Phenomenological aspects of magnetized SYM theories in higher dimensions

Hiroyuki Abe (Waseda U.)

PLANCK 2017 (May 22 - 27, 2017)
University of Warsaw, Warsaw, Poland

This talk is mainly based on

Supersymmetric models on magnetized orbifolds with flux-induced Fayet-Iliopoulos terms,

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A.,

Phys.Rev. D95 (2017) 015005, arXiv:1610.07730 [hep-ph]

Dynamical supersymmetry breaking on magnetized tori and orbifolds,

T. Kobayashi, K. Sumita & H. A.,

Nucl.Phys. B911 (2016) 606, arXiv:1605.02922 [hep-th]

in collaboration with

Tatsuo Kobayashi (Hokkaido U.)

Keigo Sumita (Waseda U.)

Yoshiyuki Tatsuta (DESY & Waseda U.)

Plan of this talk

- SYM on magnetized tori
- Phenomenological aspects
  - MSSM-like models (visible sector)
  - DSB models (hidden sector)
- Summary

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⟷ Plenary talks by
Professors W. Buchmuller and E. Dudas

- Summary

SYM ON MAGNETIZED TORI

SYM on magnetized tori

Basic features

- Degenerate chiral zero-modes appear
- The degeneracy is determined by the number of fluxes
- Analytic forms of wavefunctions -> 4D Yukawa couplings

D. Cremades, L.E. Ibanez & F. Marchesano, JHEP 0405 (2004) 079

Applications

- Phenomenological models for visible and hidden sectors

Further aspects

- D-brane interpretations and dual descriptions

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10D $U(N)$ SYM on T^6

10D coordinate : $X^M = (x^\mu, y^m) = (x^\mu, z^i)$

10D vector : $A_M = (A_\mu, A_m) = (A_\mu, A_i)$

10D Majorana-Weyl spinor : $\lambda = (\lambda_0, \lambda_i)$

$i = 1,2,3$

$$z^i \equiv \frac{1}{2}\left(x^{2+2i} + \tau_i x^{3+2i}\right)$$

$$A_i \equiv -\frac{1}{\operatorname{Im}\tau_i}\left(\tau_i^* A_{2+2i} - A_{3+2i}\right)$$

10D $U(N)$ SYM on T^6

10D coordinate : $X^M = (x^\mu, y^m) = (x^\mu, z^i)$ $\quad i = 1,2,3$

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10D Majorana-Weyl spinor : $\lambda = (\lambda_0, \lambda_i)$

$\mathcal{N} = 1$ Supermultiplets (superfields)

$$\begin{cases} V \equiv -\theta\sigma^\mu\bar{\theta}A_\mu + i\bar{\theta}\bar{\theta}\theta\lambda_0 - i\theta\theta\bar{\theta}\bar{\lambda}_0 + \frac{1}{2}\theta\theta\bar{\theta}\bar{\theta}D \\ \phi_i \equiv \frac{1}{\sqrt{2}}A_i + \sqrt{2}\theta\lambda_i + \theta\theta F_i \end{cases}$$

$U(N)$ adjoints

10D $U(N)$ SYM on magnetized T^6

Abelian flux & Wilson-line in $U(N)$ adjoint matrix

$$\langle A_i \rangle = \frac{\pi}{\mathrm{Im}\,\tau_i}\left(M^{(i)}\,\bar{z}_{\bar{i}} + \bar{\zeta}_i\right) \Rightarrow F_{z_i \bar{z}_{\bar{i}}} = 2\pi M^{(i)}$$

