SUSY2015 @ Lake Tahoe, 25 August 2015

Aspects of dynamical supersymmetry breaking and its mediation on magnetized tori

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Work in progress

Contents

Contents

SYM on magnetized tori

Basic features *D. Cremades, L. E. Ibanez & F. Marchesano '04*

- Degenerated chiral zero-modes appear
- The degeneracy is determined by the number of fluxes
- The zero-mode wavefunctions are analytically obtained

Applications

- Phenomenological models are proposed

e.g. *T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H.A. '13*

Further aspects

- D-brane interpretations and dual descriptions

Field contents in 10D SYM on T^6

10D vector : $A_M = (A_\mu, A_m) = (A_\mu, A_i)$ i = 1,2,3

$$A_i \equiv -\frac{1}{\mathrm{Im}\,\tau_i}(\tau_i^* A_{2+2i} - A_{3+2i}), \qquad \bar{A}_{\bar{i}} \equiv (A_i)^\dagger$$

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

Field contents in 10D SYM on T^6

10D vector : $A_M = (A_\mu, A_m) = (A_\mu, A_i)$ $i = 1,2,3$

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

$\mathcal{N} = 1$ supermultiplets (superfields):

$$\boldsymbol{V} = \{A_\mu, \lambda_0\}, \qquad \phi_i = \{A_i, \lambda_i\}$$

U(N) adjoints

Notations in *T. Kobayashi, H. Ohki, K. Sumita & H.A. '12*

Magnetic flux background

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

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

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

Magnetic fluxes

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

Wilson-lines

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Magnetic fluxes

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Wilson-lines

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

Notations in *T. Kobayashi, H. Ohki, K. Sumita & H.A. '12*

Contents

10D $U(8)$ SYM model

T. Kobayashi, H. Ohki, K. Sumita & H.A. '12

Magnetic fluxes

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

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

$r = 1,2,3$

10D $U(8)$ SYM model

T. Kobayashi, H. Ohki, K. Sumita & H.A. '12

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

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r = 1,2,3

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

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

10D $U(8)$ SYM model

T. Kobayashi, H. Ohki, K. Sumita & H.A. '12

Flux ansatz

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

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

SUSY conditions

$$\begin{aligned}h^{\bar{i}j}\left(\bar{\partial}_{\bar{i}}\langle A_j\rangle + \partial_j\langle \bar{A}_{\bar{i}}\rangle\right) &= 0,\\ \epsilon^{\mathrm{jkl}} e_{\mathrm{k}}{}^{k} e_{\mathrm{l}}{}^{l} \partial_k \langle A_l\rangle &= 0,\end{aligned}$$

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

Matter zero-modes on T^6

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H.A. ’13

Zero-modes in ϕ_i

$$\phi_1^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(1)} & \Xi_{CC'}^{(1)} & 0 & \Xi_{CR'}^{(1)} & \Xi_{CR''}^{(1)} \\ \Xi_{C'C}^{(1)} & \Omega_{C'}^{(1)} & 0 & \Xi_{C'R'}^{(1)} & \Xi_{C'R''}^{(1)} \\ \hline \Xi_{LC}^{(1)} & \Xi_{LC'}^{(1)} & \Omega_L^{(1)} & H_u^K & H_d^K \\ \hline 0 & 0 & 0 & \Omega_{R'}^{(1)} & \Xi_{R'R''}^{(1)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(1)} & \Omega_{R''}^{(1)} \end{array}\right) \qquad \phi_2^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(2)} & \Xi_{CC'}^{(2)} & Q^I & 0 & 0 \\ \Xi_{C'C}^{(2)} & \Omega_{C'}^{(2)} & L^I & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(2)} & 0 & 0 \\ \hline 0 & 0 & 0 & \Omega_{R'}^{(2)} & \Xi_{R'R''}^{(2)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(2)} & \Omega_{R''}^{(2)} \end{array}\right)$$

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

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Matter zero-modes on T^6

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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)

$$\phi_1^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(1)} & \Xi_{CC'}^{(1)} & 0 & \Xi_{CR'}^{(1)} & \Xi_{CR''}^{(1)} \\ \Xi_{C'C}^{(1)} & \Omega_{C'}^{(1)} & 0 & \Xi_{C'R'}^{(1)} & \Xi_{C'R''}^{(1)} \\ \hline \Xi_{LC}^{(1)} & \Xi_{LC'}^{(1)} & \Omega_L^{(1)} & \boxed{H_u^K} & \boxed{H_d^K} \\ \hline 0 & 0 & 0 & \Omega_{R'}^{(1)} & \Xi_{R'R''}^{(1)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(1)} & \Omega_{R''}^{(1)} \end{array}\right) \qquad \phi_2^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(2)} & \Xi_{CC'}^{(2)} & \boxed{Q^I} & 0 & 0 \\ \Xi_{C'C}^{(2)} & \Omega_{C'}^{(2)} & \boxed{L^I} & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(2)} & 0 & 0 \\ \hline 0 & 0 & 0 & \Omega_{R'}^{(2)} & \Xi_{R'R''}^{(2)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(2)} & \Omega_{R''}^{(2)} \end{array}\right)$$

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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. '13

Zero-modes in ϕ_i

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

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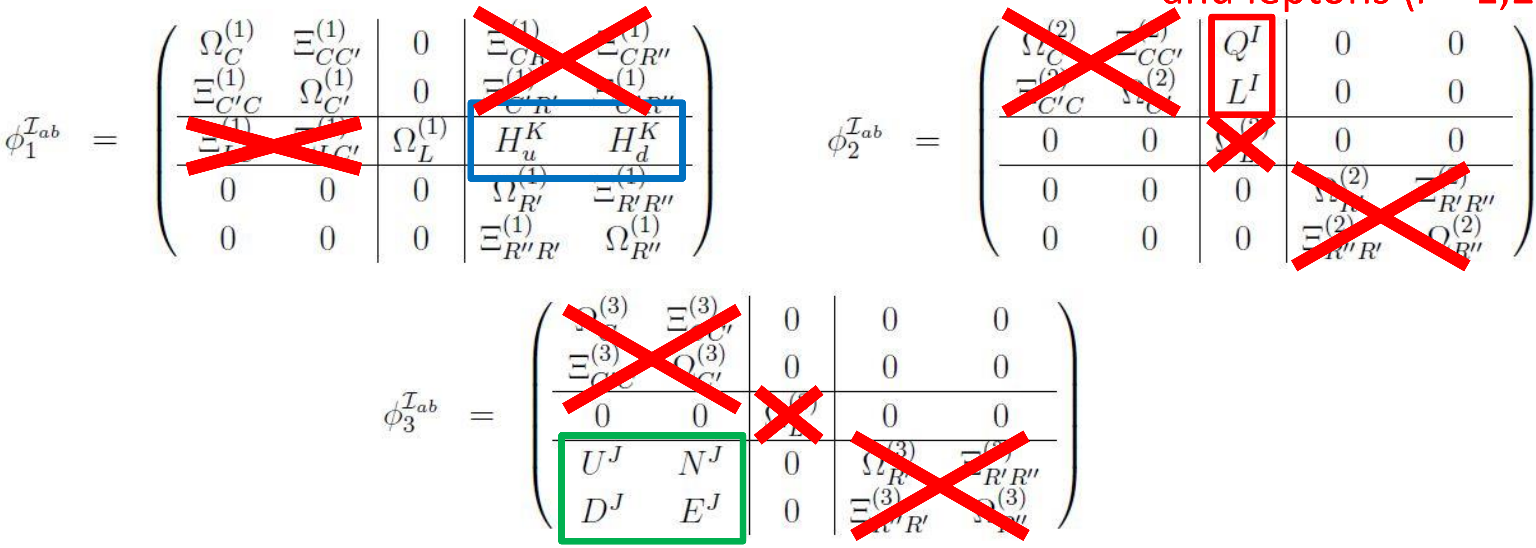

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Three generations of right-handed quarks and leptons (J = 1,2,3)

on orbifold T^6/Z_2

Matter zero-modes on T^6/Z_2

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H.A. ’12

T^6/Z_2 orbifold

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

$$\begin{aligned}
V(x, y_m, -y_n) &= +PV(x, y_m, +y_n)P^{-1}, \\
\phi_1(x, y_m, -y_n) &= +P\phi_1(x, y_m, +y_n)P^{-1}, \\
\phi_2(x, y_m, -y_n) &= -P\phi_2(x, y_m, +y_n)P^{-1}, \\
\phi_3(x, y_m, -y_n) &= -P\phi_3(x, y_m, +y_n)P^{-1},
\end{aligned}$$

