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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

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Ten-dimensional supersymmetric Yang-Mills theories

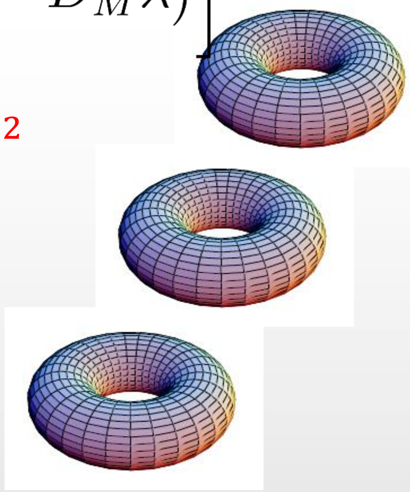
- 4D chiral spectra : Magnetic fluxes and Orbifolding
- Many SM-like models based on magnetized orbifolds

  (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

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



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 $\quad V \equiv -\theta\sigma^\mu\bar{\theta}A_\mu + i\bar{\theta}\bar{\theta}\theta\lambda_0 - i\theta\theta\bar{\theta}\bar{\lambda}_0 + \frac{1}{2}\theta\theta\bar{\theta}\bar{\theta}D$

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

N. Marcus, A. Sagnotti and W. Siegel ’83
N. Arkani-Hamed, T. Gregoire and J. Wacker ’02

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

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

$$F_{z_i \bar{z}_i} = \begin{pmatrix} M_i^a \mathbf{1}_{N_a} & 0 \\ 0 & M_i^b \mathbf{1}_{N_b} \end{pmatrix} \qquad \phi_j = \begin{pmatrix} \phi_j^{aa} & \phi_j^{ab} \\ \phi_j^{ba} & \phi_j^{bb} \end{pmatrix} \leftarrow (N_a, \overline{N_b})$$

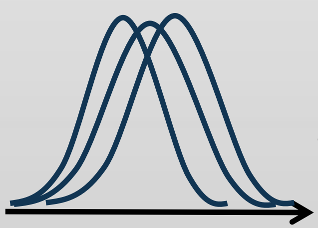
- Generations of chiral fermions [C. Bachas '95]

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

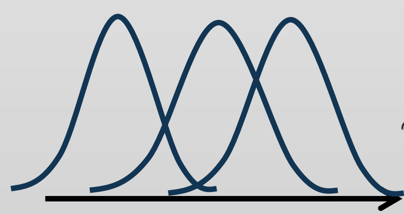
  $(\phi_j^{ab}, \phi_j^{ba})$ have $(|M_i^{ab}|, 0)$ or $(0, |M_i^{ab}|)$ zero-modes

- Gaussian zero-mode wavefunctions : hierarchical Yukawa couplings

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



$\sim \mathcal{O}(1)$



$\sim \mathcal{O}(10^{-5})$

[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 acts as $z_i \to \pm z_i$

$$V \to +PVP^{-1}$$
$$\phi_i \to \pm P\phi_i P^{-1}$$

P : $N \times N$ 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 ~ 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]

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

$\overline{F_S} = Q\tilde{Q} = 0 \rightarrow$ blows up in the second term

DSB models on Magnetized Orbifolds

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

$$F_{z_i \bar{z}_i} = \begin{pmatrix} M_i^C \mathbf{1}_{N_C} & 0 & 0 \\ 0 & M_i^x & 0 \\ 0 & 0 & M_i^y \end{pmatrix} \quad \Phi_1 = \begin{pmatrix} * & * & * \\ * & * & S \\ * & * & * \end{pmatrix}, \quad \Phi_2 = \begin{pmatrix} * & * & * \\ * & * & * \\ Q & * & * \end{pmatrix}, \quad \Phi_3 = \begin{pmatrix} * & \tilde{Q} & * \\ * & * & * \\ * & * & * \end{pmatrix}$$

- Coupling : $W = g\, \Phi_1 \Phi_2 \Phi_3 = g\, SQ\tilde{Q}$

- Unbroken gauge invariance : $M_i^S + M_i^Q + M_i^{\tilde{Q}} = 0$

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

- Z_2 invariance of the Yukawa couplings :

  Even-Even-Even or Even-Odd-Odd

Zero-mode degeneracy

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

	T^2	T^2	T^2	Total
$Q, \tilde{Q}$	N_F	1	1	N_F
S	1	1	1	1

↑

Result of a systematic research

	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)	$(-1, -2M-1, 2M+2)$

↓

	T^2	T^2	T^2	Total
$Q, \tilde{Q}$	N_F	1	1	N_F
S	1	1	1	1

Concrete Model with pattern 1

On the first torus

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

Magnetic fluxes on the other two tori

- No extra degeneracy
- Preserve SUSY : $\frac{1}{V_1} F_{z_1\overline{z_1}} + \frac{1}{V_2} F_{z_2\overline{z_2}} + \frac{1}{V_3} F_{z_3\overline{z_3}} = 0$

$$F_{z_1\overline{z_1}} \sim \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, F_{z_2\overline{z_2}} \sim \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, F_{z_3\overline{z_3}} \sim \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

- Ratios of the 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) $\rightarrow Z_2$ Even

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

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

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

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

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

One singlet S, pairs of $(Q, \tilde{Q})$, and no extra fields

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 !!