10D $U(N)$ SYM on magnetized T^6

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$$M^{(i)} = \mathrm{diag}(M_1^{(i)}, M_2^{(i)}, \ldots, M_N^{(i)}),$$ (integer) magnetic fluxes

$$\zeta_i = \mathrm{diag}(\zeta_1^{(i)}, \zeta_2^{(i)}, \ldots, \zeta_N^{(i)}),$$ (continuous) Wilson-lines

$$M_a^{(i)} \neq M_b^{(i)} \quad {}^\forall a, b \Rightarrow U(N) \to U(1)^N$$

10D $U(N)$ SYM on magnetized T^6

D. Cremades, L.E. Ibanez & F. Marchesano, JHEP 0405 (2004) 079

- $U(N) \to U(N_a) \times U(N_b) \times U(N_c)$

$$F_{45} = 2\pi \begin{pmatrix} M_a^{(1)} \mathbf{1}_{N_a \times N_a} & & 0 \\ & M_b^{(1)} \mathbf{1}_{N_b \times N_b} & \\ 0 & & M_c^{(1)} \mathbf{1}_{N_c \times N_c} \end{pmatrix}$$

$M_1 + M_2 + M_3 = 0$

$M_1 = M_a - M_b, \ \ M_2 = M_b - M_c, \ \ M_3 = M_c - M_a$

- Degenerate zero-modes in adjoint field

$$\lambda_1(x,y) = \begin{pmatrix} \lambda_a(x) & \psi_+^i(y) L_{ab}^i(x) & 0 \\ 0 & \lambda_b(x) & 0 \\ \psi_+^j(y) R_{ca}^j(x) & \psi_+^k(y) H_{cb}^k(x) & \lambda_c(x) \end{pmatrix}$$

for $M_1 > 0$,
$M_2, M_3 < 0$
$i = 0, 1, \ldots, |M_1|-1$
$j = 0, 1, \ldots, |M_2|-1$
$k = 0, 1, \ldots, |M_3|-1$

Zero-mode wavefunctions

D. Cremades, L.E. Ibanez & F. Marchesano, JHEP 0405 (2004) 079

For $j = 0, 1, 2, \ldots, |M|-1$

$$\psi_+^j(y) = \Theta^j(y_4, y_5) = N_j e^{-M\pi y_4^2} \vartheta \begin{bmatrix} j/M \\ 0 \end{bmatrix} (M(y_4 + iy_5), Mi)$$

$\psi_-(y) = 0$: no normalizable zero-modes

where
$$\vartheta \begin{bmatrix} j/M \\ 0 \end{bmatrix} (M(y_4 + iy_5), Mi) = \sum_n e^{-M\pi(n+j/M)^2 + 2\pi(n+j/M)M(y_4+iy_5)}$$

is the Jacobi theta function

Properties of zero-modes

D. Cremades, L.E. Ibanez & F. Marchesano, JHEP 0405 (2004) 079

|*M*| chiral zero-modes *j = 0, 1, 2, …, |M|-1*

$\psi_+^j(y) =$ $$\Theta^j(y_4, y_5) = N_j e^{-M\pi y_4^2} \vartheta \begin{bmatrix} j/M \\ 0 \end{bmatrix} (M(y_4 + i y_5), Mi)$$

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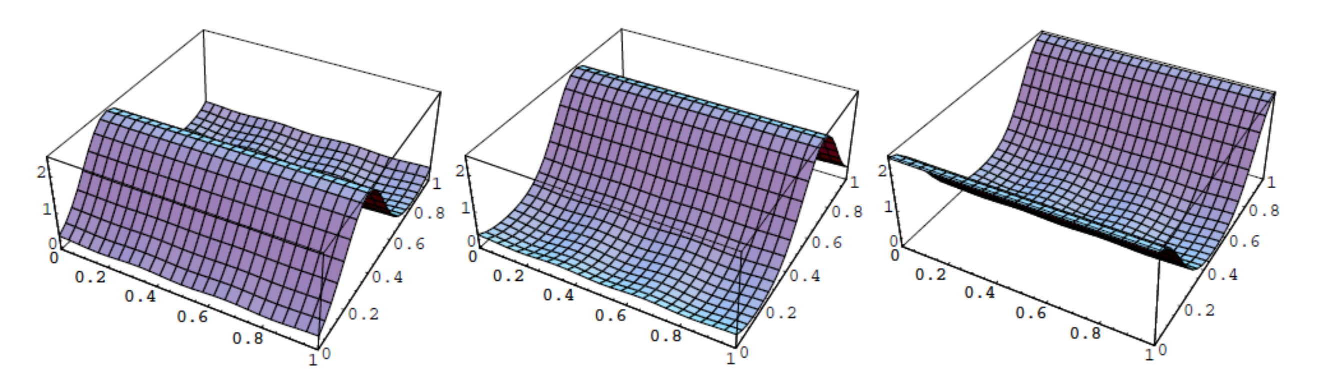
Wavefunction localization $|\psi_+^j|^2$, $|M|=3$