$^\forall m = 4, 5$ and $^\forall n = 6, 7, 8, 9$

does not break SUSY
preserved by the flux

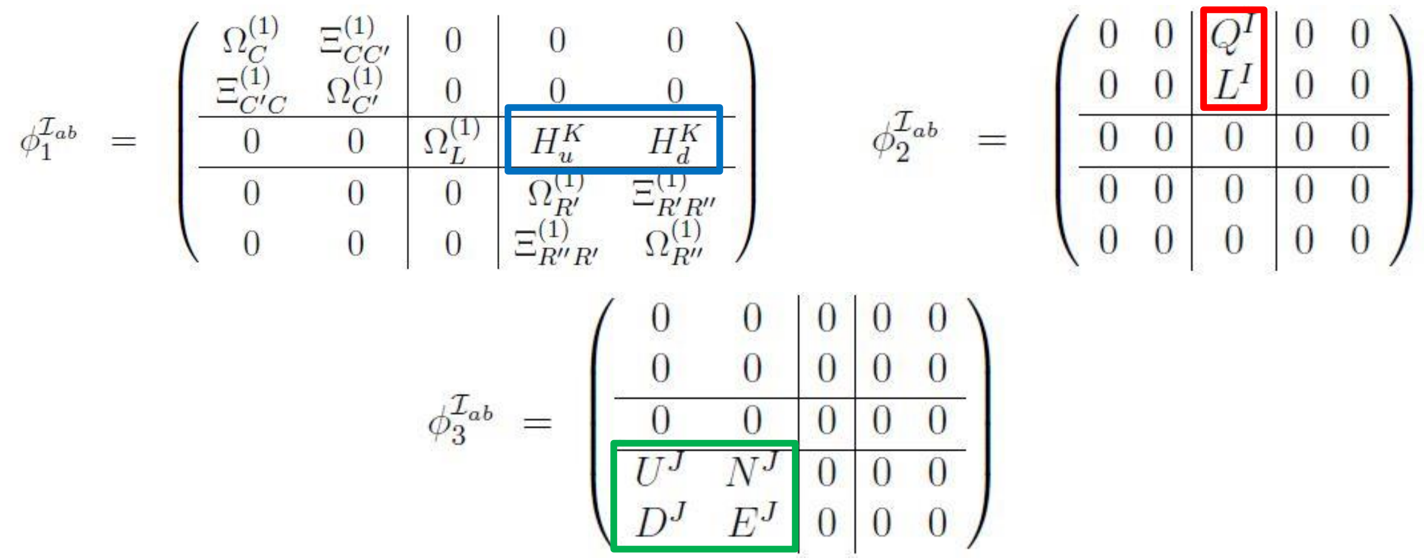
$$P_{ab} = \begin{pmatrix} -\mathbf{1}_4 & 0 & 0 \\ 0 & +\mathbf{1}_2 & 0 \\ 0 & 0 & +\mathbf{1}_2 \end{pmatrix}$$

projects out many exotic modes
without affecting MSSM contents

Matter zero-modes on T^6/Z_2

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H.A. ’13

Zero-modes in ϕ_i on orbifold T^6/Z_2



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

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

Matter zero-modes on T^6/Z_2

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Zero-modes in ϕ_i on orbifold T^6/Z_2

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

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

We assume the remaining exotics (as well as extra U(1) gauge bosons) become massive due to some other effects

Phenomenological aspects

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H.A. ’13

Higgs VEVs

$$v_u = v \sin\beta, \; v_d = v \cos\beta \text{ and } v = 174 \text{ GeV}$$

$$\begin{aligned} \tan\beta &= 25 \\ \langle H_u^K \rangle &= (0.0, 0.0, 2.7, 1.3, 0.0, 0.0)\, v_u \times \mathcal{N}_{H_u}, \\ \langle H_d^K \rangle &= (0.0, 0.1, 5.8, 5.8, 0.0, 0.1)\, v_d \times \mathcal{N}_{H_d}, \end{aligned}$$

$$\begin{aligned} \mathcal{N}_{H_u} &= 1/\sqrt{2.7^2 + 1.3^2} \\ \mathcal{N}_{H_d} &= 1/\sqrt{2(0.1^2 + 5.8^2)} \end{aligned}$$

Moduli VEVs and Wilson-lines

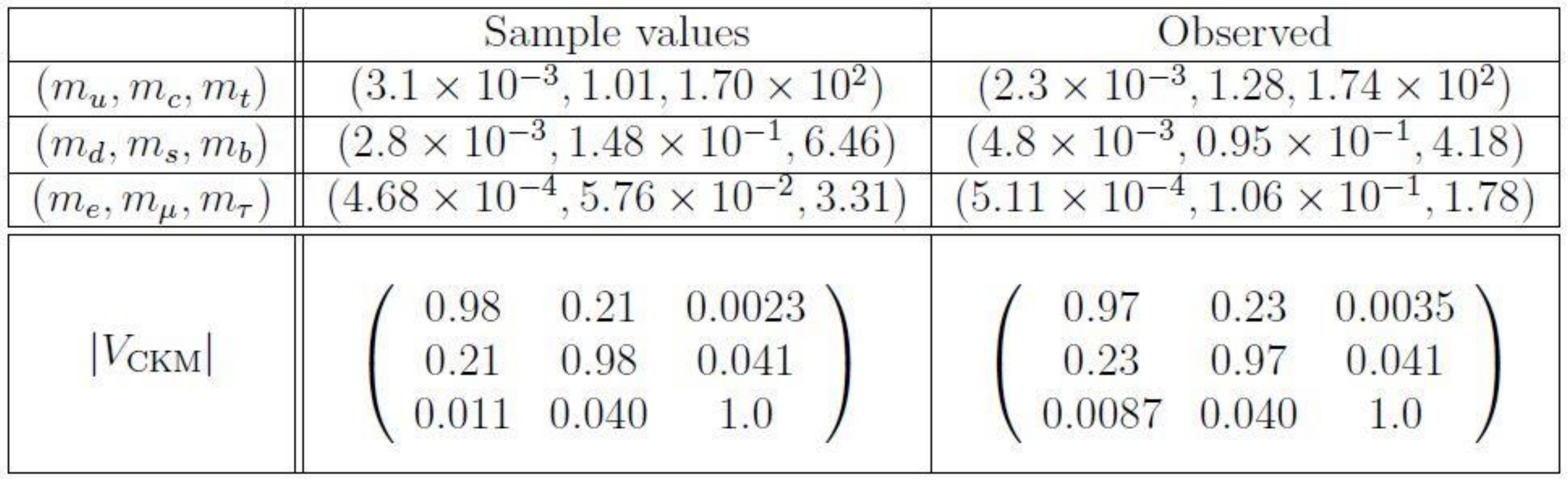
$$\pi s = 6.0, \rightarrow \; 4\pi/{g_a}^2 = 24 \quad \text{at} \quad M_{\mathrm{GUT}} = 2.0 \times 10^{16} \text{ GeV}$$

$$\begin{aligned} (t_1, t_2, t_3) &= (3.0, 1.0, 1.0) \times 2.8 \times 10^{-8}, \\ (\tau_1, \tau_2, \tau_3) &= (4.1i, 1.0i, 1.0i), \\ (\zeta_Q, \zeta_U, \zeta_D, \zeta_L, \zeta_N, \zeta_E) &= (0.6i + \eta, 0.1i + \eta, 0 + \eta, 1.5i + \eta, 1.4i + \eta) \end{aligned}$$

Phenomenological aspects

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H.A. ’13

Semi-realistic quark masses/mixings are obtained



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

Lepton masses/mixings, moduli-mediated sparticle spectra, …

are also studied assuming a SUSY breaking sector somewhere

Phenomenological aspects

10D $U(N)$ SYM on magnetized tori simply explain important phenomenological features at low energies

- Product gauge groups
- Chiral generations
- Observed masses/mixings

It is interesting to study more…

Here we consider a dynamical SUSY breaking (DSB) in this framework

Contents

DSB on local a minimum

K. A. Intriligator, N. Seiberg & D. Shih ’06

4D $SU(N_h)$ SYM with N_f massive ‘quarks’ $(q,\tilde{q})$

$$W = mq\tilde{q}$$

DSB on local a minimum

K. A. Intriligator, N. Seiberg & D. Shih '06

4D $SU(N_h)$ SYM with N_f massive 'quarks' $(q, \tilde{q})$

$$W = mq\tilde{q}$$

Dual $SU(N_f - N_h)$ SYM for $N_h < N_f < 3N_h/2$

$$W_{\mathrm{eff}} \sim \varphi\Phi\tilde{\varphi} - \mu^2\Phi \qquad \mu^2 \sim \sqrt{m\Lambda_h}$$

Φ : $N_f \times N_f$ matrix

φ : $N_h \times N_f$ matrix

$\tilde{\varphi}$: $N_f \times N_h$ matrix

DSB on local a minimum

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$$W = mq\tilde{q}$$

Dual $SU(N_f - N_h)$ SYM for $N_h < N_f < 3N_h/2$

$$W_{\mathrm{eff}} \sim \varphi\Phi\tilde{\varphi} - \mu^2\Phi \qquad \mu^2 \sim \sqrt{m\Lambda_h}$$

$$F^{\Phi} \sim \tilde{\varphi}\varphi - \mu^2\mathbf{1} \neq 0$$

$$\uparrow \qquad \qquad \uparrow$$

Rank: $N_f - Nh$ $\quad N_f$

Contents

$U(8+N_1+N_2)$ model

K. Sumita, T. Watanabe & H.A. in progress

The Abelian flux $\rightarrow U(4)_C \times U(2)_L \times U(2)_R \times U(N_1) \times U(N_2)$

r = 1,2,3

$$F_{2+2r,3+2r} = 2\pi \begin{pmatrix} M_C^{(r)}\mathbf{1}_4 & & & & \\ & M_L^{(r)}\mathbf{1}_2 & & & \\ & & M_R^{(r)}\mathbf{1}_2 & & \\ & & & M_1^{(r)}\mathbf{1}_{N_1} & \\ & & & & M_2^{(r)}\mathbf{1}_{N_2} \end{pmatrix}$$

