

Magnetized orbifold models of dynamical supersymmetry breaking

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Introduction

- New physics beyond the SM
- Supersymmetry : Higgs mass, DM, UV completion, ...
- Extra dimensional space : origin of the flavor structure



Ten-dimensional supersymmetric Yang-Mills theories

- 4D chiral spectra : Magnetic fluxes and Orbifolding
- Many SM-like models based on magnetized orbifolds

(Abe, Choi, Kobayashi, Ohki '09; Abe, Fujimoto, Kobayashi, Miura, Nishiwaki, Sakamoto, Tatsuta'15)

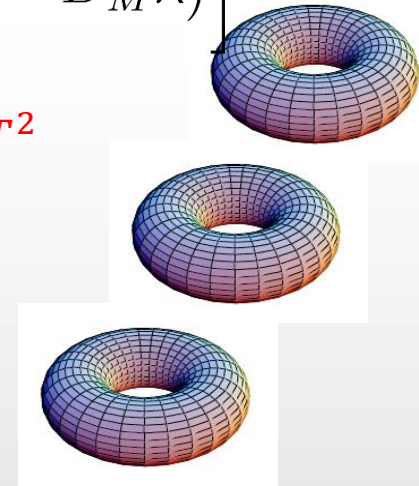
- Hidden sector based on magnetized orbifolds
- **Supersymmetry breaking**, Moduli stabilization, ...

Superfield description of 10D SYM theories on

$$S = \int dx^{10} \sqrt{-G} \left[-\frac{1}{4g^2} \text{tr} (F^{MN} F_{MN}) + \frac{i}{2g^2} \text{tr} (\bar{\lambda} \Gamma^M D_M \lambda) \right]$$

compactified on $M^4 \times T^2 \times T^2 \times T^2$

10D Coordinates	$X_M = (x_\mu, z_1, z_2, z_3)$
10D Vector Field	$A_M = (A_\mu, \varphi_1, \varphi_2, \varphi_3)$
10D Spinor Field	$\lambda = (\lambda_0, \lambda_1, \lambda_2, \lambda_3)$



- 4D N=1 supersymmetric decomposition

4D N=1 vector multiplet $V \equiv -\theta \sigma^\mu \bar{\theta} A_\mu + i \bar{\theta} \bar{\theta} \theta \lambda_0 - i \theta \theta \bar{\theta} \bar{\lambda}_0 + \frac{1}{2} \theta \theta \bar{\theta} \bar{\theta} D$

4D N=1 chiral multiplets $\phi_i \equiv \frac{1}{\sqrt{2}} \varphi_i + \sqrt{2} \theta \lambda_i + \theta \theta F_i$

Abelian magnetic fluxes on $T^2 \times T^2 \times T^2$

- Gauge symmetry breaking : $U(N) \rightarrow U(N_a) \times U(N_b)$

$$F_{Z_i \bar{Z}_i} = \begin{pmatrix} M_i^a \mathbf{1}_{N_a} & 0 \\ 0 & M_i^b \mathbf{1}_{N_b} \end{pmatrix} \quad \phi_j = \begin{pmatrix} \phi_j^{aa} & \phi_j^{ab} \\ \phi_j^{ba} & \phi_j^{bb} \end{pmatrix} \leftarrow (N_a, \bar{N}_b)$$

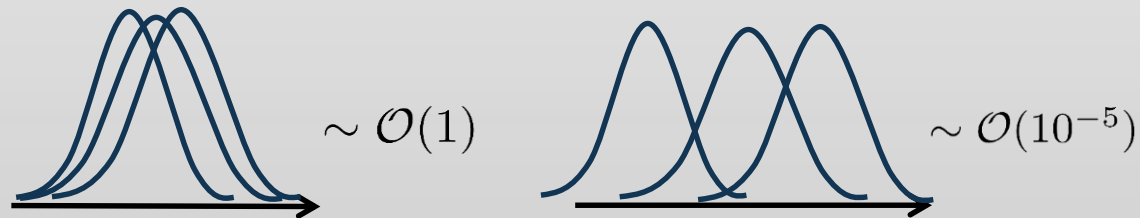
- Generations of chiral fermions [C. Bachas '95]

Given a non-vanishing value for $M_i^{ab} \equiv M_i^a - M_i^b$,

$(\phi_j^{ab}, \phi_j^{ba})$ have $(|M_i^{ab}|, 0)$ or $(0, |M_i^{ab}|)$ zero-modes

- Gaussian profiles of zero modes : hierarchical Yukawa couplings

$$y_{IJK} = \int dy^2 \Theta^{I, M_{ab}}(y) \Theta^{J, M_{bc}}(y) \Theta^{K, M_{ca}}(y)$$



[D. Cremades, L. E. Ibanez & F. Marchesano '04]

Magnetized Orbifolds T^6/Z_2

- # of degenerate zero-modes is reduced
- Eliminate extra massless fields

M	0	1	2	3	4	5	2n	2n+1
Pure T^2	1	1	2	3	4	5	2n	2n+1
Even	1	1	2	2	3	3	n+1	n+1
Odd	0	0	0	1	1	2	n-1	n

[H. Abe, T. Kobayashi & H. Ohki '08]

- Z_2 parity assignment respecting the N=1 SUSY

$$Z_2 \text{ acts as } z_i \rightarrow \pm z_i \quad \begin{array}{l} V \rightarrow + PVP^{-1} \\ \phi_i \rightarrow \pm P\phi_iP^{-1} \end{array} \quad P : N \times N \text{ matrix satisfying } P^2 = 1$$