PHENOMENOLOGICAL ASPECTS

MSSM-LIKE MODELS (VISIBLE SECTOR)

10D $U(8)$ SYM model on T^6

T. Kobayashi, H. Ohki, K. Sumita & H. A., NPB 863 (2012) 1

Magnetic fluxes $\quad U(8) \rightarrow U(4)_C \times U(2)_L \times U(2)_R$

$$F_{2+2r,3+2r} = 2\pi \begin{pmatrix} M_C^{(r)} \mathbf{1}_4 & & \\ & M_L^{(r)} \mathbf{1}_2 & \\ & & M_R^{(r)} \mathbf{1}_2 \end{pmatrix}$$

$r = 1,2,3$

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r = 1,2,3

Wilson-lines $\rightarrow U(3)_C \times U(2)_L \times U(1)_{C'} \times U(1)_{R'} \times U(1)_{R''}$

$$\zeta_r = \begin{pmatrix} \zeta_C^{(r)} \mathbf{1}_3 & & & & \\ & \zeta_{C'}^{(r)} & & & \\ & & \zeta_L^{(r)} \mathbf{1}_2 & & \\ & & & \zeta_{R'}^{(r)} & \\ & & & & \zeta_{R''}^{(r)} \end{pmatrix}$$

10D $U(8)$ SYM model on T^6

T. Kobayashi, H. Ohki, K. Sumita & H. A., NPB 863 (2012) 1

Flux ansatz

$$
\begin{aligned}
(M_C^{(1)}, M_L^{(1)}, M_R^{(1)}) &= (0, +3, -3), \\
(M_C^{(2)}, M_L^{(2)}, M_R^{(2)}) &= (0, -1, 0), \\
(M_C^{(3)}, M_L^{(3)}, M_R^{(3)}) &= (0, 0, +1),
\end{aligned}
$$

$\rightarrow$ Three generations of quarks and leptons and six generations of Higgs

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→ Three generations of quarks and leptons and six generations of Higgs

D-flat condition: $$\frac{1}{\mathcal{A}^{(1)}} M_a^{(1)} + \frac{1}{\mathcal{A}^{(2)}} M_a^{(2)} + \frac{1}{\mathcal{A}^{(3)}} M_a^{(3)} = 0$$

$$\Leftrightarrow \quad \mathcal{A}^{(1)}/\mathcal{A}^{(2)} = \mathcal{A}^{(1)}/\mathcal{A}^{(3)} = 3$$

Matter zero-modes on T^6

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

Zero-modes in ϕ_i

$$\phi_1^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(1)} & \Xi_{CC'}^{(1)} & 0 & \Xi_{CR'}^{(1)} & \Xi_{CR''}^{(1)} \\ \Xi_{C'C}^{(1)} & \Omega_{C'}^{(1)} & 0 & \Xi_{C'R'}^{(1)} & \Xi_{C'R''}^{(1)} \\ \hline \Xi_{LC}^{(1)} & \Xi_{LC'}^{(1)} & \Omega_L^{(1)} & H_u^K & H_d^K \\ \hline 0 & 0 & 0 & \Omega_{R'}^{(1)} & \Xi_{R'R''}^{(1)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(1)} & \Omega_{R''}^{(1)} \end{array}\right)$$

$$\phi_2^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(2)} & \Xi_{CC'}^{(2)} & Q^I & 0 & 0 \\ \Xi_{C'C}^{(2)} & \Omega_{C'}^{(2)} & L^I & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(2)} & 0 & 0 \\ \hline 0 & 0 & 0 & \Omega_{R'}^{(2)} & \Xi_{R'R''}^{(2)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(2)} & \Omega_{R''}^{(2)} \end{array}\right)$$

