli

- Kähler class: absorbed by massive $U(1)$'s

  kinetic mixing with magnetized $U(1)$'s

$\Rightarrow$ need at least 9 brane stacks

- Complex structure: get potential

  through mixing with NS moduli

Bianchi-Trevigne '05

Tadpole conditions

$Q_9 = \sum_a N_a \det W_a = 16 \leftarrow$ O9 charge

$Q_5 = \sum_a N_a \det W_a \epsilon^{\alpha\beta\gamma\delta\sigma\tau} p^a_{\gamma\delta} p^a_{\sigma\tau} = 0$

$\forall$ 2-cycle $\alpha, \beta = 1, \ldots, 6$

SUSY + tadpole conditions seem incompatible

- use 9 magnetized branes to fix all moduli

  impose SUSY conditions

- introduce an extra brane(s)

  to satisfy RR tadpole cancellation

  $\Rightarrow$ dilaton potential from the FI D-term

$\Rightarrow$ two possibilities:

• keep SUSY by turning on charged scalar VEVs

I.A.-Kumar-Maillard '06

D-term condition (2) is modified to:

$$qv^2(J\wedge J\wedge J - J\wedge F\wedge F) = -(F\wedge F\wedge F - F\wedge J\wedge J)$$

- EFT validity $\Rightarrow v < 1$ in string units

- Infinite family of (large volume) solutions

invariance: $\{F_a, J\} \to \{\Lambda F_a, \Lambda J\}$ for $\Lambda \in \mathbb{N}$

- fixing the dilaton?

combine magnetic and 3-form fluxes

3-brane charge $\Rightarrow T^6/\mathbb{Z}_2$ with O3 planes

• break SUSY in a AdS vacuum

I.A.-Derendinger-Maillard in preparation

add a 'non-critical' dilaton potential

D-term SUSY breaking $\Rightarrow$

problem with Majorana gaugino masses

- lowest order: exact R-symmetry

- higher orders: suppressed by the string scale

I.A.-Taylor '04, I.A.-Narain-Taylor '05

However in toroidal models:

- gauge multiplets have extended SUSY

  $\Rightarrow$ Dirac gaugino masses without $\not{R}$

- non chiral intersections have $N = 2$ SUSY

  $\Rightarrow$ Higgs in $N = 2$ hypermultiplet

$\Rightarrow$ New gauge mediation mechanism

I.A.-Benakli-Delgado-Quiros '07

SM observable sector: SUSY

gauginos: extended susy, Higgs hypermultiplet

Hidden (secluded) sector: SUSY breaking

messengers: $N = 2$ hypermultiplets

with mixed quantum numbers

- Dirac gaugino masses: $\sim \frac{\alpha}{4\pi}\frac{D}{M}$
- Higgs potential:

$$V = V_{\text{soft}} + \frac{1}{8}(g^2 + g'^2)(|H_1|^2 - |H_2|^2)^2$$

$$+ \frac{1}{2}(g^2 + g'^2)|H_1 H_2|^2 \quad \Rightarrow$$

- lightest higgs h behaves as in SM

- heaviest H plays no role in EWSB, $g_{ZHH} = 0$

- same as MSSM in $\tan\beta \to \infty$

$\Rightarrow$ "little" fine tuning is greatly reduced

- Distinct collider signals different from MSSM