$U(8+N_1+N_2)$ model

K. Sumita, T. Watanabe & H.A. in progress

The Abelian flux $\rightarrow U(4)_C \times U(2)_L \times U(2)_R \times U(N_1) \times U(N_2)$

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Fluxes yielding the visible (MSSM) sector

$$\left(M_C^{(1)}, M_L^{(1)}, M_R^{(1)}\right) = (0, +3, -3)$$
$$\left(M_C^{(1)}, M_L^{(1)}, M_R^{(1)}\right) = (0, -1, 0)$$
$$\left(M_C^{(1)}, M_L^{(1)}, M_R^{(1)}\right) = (0,0, +1)$$

→ Three generations of quarks and leptons

$U(8+N_1+N_2)$ model

K. Sumita, T. Watanabe & H.A. in progress

The Abelian flux → $U(4)_C \times U(2)_L \times U(2)_R \times U(N_1) \times U(N_2)$

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Fluxes yielding the hidden (DSB) sector?

$$\left(M_C^{(1)}, M_L^{(1)}, M_R^{(1)}, M_1^{(1)}, M_2^{(1)}\right) = (0, +3, -3, ?, ?)$$
$$\left(M_C^{(2)}, M_L^{(2)}, M_R^{(2)}, M_1^{(2)}, M_2^{(2)}\right) = (0, -1, 0, ?, ?)$$
$$\left(M_C^{(3)}, M_L^{(3)}, M_R^{(3)}, M_1^{(3)}, M_2^{(3)}\right) = (0,0, +1, ?, ?)$$

→ $SU(N_h)$ SYM
with N_f ‘quarks’ $(q, \tilde{q})$

$U(8+N_1+N_2)$ model

K. Sumita, T. Watanabe & H.A. in progress

Matter contents

$$U(4)_C \times U(2)_L \times U(2)_R \times U(N_1) \times U(N_2)$$

i = 1,2,3

$$\phi_i = \left(\begin{array}{c|c:c} \text{visible} & \psi_1 & \psi_2 \\ \hline \tilde{\psi}_1 & \Omega_1 & q \\ \hdashline \tilde{\psi}_2 & \tilde{q} & \Omega_2 \end{array}\right)$$

$U(8+N_1+N_2)$ model

K. Sumita, T. Watanabe & H.A. in progress

Matter contents

$$\begin{array}{cccc} U(4)_C \times U(2)_L \times U(2)_R \times & U(N_1) & \times & U(N_2) \\ & \wr & & \cup \\ & SU(N_f) & \times & SU(N_h) \end{array}$$

i = 1,2,3

$$\phi_i = \left(\begin{array}{c|c:c} \text{visible} & \psi_1 & \psi_2 \\ \hline \tilde{\psi}_1 & \Omega_1 & q \\ \hdashline \tilde{\psi}_2 & \tilde{q} & \Omega_2 \end{array}\right)$$

$q, \tilde{q}$: $SU(N_h)$ quarks

$U(8+N_1+N_2)$ model

K. Sumita, T. Watanabe & H.A. in progress

Matter contents

$$\begin{array}{ccc} U(4)_C \times U(2)_L \times U(2)_R \times & U(N_1) & \times\, U(N_2) \\ & \wr & \cup \\ & SU(N_f) & \times\, SU(N_h) \end{array}$$

i = 1,2,3

$$\phi_i = \left(\begin{array}{c|c:c} \text{visible} & \psi_1 & \cancel{\psi_2} \\ \hline \tilde{\psi}_1 & \Omega_1 & q \\ \hdashline \cancel{\tilde{\psi}_2} & \tilde{q} & \Omega_2 \end{array}\right)$$

$q, \tilde{q}$: $SU(N_h)$ quarks

$U(8+N_1+N_2)$ model

K. Sumita, T. Watanabe & H.A. in progress

Matter contents

$$\begin{array}{ccccccccc} U(4)_C & \times & U(2)_L & \times & U(2)_R & \times & U(N_1) & \times & U(N_2) \\ & & & & & & \wr & & \cup \\ & & & & & & SU(N_f) & \times & SU(N_h) \end{array}$$

i = 1,2,3

$$\phi_i = \left(\begin{array}{c|c:c} \text{visible} & \psi & - \\ \hline \tilde{\psi} & \Omega_1 & q \\ \hdashline - & \tilde{q} & \Omega_2 \end{array} \right)$$

$q, \tilde{q}$: $SU(N_h)$ quarks

ISS-type SUSY breaking

K. Sumita, T. Watanabe & H.A. in progress

Assume $\Omega_{1,2} = \zeta_{1,2} + \widetilde{\Omega}_{1,2}$with heavy masses $M_{1,2}$ and integrate them out

$$W \sim \ (\zeta_1 - \zeta_2)\,\tilde{q}q + (\zeta_1 - \zeta_{\rm vis})\,\tilde{\psi}\psi$$
$$+\left(\frac{1}{M_1} - \frac{1}{M_2}\right) q\tilde{q}\tilde{q}q + \frac{1}{M_1} q\tilde{q}\tilde{\psi}\psi + \cdots$$

H. Murayama & Y. Nomura '07

ISS-type SUSY breaking

K. Sumita, T. Watanabe & H.A. in progress

If $SU(N_1)$ is weak below the dynamical scale $\Lambda_2 \equiv \Lambda_h$ of $SU(N_2)$

$$W_{\text{eff}} \sim \varphi\Phi\tilde{\varphi} - \mu^2\Phi + M\Phi^2 + W_{\text{mess}}$$

$$\mu^2 \sim (\zeta_1 - \zeta_2)\Lambda_h, \qquad M \sim \left(\frac{1}{M_1} - \frac{1}{M_2}\right)\Lambda_h^2$$

H. Murayama & Y. Nomura '07

ISS-type SUSY breaking

K. Sumita, T. Watanabe & H.A. in progress

If $SU(N_1)$ is weak below the dynamical scale $\Lambda_2 \equiv \Lambda_h$ of $SU(N_2)$

$$W_{\rm eff} \sim \varphi\Phi\tilde{\varphi} - \mu^2\Phi + M\Phi^2 + W_{\rm mess}$$

$$\mu^2 \sim (\zeta_1 - \zeta_2)\Lambda_h, \qquad M \sim \left(\frac{1}{M_1} - \frac{1}{M_2}\right)\Lambda_h^2$$

On the (metastable) minimum $F^\Phi \sim \mu^2$, $\langle\Phi\rangle \sim 16\pi^2 M$

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ISS-type SUSY breaking

K. Sumita, T. Watanabe & H.A. in progress

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$$\mu^2 \sim (\zeta_1 - \zeta_2)\Lambda_h, \qquad M \sim \left(\frac{1}{M_1} - \frac{1}{M_2}\right)\Lambda_h^2$$

On the (metastable) minimum $F^\Phi \sim \mu^2, \ \langle\Phi\rangle \sim 16\pi^2 M$

$M_{\mathrm{SB}} \sim \sqrt{F^\Phi}$: SUSY breaking scale

$M_\psi \sim \zeta_1 - \zeta_{\mathrm{vis}} + \frac{\Lambda_h}{M_1}\langle\Phi\rangle$: Messenger mass scale

H. Murayama & Y. Nomura '07

ISS-type SUSY breaking

K. Sumita, T. Watanabe & H.A. in progress

Matter contents

$$U(4)_C \times U(2)_L \times U(2)_R \times \begin{array}{ccc} U(N_1) & \times & U(N_2) \\ \wr & & \cup \\ SU(N_f) & \times & SU(N_h) \end{array}$$

i = 1,2,3

$$\phi_i = \left(\begin{array}{c|c:c} \text{visible} & \psi & - \\ \hline \tilde{\psi} & \zeta_1 & q \\ \hdashline - & \tilde{q} & \zeta_2 \end{array}\right)$$

$q, \tilde{q}$: $SU(N_h)$ quarks

$\psi, \tilde{\psi}$: Messengers

Flux configurations on T^6

K. Sumita, T. Watanabe & H.A. in progress

SUSY fluxes yielding no chiral modes in DSB/messenger sectors

Model	$(M_1^{(1)}, M_2^{(1)})$	$(M_1^{(2)}, M_2^{(2)})$	$(M_1^{(3)}, M_2^{(3)})$
1	$(0,0)$	$(0,0)$	$(0,0)$
2	$(3,3)$	$(0,0)$	$(-1,-1)$
3	$(-3,-3)$	$(1,1)$	$(0,0)$
4	$(0,3)$	$(0,0)$	$(0,-1)$
5	$(3,0)$	$(0,0)$	$(-1,0)$
6	$(0,-3)$	$(0,1)$	$(0,0)$
7	$(-3,0)$	$(1,0)$	$(0,0)$