$$\phi_3^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(3)} & \Xi_{CC'}^{(3)} & 0 & 0 & 0 \\ \Xi_{C'C}^{(3)} & \Omega_{C'}^{(3)} & 0 & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(3)} & 0 & 0 \\ \hline U^J & N^J & 0 & \Omega_{R'}^{(3)} & \Xi_{R'R''}^{(3)} \\ D^J & E^J & 0 & \Xi_{R''R'}^{(3)} & \Omega_{R''}^{(3)} \end{array}\right)$$

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Zero-modes in ϕ_i

Six generations of Higgs (K = 1,2,…,6)

Three generations of left-handed quarks and leptons (I = 1,2,3)

$$\phi_1^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(1)} & \Xi_{CC'}^{(1)} & 0 & \Xi_{CR'}^{(1)} & \Xi_{CR''}^{(1)} \\ \Xi_{C'C}^{(1)} & \Omega_{C'}^{(1)} & 0 & \Xi_{C'R'}^{(1)} & \Xi_{C'R''}^{(1)} \\ \hline \Xi_{LC}^{(1)} & \Xi_{LC'}^{(1)} & \Omega_L^{(1)} & H_u^K & H_d^K \\ \hline 0 & 0 & 0 & \Omega_{R'}^{(1)} & \Xi_{R'R''}^{(1)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(1)} & \Omega_{R''}^{(1)} \end{array}\right)$$

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Three generations of right-handed quarks and leptons (J = 1,2,3)

Matter zero-modes on T^6/Z_2

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

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$$\phi_2^{\mathcal{I}_{ab}} = \begin{pmatrix} \Omega_C^{(2)} & \Xi_{CC'}^{(2)} & Q^I & 0 & 0 \\ \Xi_{C'C}^{(2)} & \Omega_{C'}^{(2)} & L^I & 0 & 0 \\ 0 & 0 & \Omega_L^{(2)} & 0 & 0 \\ 0 & 0 & 0 & \Omega_{R'}^{(2)} & \Xi_{R'R''}^{(2)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(2)} & \Omega_{R''}^{(2)} \end{pmatrix}$$

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on orbifold T^6/Z_2

Three generations of right-handed quarks and leptons (J = 1,2,3)

$$P = \begin{pmatrix} -\mathbf{1}_4 & & \\ & +\mathbf{1}_2 & \\ & & +\mathbf{1}_2 \end{pmatrix}$$

$$Z_2:\ (z_1, z_2, z_3) \rightarrow (z_1, -z_2, -z_3)$$

Matter zero-modes on T^6/Z_2

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

Zero-modes in ϕ_i on orbifold T^6/Z_2

$$\phi_1^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(1)} & \Xi_{CC'}^{(1)} & 0 & 0 & 0 \\ \Xi_{C'C}^{(1)} & \Omega_{C'}^{(1)} & 0 & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(1)} & H_u^K & H_d^K \\ \hline 0 & 0 & 0 & \Omega_{R'}^{(1)} & \Xi_{R'R''}^{(1)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(1)} & \Omega_{R''}^{(1)} \end{array}\right) \qquad \phi_2^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} 0 & 0 & Q^I & 0 & 0 \\ 0 & 0 & L^I & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{array}\right)$$

$$\phi_3^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ \hline U^J & N^J & 0 & 0 & 0 \\ D^J & E^J & 0 & 0 & 0 \end{array}\right)$$