Dynamical Supersymmetry Breaking (DSB)

- 10D SYM theory : restricted field contents and couplings
- Supersymmetric $SU(N_C)$ gauge theory with N_F fundamental flavors (Q, \tilde{Q})
- SUSY breaking scale \sim Dynamical Scale Λ
- For $N_C > N_F$, the Affleck-Dine-Seiberg potential is obtained

$$W_{ADS} = C \times \left(\frac{\Lambda^{3N_C - N_F}}{\det(Q\tilde{Q})} \right)^{1/(N_C - N_F)}$$

- Simplest DSB model with **a singlet S** [I. Affleck, M. Dine & N. Seiberg '85]

$$W_{\text{eff}} = g S Q \tilde{Q} + C \times \left(\frac{\Lambda^{3N_C - N_F}}{\det(Q\tilde{Q})} \right)^{1/(N_C - N_F)}$$

$$\bar{F}_S = Q \tilde{Q} = 0 \rightarrow \text{blows up in the second term}$$

DSB models on Magnetized Orbifolds

- Gauge Symmetry Breaking : $U(N) \rightarrow U(N_C) \times U(1) \times U(1)$

$$F_{Z_i \bar{Z}_i} = \begin{pmatrix} M_i^C \mathbf{1}_{N_C} & 0 & 0 \\ 0 & M_i^x & 0 \\ 0 & 0 & M_i^y \end{pmatrix} \quad \Phi_i = \begin{pmatrix} * & * & * \\ * & * & S \\ * & * & * \end{pmatrix}, \quad \Phi_j = \begin{pmatrix} * & * & * \\ * & * & * \\ Q & * & * \end{pmatrix}, \quad \Phi_k = \begin{pmatrix} * & \tilde{Q} & * \\ * & * & * \\ * & * & * \end{pmatrix}$$

- Coupling : $W = g \Phi_i \Phi_j \Phi_k = g S Q \tilde{Q}$
- Unbroken gauge invariance : $M_i^S + M_i^Q + M_i^{\tilde{Q}} = 0$
- Z_2 invariance of the Yukawa couplings

$M_i^S \equiv M_i^x - M_i^y,$
$M_i^Q \equiv M_i^y - M_i^C,$
$M_i^{\tilde{Q}} \equiv M_i^C - M_i^x,$

No extra fields irrelevant to the DSB

- Degeneracy of fields $(S, Q, \tilde{Q}) = (1, N_F, N_F)$
- $(Q, \tilde{Q}) \times N_F$ originate from a single torus

Configurations to get the essential structure

	Z_2 parity of (S, Q, \tilde{Q})	Flux $(M_i^S, M_i^Q, M_i^{\tilde{Q}})$
Pattern 1	(Even, Even, Even)	$(0, M, -M)$
Pattern 2	(Even, Even, Even)	$(-1, -2M, 2M + 1)$
Pattern 3	(Odd, Even, Odd)	$(-3, -M, M + 3)$
Pattern 4	(Odd, Even, Odd)	$(-4, -2M, 2M + 4)$
Pattern 5	(Even, Odd, Odd)	$(0, M, -M)$
Pattern 6	(Even, Odd, Odd)	$(-1, -2M - 1, 2M + 2)$

Concrete Model with pattern 1

On the first torus

- Flux $(M_1^S, M_1^Q, M_1^{\tilde{Q}}) = (0, M, -M)$ ($M > 0$)
- Z_2 parity of $(S, Q, \tilde{Q}) = (\text{Even}, \text{Even}, \text{Even})$

Magnetic fluxes on the other two tori

- No extra degeneracy
- Preserve SUSY : $\frac{1}{V_1} F_{z_1 \bar{z}_1} + \frac{1}{V_2} F_{z_2 \bar{z}_2} + \frac{1}{V_3} F_{z_3 \bar{z}_3} = 0$

$$F_{z_1 \bar{z}_1} \sim \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, F_{z_2 \bar{z}_2} \sim \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, F_{z_3 \bar{z}_3} \sim \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

- Ratios of torus areas : $\frac{V_1}{V_2} = \frac{V_1}{V_3} = M$
- $(M_2^S, M_2^Q, M_2^{\tilde{Q}}) = (-1, 0, +1)$; $(M_3^S, M_3^Q, M_3^{\tilde{Q}}) = (+1, -1, 0)$

Concrete Model : $T^6 / Z_2 \times Z'_2$ orbifold

Z_2 transformations

- Z_2 acts as $z_i \rightarrow \pm z_i$; $\phi_i \rightarrow \pm P\phi_i P^{-1}$, $P : N \times N$ matrix
- $(S, Q, \tilde{Q}) \rightarrow + (S, Q, \tilde{Q})$ under $z_i \rightarrow -z_i$

$Z_2 \times Z'_2$ Orbifold projection and resultant massless modes

$$Z_2 : (z_1, z_2, z_3) \rightarrow (-z_1, -z_2, z_3) \text{ with } P = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

$$Z'_2 : (z_1, z_2, z_3) \rightarrow (z_1, -z_2, -z_3) \text{ with } P' = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\Phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \Phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \Phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & 0 & 0 \end{pmatrix}$$

Summary

- Simple DSB models based on magnetized orbifolds
- # of the flavors controlled by the magnetic fluxes M
- $Z_2 \times Z'_2$ orbifold eliminating all of extra massless fields
- The similar models with the other patterns (2,3,4,5,6)

Future prospects

- Association with other sectors (the MSSM, moduli stabilizations)
- Phenomenology (SUSY breaking scale, Moduli couplings)

Thank you very much !!