Degeneracies on T^6

K. Sumita, T. Watanabe & H.A. in progress

Model 1

$(M_1^{(1)}, M_2^{(1)})$	$(0,0)$
$(M_1^{(2)}, M_2^{(2)})$	$(0,0)$
$(M_1^{(3)}, M_2^{(3)})$	$(0,0)$

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**1**	1
$U(2)_L$				**3**	3
$U(2)_R$				**0**	0
$U(N_1)$	**1**	**0**	**3**	1	**1**
$U(N_2)$	1	0	3	**1**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**1**	1
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**1**	**3**	**0**	1	**1**
$U(N_2)$	1	3	0	**1**	1

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**1**	1
$U(2)_L$				**0**	0
$U(2)_R$				**3**	3
$U(N_1)$	**1**	**0**	**0**	1	**1**
$U(N_2)$	1	0	0	**1**	1

Degeneracies on T^6

K. Sumita, T. Watanabe & H.A. in progress

Model 2

$(M_1^{(1)}, M_2^{(1)})$	$(3,3)$
$(M_1^{(2)}, M_2^{(2)})$	$(0,0)$
$(M_1^{(3)}, M_2^{(3)})$	$(-1,-1)$

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**3**	**0**	**6**	1	**1**
$U(N_2)$	3	0	6	**1**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**0**	**1**	**0**	1	**1**
$U(N_2)$	0	1	0	**1**	1

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**3**	3
$U(2)_L$				**1**	1
$U(2)_R$				**6**	6
$U(N_1)$	**0**	**0**	**0**	1	**1**
$U(N_2)$	0	0	0	**1**	1

Degeneracies on T^6

K. Sumita, T. Watanabe & H.A. in progress

Model 3

$(M_1^{(1)}, M_2^{(1)})$	$(-3,-3)$
$(M_1^{(2)}, M_2^{(2)})$	$(0,0)$
$(M_1^{(3)}, M_2^{(3)})$	$(1,1)$

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**3**	3
$U(2)_L$				**6**	6
$U(2)_R$				**0**	0
$U(N_1)$	**0**	**0**	**0**	1	**1**
$U(N_2)$	0	0	0	**1**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**3**	**6**	**1**	1	**1**
$U(N_2)$	3	6	1	**1**	1

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**1**	1
$U(N_1)$	**0**	**0**	**0**	1	**1**
$U(N_2)$	0	0	0	**1**	1

Degeneracies on T^6

K. Sumita, T. Watanabe & H.A. in progress

Model 4

$(M_1^{(1)}, M_2^{(1)})$	$(0,3)$
$(M_1^{(2)}, M_2^{(2)})$	$(0,0)$
$(M_1^{(3)}, M_2^{(3)})$	$(0,-1)$

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**1**	0
$U(2)_L$				**3**	0
$U(2)_R$				**0**	0
$U(N_1)$	**1**	**0**	**3**	1	**0**
$U(N_2)$	3	0	12	**3**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**1**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**1**	**3**	**0**	1	**0**
$U(N_2)$	0	1	0	**0**	1

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**1**	3
$U(2)_L$				**0**	1
$U(2)_R$				**3**	12
$U(N_1)$	**1**	**0**	**0**	1	**3**
$U(N_2)$	0	0	0	**0**	1

Degeneracies on T^6

K. Sumita, T. Watanabe & H.A. in progress

Model 5

$(M_1^{(1)}, M_2^{(1)})$	$(3,0)$
$(M_1^{(2)}, M_2^{(2)})$	$(0,0)$
$(M_1^{(3)}, M_2^{(3)})$	$(-1,0)$

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**0**	1
$U(2)_L$				**0**	3
$U(2)_R$				**0**	0
$U(N_1)$	**3**	**0**	**12**	1	**0**
$U(N_2)$	1	0	3	**3**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**0**	1
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**0**	**1**	**0**	1	**0**
$U(N_2)$	1	3	0	**0**	1

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**3**	1
$U(2)_L$				**1**	0
$U(2)_R$				**12**	3
$U(N_1)$	**0**	**0**	**0**	1	**3**
$U(N_2)$	1	0	0	**0**	1

Degeneracies on T^6

K. Sumita, T. Watanabe & H.A. in progress

Model 6

$(M_1^{(1)}, M_2^{(1)})$	$(0, -3)$
$(M_1^{(2)}, M_2^{(2)})$	$(0,1)$
$(M_1^{(3)}, M_2^{(3)})$	$(0,0)$

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**1**	3
$U(2)_L$				**1**	12
$U(2)_R$				**0**	0
$U(N_1)$	**6**	**0**	**3**	1	**3**
$U(N_2)$	0	0	0	**0**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**1**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**1**	**3**	**0**	1	**0**
$U(N_2)$	3	12	1	**3**	1

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**1**	0
$U(2)_L$				**0**	0
$U(2)_R$				**3**	1
$U(N_1)$	**1**	**0**	**0**	1	**0**
$U(N_2)$	0	0	0	**0**	1

Degeneracies on T^6

K. Sumita, T. Watanabe & H.A. in progress

Model 7

$(M_1^{(1)}, M_2^{(1)})$	$(-3{,}0)$
$(M_1^{(2)}, M_2^{(2)})$	$(1{,}0)$
$(M_1^{(3)}, M_2^{(3)})$	$(0{,}0)$

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**3**	1
$U(2)_L$				**12**	3
$U(2)_R$				**0**	0
$U(N_1)$	**0**	**0**	**0**	1	**0**
$U(N_2)$	1	0	3	**3**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**0**	1
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**3**	**12**	**1**	1	**3**
$U(N_2)$	1	3	0	**0**	1

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6			**0**	1
$U(2)_L$				**0**	0
$U(2)_R$				**1**	3
$U(N_1)$	**0**	**0**	**0**	1	**0**
$U(N_2)$	1	0	0	**0**	1

Flux configurations on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

SUSY fluxes parameterized by (x, s, t)

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$

Chiral modes in DSB/messenger sectors are inevitable

Flux configurations on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

SUSY fluxes parameterized by (x, s, t)

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$

Chiral modes in DSB/messenger sectors are inevitable

Model	(x, s, t)	$P^{\pm\mp}$
1	$(0,1,0)$	P^{-+}
2	$(0,-1,0)$	P^{-+}
3	$(0,1,-1)$	P^{-+}
4	$(1,0,0)$	P^{+-}
5	$(-1,0,0)$	P^{-+}
6	$(1,-1,-1)$	P^{+-}
7	$(1,-1,1)$	P^{+-}

Vector-like messengers appear in $SU(N_1)$ sector

Flux configurations on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

SUSY fluxes parameterized by (x, s, t)

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$

Model	(x, s, t)	$P^{\pm\mp}$
1	$(0,1,0)$	P^{-+}
2	$(0,-1,0)$	P^{-+}
3	$(0,1,-1)$	P^{-+}
4	$(1,0,0)$	P^{+-}
5	$(-1,0,0)$	P^{-+}
6	$(1,-1,-1)$	P^{+-}
7	$(1,-1,1)$	P^{+-}

$$\begin{aligned}
V(x, y_m, -y_n) &= +PV(x, y_m, +y_n)P^{-1}, \\
\phi_1(x, y_m, -y_n) &= +P\phi_1(x, y_m, +y_n)P^{-1}, \\
\phi_2(x, y_m, -y_n) &= -P\phi_2(x, y_m, +y_n)P^{-1}, \\
\phi_3(x, y_m, -y_n) &= -P\phi_3(x, y_m, +y_n)P^{-1},
\end{aligned}$$

$${}^{\forall}m = 4, 5 \text{ and } {}^{\forall}n = 6, 7, 8, 9$$

$$P_{ab}^{\pm\mp} = \begin{pmatrix} -1_4 & 0 & 0 & 0 & 0 \\ 0 & +1_2 & 0 & 0 & 0 \\ 0 & 0 & +1_2 & 0 & 0 \\ 0 & 0 & 0 & \pm 1_{N_1} & 0 \\ 0 & 0 & 0 & 0 & \mp 1_{N_2} \end{pmatrix}$$

Degeneracies on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

Model 1

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$
(x, s, t), $P^{\pm\mp}$	$(0,1,0)$, P^{-+}

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	1
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**0**	**0**	**0**	1	**0**
$U(N_2)$	1	0	3	**0**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**1**	**0**	**0**	0	**1**
$U(N_2)$	0	1	0	**0**	0

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**1**	0
$U(2)_L$				**0**	0
$U(2)_R$				**6**	0
$U(N_1)$	**0**	**0**	**0**	0	**0**
$U(N_2)$	0	0	0	**1**	0

Degeneracies on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

Model 2

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$
(x, s, t), $P^{\pm\mp}$	$(0, -1, 0)$, P^{-+}

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	1
$U(2)_L$				**3**	0
$U(2)_R$				**0**	0
$U(N_1)$	**0**	**0**	**0**	1	**0**
$U(N_2)$	1	0	3	**0**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**1**	0
$U(2)_L$				**0**	0
$U(2)_R$				**3**	0
$U(N_1)$	**0**	**0**	**0**	0	**0**
$U(N_2)$	0	3	0	**1**	0

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**1**	**0**	**0**	0	**1**
$U(N_2)$	0	0	0	**0**	0