Overlap integrals of wavefunctions -> 4D Yukawa couplings

Flavor structure on T^6/Z_2

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

	Sample values	Observed	
(m_u, m_c, m_t)	$(3.1 \times 10^{-3}, 1.01, 1.70 \times 10^2)$	$(2.3 \times 10^{-3}, 1.28, 1.74 \times 10^2)$	(GeV)
(m_d, m_s, m_b)	$(2.8 \times 10^{-3}, 1.48 \times 10^{-1}, 6.46)$	$(4.8 \times 10^{-3}, 0.95 \times 10^{-1}, 4.18)$	(GeV)
(m_e, m_μ, m_τ)	$(4.68 \times 10^{-4}, 5.76 \times 10^{-2}, 3.31)$	$(5.11 \times 10^{-4}, 1.06 \times 10^{-1}, 1.78)$	(GeV)
$\lvert V_{\rm CKM}\rvert$	$\begin{pmatrix} 0.98 & 0.21 & 0.0023 \\ 0.21 & 0.98 & 0.041 \\ 0.011 & 0.040 & 1.0 \end{pmatrix}$	$\begin{pmatrix} 0.97 & 0.23 & 0.0035 \\ 0.23 & 0.97 & 0.041 \\ 0.0087 & 0.040 & 1.0 \end{pmatrix}$	

	Sample values	Observed	
$(m_{\nu_1}, m_{\nu_2}, m_{\nu_3})$	$(3.6 \times 10^{-19}, 8.8 \times 10^{-12}, 2.7 \times 10^{-11})$	$< 2 \times 10^{-9}$	(GeV)
$\lvert m^2_{\nu_1} - m^2_{\nu_2}\rvert$	7.67×10^{-23}	7.50×10^{-23}	$(\mathrm{GeV})^2$
$\lvert m^2_{\nu_1} - m^2_{\nu_3}\rvert$	7.12×10^{-22}	2.32×10^{-21}	$(\mathrm{GeV})^2$
$\lvert V_{\rm PMNS}\rvert$	$\begin{pmatrix} 0.85 & 0.46 & 0.25 \\ 0.50 & 0.59 & 0.63 \\ 0.15 & 0.66 & 0.73 \end{pmatrix}$	$\begin{pmatrix} 0.82 & 0.55 & 0.16 \\ 0.51 & 0.58 & 0.64 \\ 0.26 & 0.61 & 0.75 \end{pmatrix}$	

Particle Data Group Collaboration (Beringer, J. et al.), PRD 86 (2012) 010001

A semi-realistic pattern from non-hierarchical paramters

Matter zero-modes on T^6/Z_2

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Zero-modes in ϕ_i on orbifold T^6/Z_2

$$\phi_1^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(1)} & \Xi_{CC'}^{(1)} & 0 & 0 & 0 \\ \Xi_{C'C}^{(1)} & \Omega_{C'}^{(1)} & 0 & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(1)} & H_u^K & H_d^K \\ \hline 0 & 0 & 0 & \Omega_{R'}^{(1)} & \Xi_{R'R''}^{(1)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(1)} & \Omega_{R''}^{(1)} \end{array}\right) \qquad \phi_2^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} 0 & 0 & Q^I & 0 & 0 \\ 0 & 0 & L^I & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{array}\right)$$

$$\phi_3^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ \hline U^J & N^J & 0 & 0 & 0 \\ D^J & E^J & 0 & 0 & 0 \end{array}\right)$$

Matter zero-modes on T^6/Z_2

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Is it possible to eliminate these exotics by orbifolding further?

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Continuous Wilson-lines are not allowed

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Continuous Wilson-lines are not allowed

Magnetic fluxes $U(8) \rightarrow U(3)_C \times U(1)_l \times U(2)_L \times U(1)_r \times U(1)_{r'}$

$$M^{(i)} = \begin{pmatrix} M_C^{(i)} \times \mathbf{1}_3 & 0 & 0 & 0 & 0 \\ 0 & M_\ell^{(i)} & 0 & 0 & 0 \\ 0 & 0 & M_L^{(i)} \times \mathbf{1}_2 & 0 & 0 \\ 0 & 0 & 0 & M_r^{(i)} & 0 \\ 0 & 0 & 0 & 0 & M_{r'}^{(i)} \end{pmatrix}$$

$i = 1,2,3$

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Continuous Wilson-lines are not allowed

Magnetic fluxes $U(8) \rightarrow U(3)_C \times U(1)_l \times U(2)_L \times U(1)_r \times U(1)_{r'}$

$$M^{(i)} = \begin{pmatrix} M_C^{(i)} \times \mathbf{1}_3 & 0 & 0 & 0 & 0 \\ 0 & M_\ell^{(i)} & 0 & 0 & 0 \\ 0 & 0 & M_L^{(i)} \times \mathbf{1}_2 & 0 & 0 \\ 0 & 0 & 0 & M_r^{(i)} & 0 \\ 0 & 0 & 0 & 0 & M_{r'}^{(i)} \end{pmatrix}$$

$i = 1,2,3$

D-flat condition: $$\frac{1}{\mathcal{A}^{(1)}} M_a^{(1)} + \frac{1}{\mathcal{A}^{(2)}} M_a^{(2)} + \frac{1}{\mathcal{A}^{(3)}} M_a^{(3)} = 0$$

Look for non-degenerate five flux parameters yielding
three generations of quarks/leptons and hopefully no exotic

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Orbifold projections

$$\begin{aligned} Z_2 &: (z_1, z_2, z_3) \to (-z_1, -z_2, z_3) \\ Z_2' &: (z_1, z_2, z_3) \to (z_1, -z_2, -z_3) \end{aligned}$$

$$P = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \qquad P' = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}$$

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Zero-modes in ϕ_i on $T^6/(Z_2 \times Z_2')$

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & H_u & H_d \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & S & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & 0 & Q & 0 & 0 \\ 0 & 0 & L & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ U & N & 0 & 0 & 0 \\ D & E & 0 & 0 & 0 \end{pmatrix}$$

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

M	0	1	2	3	4	5	6	7	8	9	10
even	1	1	2	2	3	3	4	4	5	5	6
odd	0	0	0	1	1	2	2	3	3	4	4

Zero-modes in ϕ_i on $T^6/(Z_2 \times Z_2')$

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & H_u & H_d \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & S & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & 0 & Q & 0 & 0 \\ 0 & 0 & L & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ U & N & 0 & 0 & 0 \\ D & E & 0 & 0 & 0 \end{pmatrix}$$

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Zero-modes in ϕ_i on $T^6/(Z_2 \times Z_2')$

Three generations of quarks and leptons and five generations of Higgs

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & H_u & H_d \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & S & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & 0 & Q & 0 & 0 \\ 0 & 0 & L & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ U & N & 0 & 0 & 0 \\ D & E & 0 & 0 & 0 \end{pmatrix}$$

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Zero-modes in ϕ_i on $T^6/(Z_2 \times Z_2')$

Three generations of quarks and leptons and five generations of Higgs

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & H_u & H_d \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & S & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & 0 & Q & 0 & 0 \\ 0 & 0 & L & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ U & N & 0 & 0 & 0 \\ D & E & 0 & 0 & 0 \end{pmatrix}$$

Exotic mode S

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Three generations of quarks and leptons and five generations of Higgs

Zero-modes in ϕ_i on $T^6/(Z_2 \times Z_2')$

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & H_u & H_d \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & S & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & 0 & Q & 0 & 0 \\ 0 & 0 & L & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ U & N & 0 & 0 & 0 \\ D & E & 0 & 0 & 0 \end{pmatrix}$$

Exotic mode S can be eliminated by $U(1)_{r'}$ twist

T. H. Abe, Y. Fujimoto, T. Kobayashi, T. Miura, K. Nishiwaki & M. Sakamoto, JHEP 1401 (2014) 065

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Zero-modes in ϕ_i on $T^6/(Z_2 \times Z_2')$

Three generations of quarks and leptons and five generations of Higgs

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & H_u & H_d \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & S & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & 0 & Q & 0 & 0 \\ 0 & 0 & L & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ U & N & 0 & 0 & 0 \\ D & E & 0 & 0 & 0 \end{pmatrix}$$

Exotic mode S can be eliminated by $U(1)_{r'}$ twist <-> Vortex configuration?