Degeneracies on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

Model 3

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$
(x, s, t), $P^{\pm\mp}$	$(0,1,-1)$, P^{-+}

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**0**	**0**	**0**	1	**0**
$U(N_2)$	0	0	3	**0**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**1**	**0**	**0**	0	**4**
$U(N_2)$	0	0	0	**0**	0

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**1**	0
$U(2)_L$				**0**	0
$U(2)_R$				**6**	0
$U(N_1)$	**0**	**0**	**0**	0	**0**
$U(N_2)$	0	3	0	**4**	0

Degeneracies on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

Model 4

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$
(x, s, t), $P^{\pm\mp}$	$(1,0,0)$, P^{+-}

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**3**	**0**	**12**	1	**0**
$U(N_2)$	0	0	0	**0**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**0**	**1**	**0**	0	**1**
$U(N_2)$	0	0	0	**1**	0

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	3
$U(2)_L$				**1**	0
$U(2)_R$				**0**	12
$U(N_1)$	**0**	**0**	**0**	0	**1**
$U(N_2)$	0	0	0	**1**	0

Degeneracies on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

Model 5

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$
(x, s, t), $P^{\pm\mp}$	$(-1,0,0)$, P^{-+}

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			0	3
$U(2)_L$				6	0
$U(2)_R$				0	1
$U(N_1)$	0	0	0	1	0
$U(N_2)$	0	0	1	0	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			0	0
$U(2)_L$				0	0
$U(2)_R$				1	0
$U(N_1)$	0	0	1	0	1
$U(N_2)$	0	0	0	1	0

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			0	0
$U(2)_L$				0	0
$U(2)_R$				1	0
$U(N_1)$	3	0	1	0	1
$U(N_2)$	0	0	0	1	0

Degeneracies on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

Model 6

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$
(x, s, t), $P^{\pm\mp}$	$(1, -1, -1)$, P^{+-}

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			0	0
$U(2)_L$				0	1
$U(2)_R$				0	0
$U(N_1)$	3	0	0	1	0
$U(N_2)$	0	1	6	0	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			0	3
$U(2)_L$				1	0
$U(2)_R$				0	0
$U(N_1)$	0	1	0	0	1
$U(N_2)$	0	0	0	1	0

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			0	0
$U(2)_L$				1	0
$U(2)_R$				0	0
$U(N_1)$	0	1	0	0	1
$U(N_2)$	0	0	0	1	0

Degeneracies on T^6/Z_2

K. Sumita, T. Watanabe & H.A. in progress

Model 7

$(M_1^{(1)}, M_2^{(1)})$	$(3x, 3x)$
$(M_1^{(2)}, M_2^{(2)})$	(s, t)
$(M_1^{(3)}, M_2^{(3)})$	$(-x-s, -x-t)$
(x, s, t), $P^{\pm\mp}$	$(1, -1, 1)$, P^{+-}

Φ_1	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	0
$U(2)_L$				**0**	0
$U(2)_R$				**0**	0
$U(N_1)$	**3**	**0**	**6**	1	**0**
$U(N_2)$	0	0	0	**1**	1

Φ_2	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	0
$U(2)_L$				**1**	0
$U(2)_R$				**0**	0
$U(N_1)$	**0**	**1**	**0**	0	**1**
$U(N_2)$	0	0	0	**0**	0

Φ_3	$U(4)_C$	$U(2)_L$	$U(2)_R$	$U(N_1)$	$U(N_2)$
$U(4)_C$	T^6/Z_2			**0**	6
$U(2)_L$				**1**	0
$U(2)_R$				**0**	12
$U(N_1)$	**0**	**1**	**0**	0	**0**
$U(N_2)$	0	0	0	**0**	0

Gauge coupling unification

K. Sumita, T. Watanabe & H.A. in progress

SUSY breaking scale and messenger scale

$$M_{\mathrm{SB}} \sim \sqrt{(\zeta_1 - \zeta_2)\Lambda_h}$$

$$M_\psi \sim \zeta_1 - \zeta_{\mathrm{vis}} + 16\pi^2 \frac{\Lambda_h^3}{M_{1,2}^2}$$

determined by parameters $\zeta_{1,2}, \zeta_{\mathrm{vis}}, \Lambda_h, M_{1,2}$

Threshold corrections to gauge couplings?