W. Buchmuller, M. Dierigl, F. Ruehle & J. Schweizer, PRD 92 (2015) 105031

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

D-flat condition: $\frac{1}{\mathcal{A}^{(1)}}M^{(1)} + \frac{1}{\mathcal{A}^{(2)}}M^{(2)} + \frac{1}{\mathcal{A}^{(3)}}M^{(3)} \neq 0$

can not be satisfied by fluxes themselves

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

D-flat condition: $\frac{1}{\mathcal{A}^{(1)}} M^{(1)} + \frac{1}{\mathcal{A}^{(2)}} M^{(2)} + \frac{1}{\mathcal{A}^{(3)}} M^{(3)} \neq 0$

can not be satisfied by fluxes themselves

⟷ Plenary talks by
Professors W. Buchmuller and E. Dudas

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

D-flat condition: $\frac{1}{\mathcal{A}^{(1)}} M^{(1)} + \frac{1}{\mathcal{A}^{(2)}} M^{(2)} + \frac{1}{\mathcal{A}^{(3)}} M^{(3)} + X = 0$

$$X = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & qx & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -qx & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \qquad x = \sum_i \langle \tilde{\nu}_i \rangle^2$$

$$q = \pm 1$$

10D $U(8)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

Flux ansatz

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -8 & 0 \\ 0 & 0 & 0 & 0 & -5 \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

D-flat condition: $\frac{1}{\mathcal{A}^{(1)}} M^{(1)} + \frac{1}{\mathcal{A}^{(2)}} M^{(2)} + \frac{1}{\mathcal{A}^{(3)}} M^{(3)} + X = 0$

$$X = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & qx & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -qx & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$x = \sum_i \langle \tilde{\nu}_i \rangle^2$

$q = \pm 1$

$$q = x = +1$$
$$\mathcal{A}^{(1)}/\mathcal{A}^{(2)} = 4$$
$$\mathcal{A}^{(1)}/\mathcal{A}^{(3)} = 9$$

in the unit of $1/\sqrt{\mathcal{A}^{(1)}}$

Flavor structure on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita, Y. Tatsuta & H. A., PRD 95 (2017) 015005

	Sample values	Observed
$(m_u/m_t, m_c/m_t)$	$(6.6 \times 10^{-5}, 6.8 \times 10^{-2})$	$(1.3 \times 10^{-5}, 7.4 \times 10^{-3})$
$(m_d/m_b, m_s/m_b)$	$(2.0 \times 10^{-4}, 3.5 \times 10^{-2})$	$(1.1 \times 10^{-3}, 2.3 \times 10^{-2})$
$(m_e/m_\tau, m_\mu/m_\tau)$	$(1.7 \times 10^{-3}, 1.6 \times 10^{-2})$	$(2.9 \times 10^{-4}, 6.0 \times 10^{-2})$
$\lvert V_{\mathrm{CKM}} \rvert$	$\begin{pmatrix} 0.97 & 0.24 & 0.030 \\ 0.23 & 0.95 & 0.22 \\ 0.081 & 0.20 & 0.98 \end{pmatrix}$	$\begin{pmatrix} 0.97 & 0.23 & 0.0035 \\ 0.23 & 0.97 & 0.041 \\ 0.0087 & 0.040 & 1.0 \end{pmatrix}$
$\lvert V_{\mathrm{PMNS}} \rvert$	$\begin{pmatrix} 0.91 & 0.37 & 0.13 \\ 0.32 & 0.90 & 0.29 \\ 0.23 & 0.23 & 0.95 \end{pmatrix}$	$\begin{pmatrix} 0.82 & 0.55 & 0.16 \\ 0.51 & 0.58 & 0.64 \\ 0.26 & 0.61 & 0.75 \end{pmatrix}$

Particle Data Group Collaboration (Beringer, J. et al.)
Phys.Rev. D86 (2012) 010001

A semi-realistic pattern from non-hierarchical paramters

PHENOMENOLOGICAL ASPECTS

DSB MODELS (HIDDEN SECTOR)

Hidden sector models

- Magnetized SYM in higher-dim.

  → 4D chiral gauge theories with flavors

  will be applied to

  not only the visible (SM) sector

  but also the hidden (DSB or moduli stab.) sectors

10D $U(N)$ SYM model on T^6

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \to U(N_C) \times U(N_X) \times U(N_Y)$

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in ϕ_i

$$\phi_1 = \begin{pmatrix} \Xi_1 & 0 & 0 \\ \tilde{Q}' & \Xi_1' & 0 \\ Q & 0 & \Xi_1'' \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} \Xi_2 & \tilde{Q} & 0 \\ 0 & \Xi_2' & 0 \\ 0 & S' & \Xi_2'' \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} \Xi_3 & 0 & Q' \\ 0 & \Xi_3' & S \\ 0 & 0 & \Xi_3'' \end{pmatrix}$$

10D $U(N)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \to U(N_C) \times U(N_X) \times U(N_Y)$

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in ϕ_i

$$\phi_1 = \begin{pmatrix} \times & 0 & 0 \\ \times & \times & 0 \\ Q & 0 & \times \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} \times & \tilde{Q} & 0 \\ 0 & \times & 0 \\ 0 & \times & \times \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} \times & 0 & \times \\ 0 & \times & S \\ 0 & 0 & \times \end{pmatrix}$$

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

$$P = \begin{pmatrix} +1 & & \\ & -1 & \\ & & +1 \end{pmatrix} \quad P' = \begin{pmatrix} +1 & & \\ & -1 & \\ & & -1 \end{pmatrix}$$

10D $U(N)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \to U(N_C) \times U(N_X) \times U(N_Y)$

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in ϕ_i

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & 0 & 0 \end{pmatrix}$$

10D $U(N)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \rightarrow U(N_C) \times U(N_X) \times U(N_Y)$

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in ϕ_i

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & 0 & 0 \end{pmatrix}$$

Superpotential

$$W = SQ\tilde{Q}$$

10D $U(N)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \to U(N_C) \times U(N_X) \times U(N_Y)$

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in ϕ_i $\to$ $U(N_C)$ SYM with N_F flavors $Q, \tilde{Q}$

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & 0 & 0 \end{pmatrix}$$

Superpotential

$$W = SQ\tilde{Q}$$

10D $U(N)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \to U(N_C) \times U(N_X) \times U(N_Y)$

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in ϕ_i $\to$ $U(N_C)$ SYM with N_F flavors $Q, \tilde{Q}$

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & 0 & 0 \end{pmatrix}$$

Superpotential for $N_C > N_F$

$$W = SQ\tilde{Q} + C_{N_C,N_F} \left(\frac{\Lambda^{3N_C - N_F}}{\det Q\tilde{Q}} \right)^{1/(N_C - N_F)}$$

→ Dynamical SUSY breaking (DSB)

I. Affleck, M. Dine and N. Seiberg, NPB 241 (1984) 493-534, PLB 137 (1984) 187

10D $U(N)$ SYM model on $T^6/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \to U(N_C) \times U(N_X) \times U(N_Y)$

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Zero-modes in ϕ_i $\to$ $U(N_C)$ SYM with N_F flavors $Q, \tilde{Q}$

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & S' & 0 \end{pmatrix}$$

Superpotential for $N_C > N_F$

$$W = SQ\tilde{Q} + C_{N_C,N_F}\left(\frac{\Lambda^{3N_C-N_F}}{\det Q\tilde{Q}}\right)^{1/(N_C-N_F)}$$

→ Dynamical SUSY breaking (DSB)

I. Affleck, M. Dine and N. Seiberg, NPB 241 (1984) 493-534, PLB 137 (1984) 187

SUMMARY

SYM on magnetized tori

- Magnetic fluxes would determine almost everything :

  Gauge syms, chirality, # of gens, hierarchies, DSB, …

  Phenomenological aspects are quite interesting

- Not God but (static) dynamics could yield the hierarchy of elements

Some prospects

- $U(8+N) \rightarrow U(8)_{\text{visible}} \times U(N)_{\text{hidden}}$
  - Viable flux/orbifold configurations?
  - Possible messengers?
- Moduli stabilization sector?
- String realization?