$$SU(3)_C \times SU(2)_L \times U(1)_Y \times SU(N_f) \times SU(N_h)$$

Gauge coupling unification

K. Sumita, T. Watanabe & H.A. in progress

Parameters $\zeta_{1,2}\,,\zeta_{\mathrm{vis}}\,,\,\Lambda_h,\,M_{1,2}$

Gauge coupling unification

K. Sumita, T. Watanabe & H.A. in progress

Parameters $\zeta_{1,2}, \zeta_{\mathrm{vis}}, \Lambda_h, M_{1,2}$

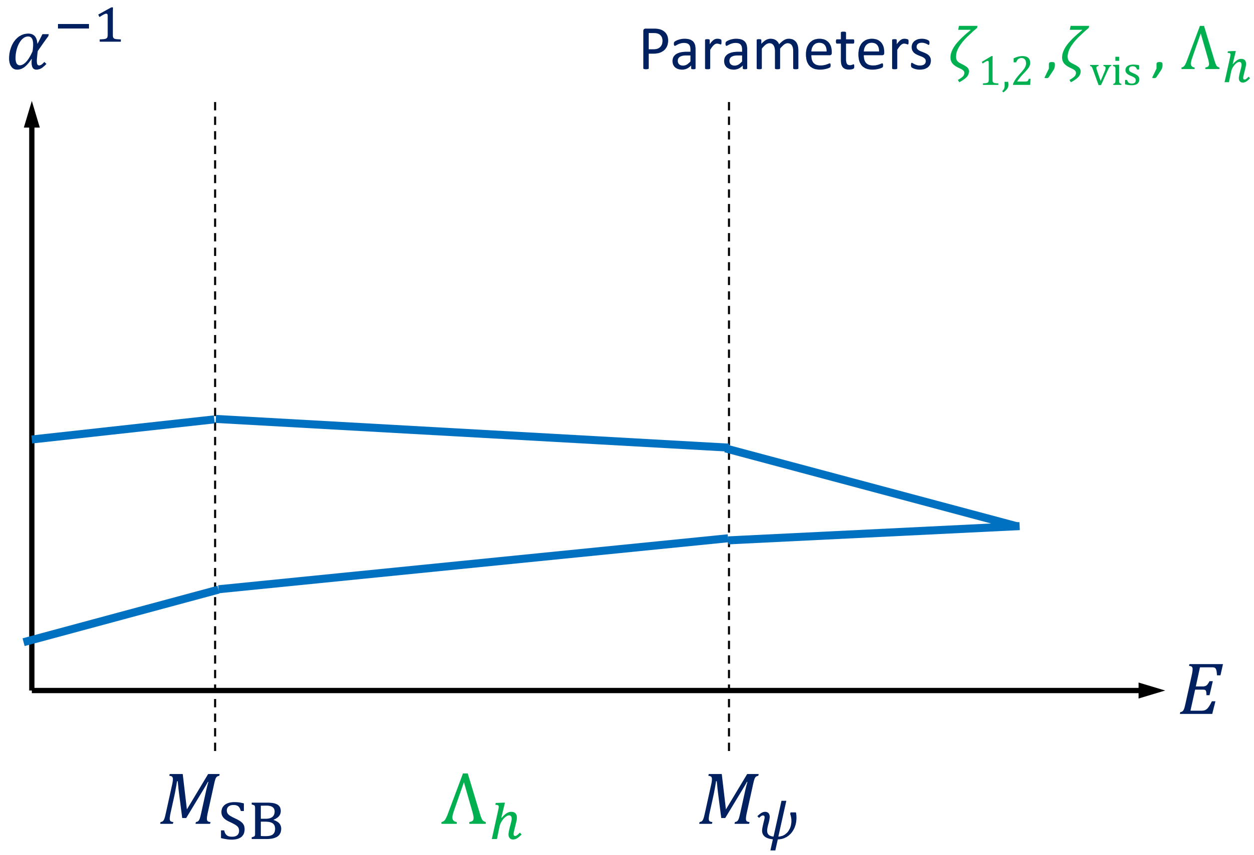
E

M_{SB} Λ_h M_ψ

Gauge coupling unification

K. Sumita, T. Watanabe & H.A. in progress

Parameters $\zeta_{1,2}, \zeta_{\rm vis}, \Lambda_h, M_{1,2}$



Gauge coupling unification

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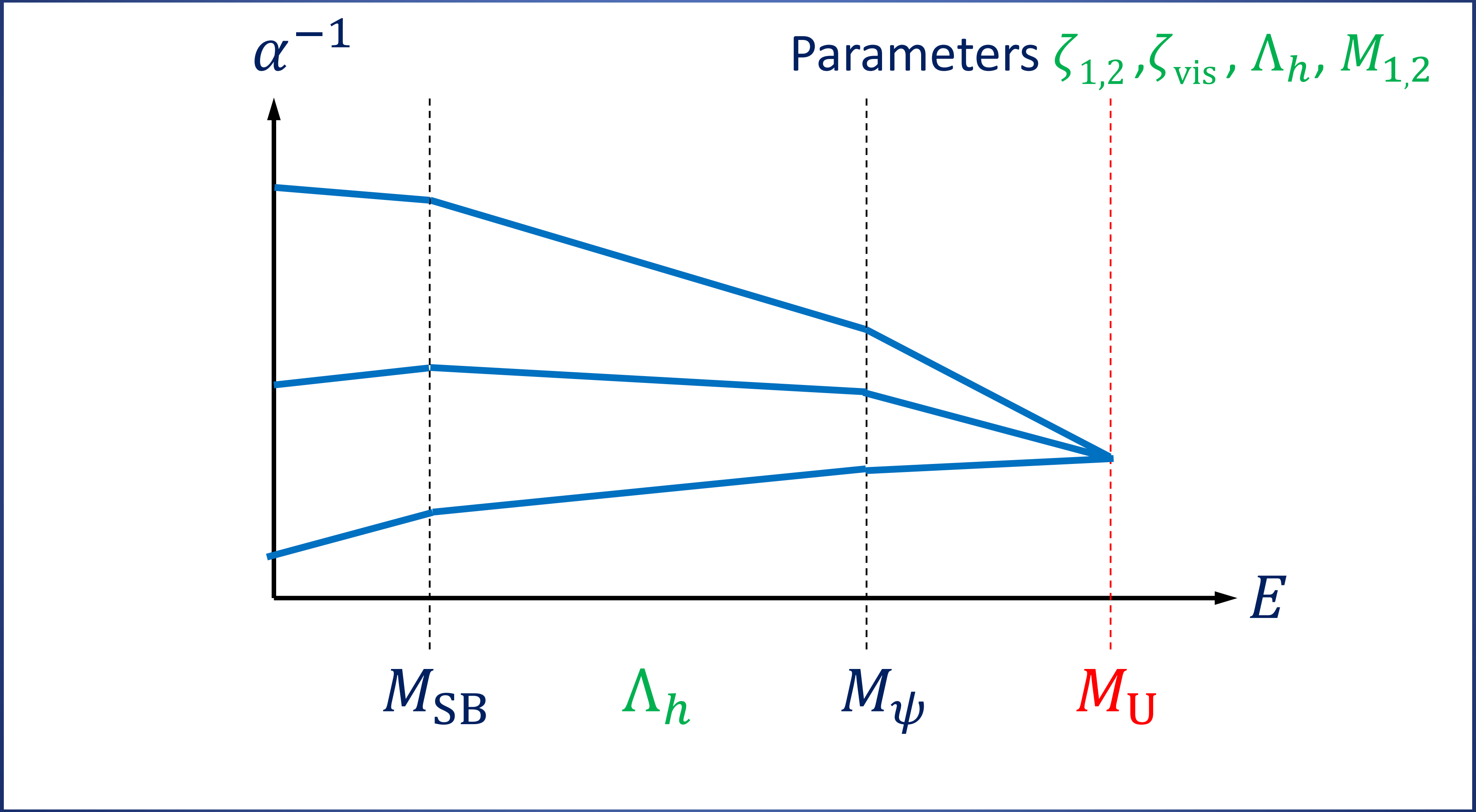
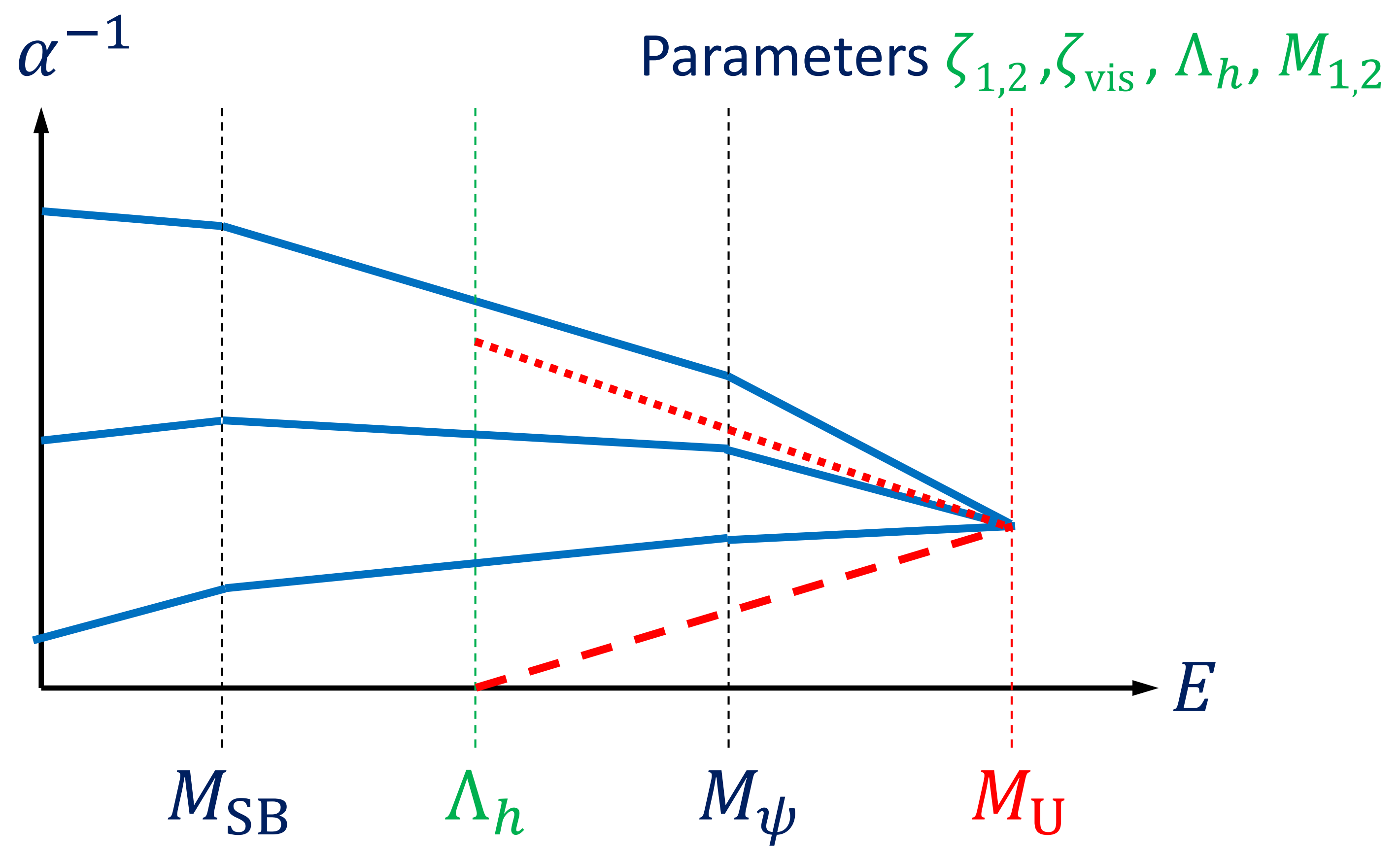


Gauge coupling unification

K. Sumita, T. Watanabe & H.A. in progress



Contents

Numerical results (preliminary)

K. Sumita, T. Watanabe & H.A. in progress

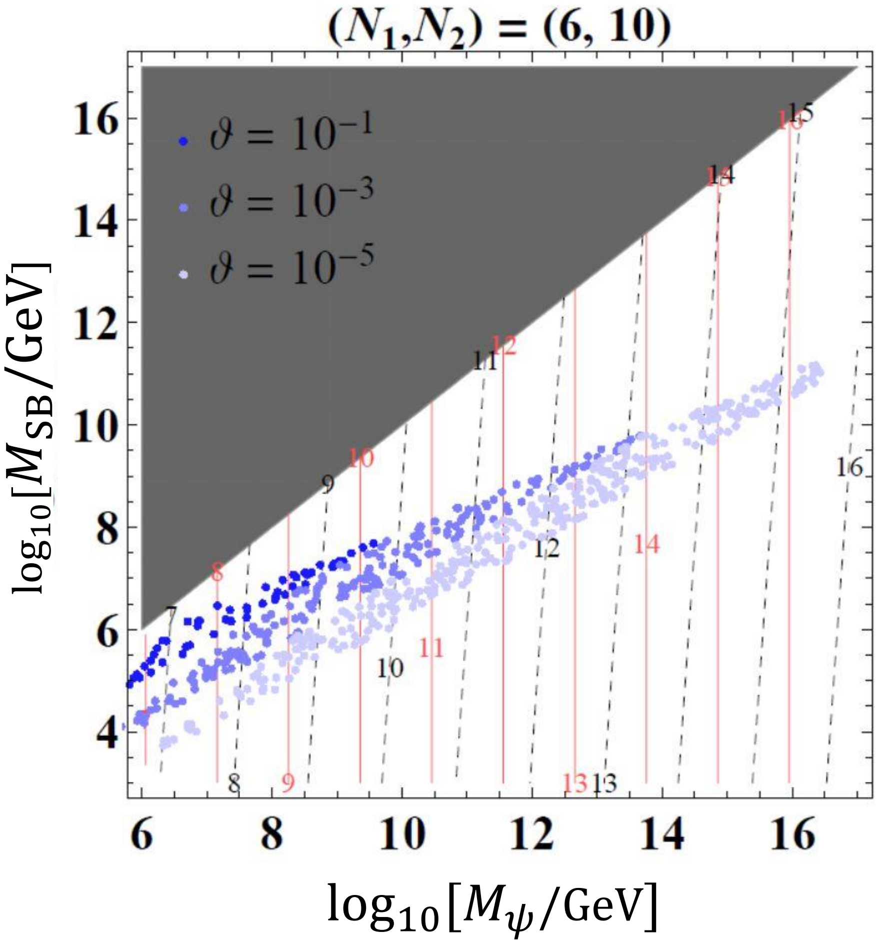
Model 6 on T^6/Z_2

M_{SB} v.s. $M_\psi \sim \zeta_1 - \zeta_{\mathrm{vis}}$

with $\vartheta = \zeta_{1,2}/\zeta_{\mathrm{vis}}$ fixed

Dashed contours: $\log_{10}\Lambda_h$

Red contours: $\log_{10}M_{\mathrm{U}}$



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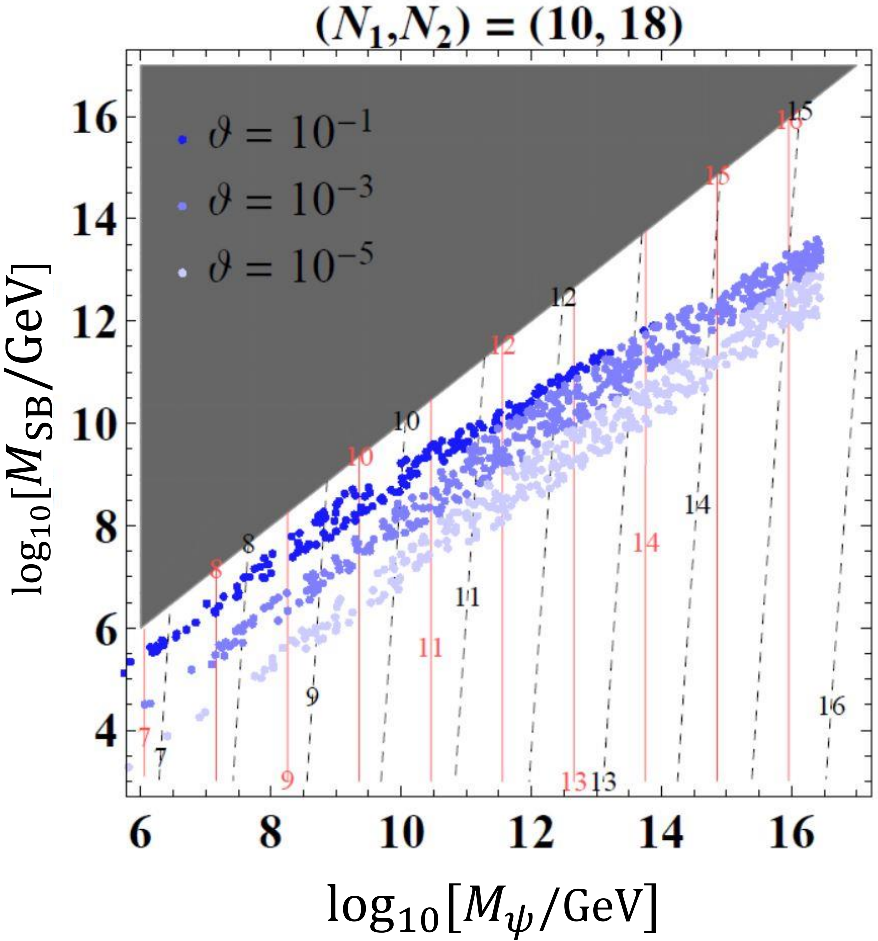

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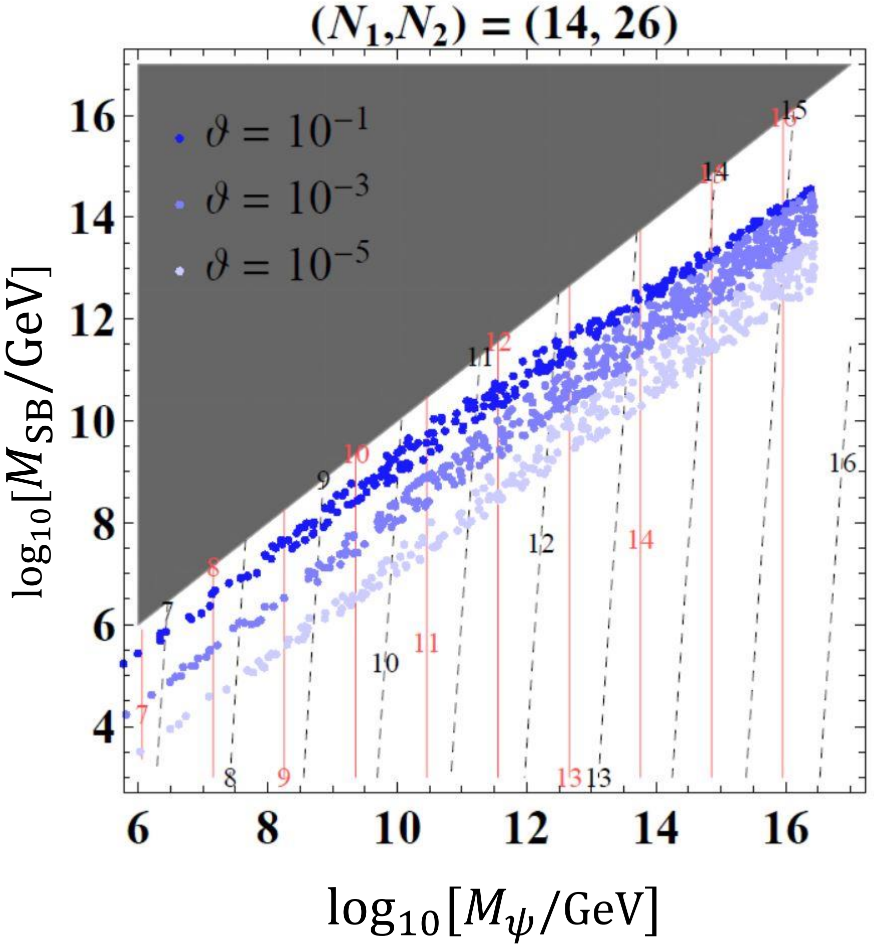

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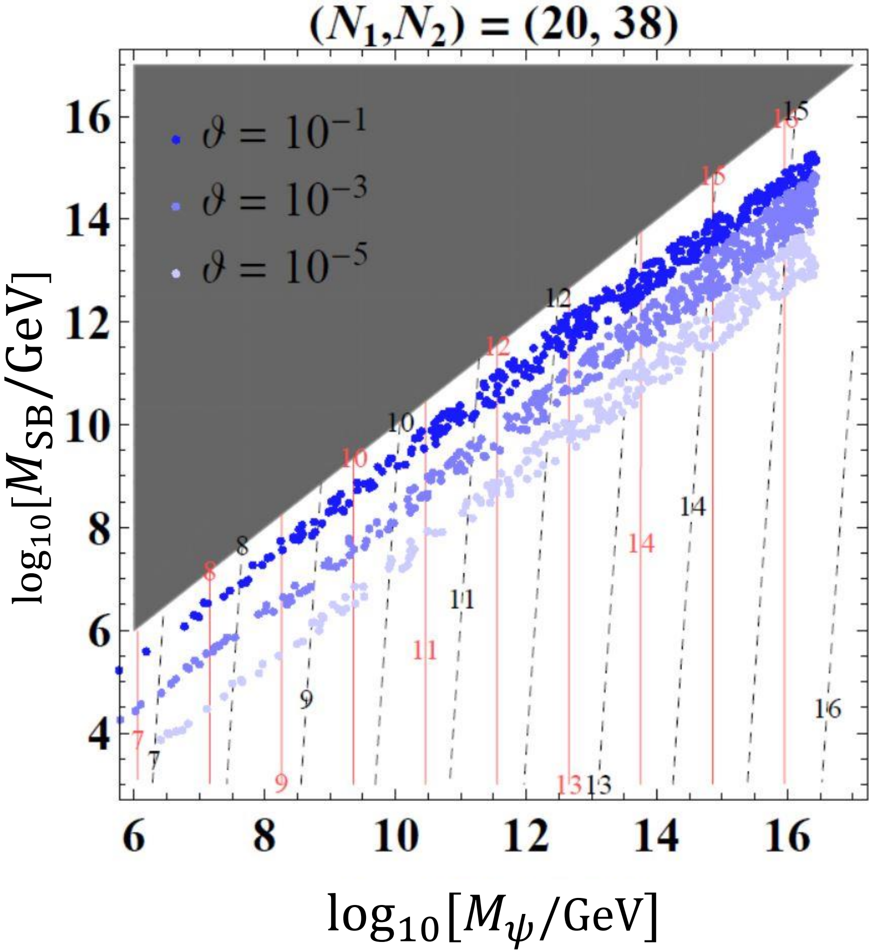


Numerical results (preliminary)

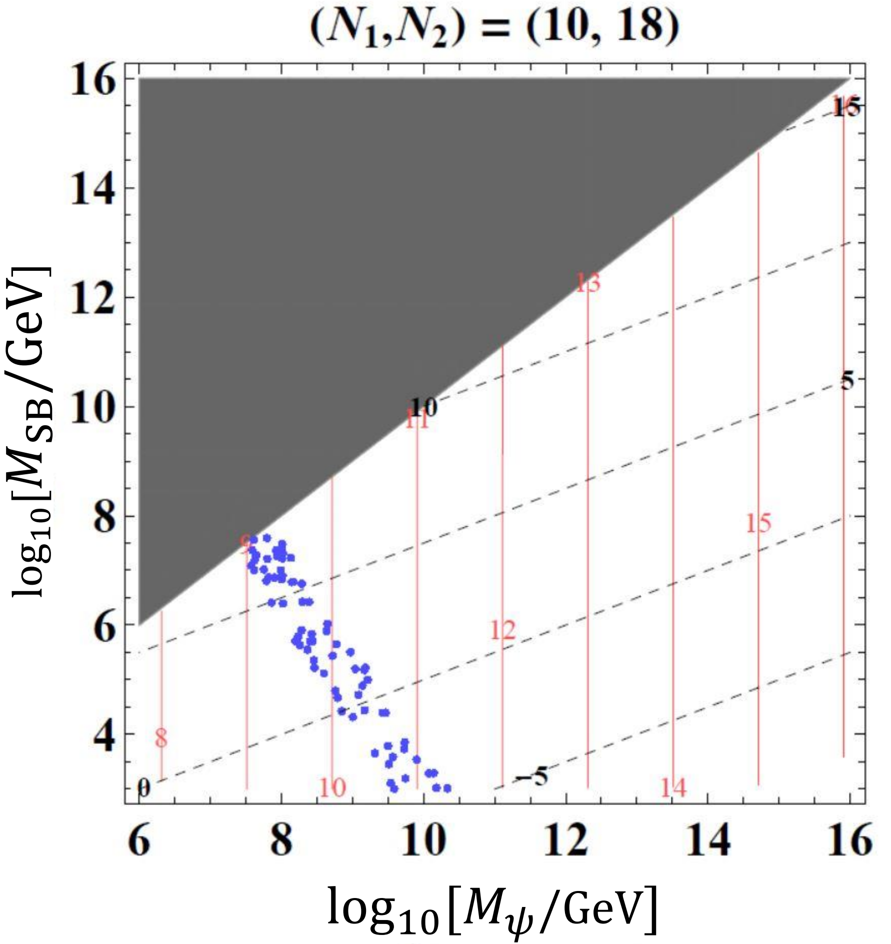
K. Sumita, T. Watanabe & H.A. in progress

Model 6 on T^6/Z_2

M_{SB} v.s. $M_\psi \sim 16\pi^2 \frac{\Lambda_h^3}{M_{1,2}^2}$

Dashed contours: $\log_{10}\zeta_{\mathrm{vis}}$

Red contours: $\log_{10}M_{\mathrm{U}}$



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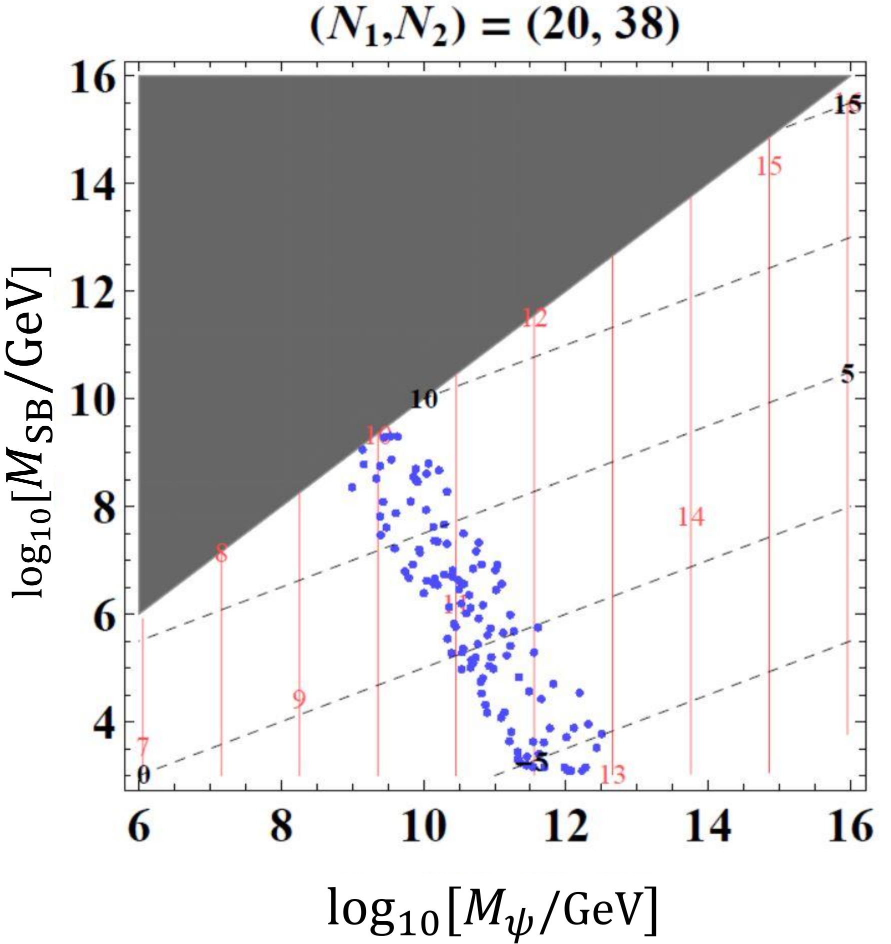

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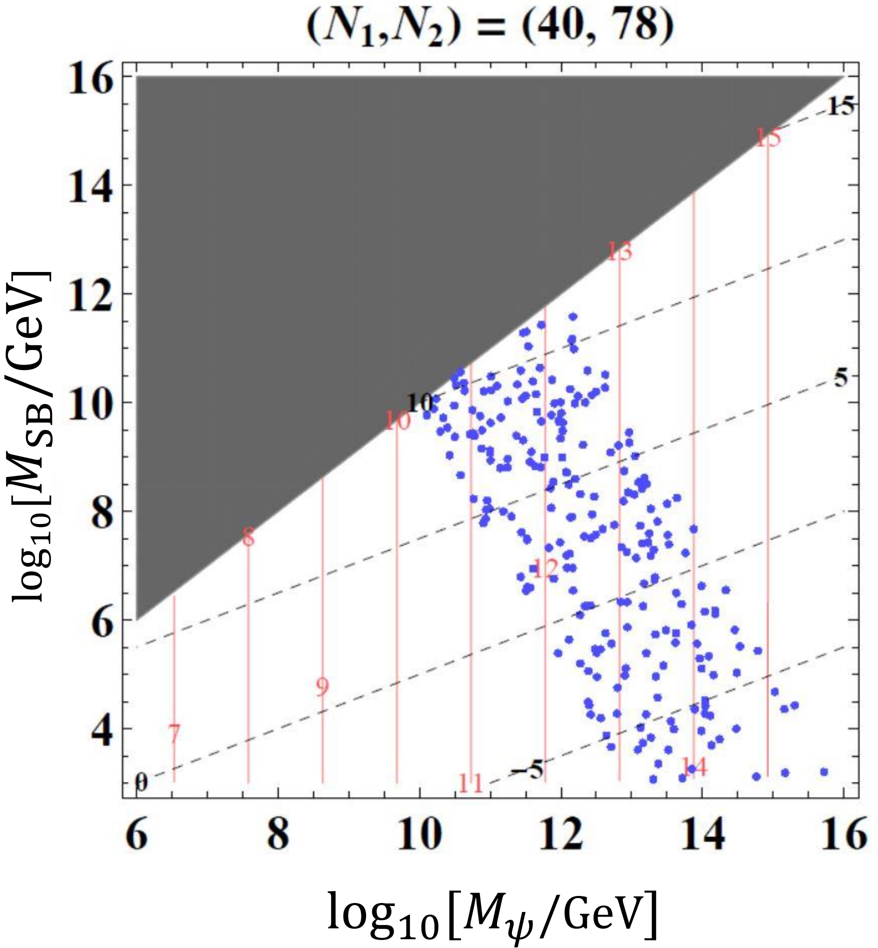

Contents

I. Introduction
  - SYM on magnetized tori
  - Phenomenological models

II. Aspects of DSB on magnetized tori
  - DSB on a local minimum (ISS model)
  - Embedding DSB sector
  - Numerical results

III. Summary

Summary

Aspects of DSB on magnetized T^6 and T^6/Z_2

- Extend the gauge group to include the ISS-type hidden sector
- The DSB sector is accompanied by a messenger sector

  Gauge mediated contributions
- Certain correlations between SUSY breaking and messenger scales are detected
- The results provide a guideline for magnetized model buildings

Summary

Issues remaining

- Numerical analysis on T^6
- Some chiral exotics in hidden/messenger sector on T^6/Z_2
- Stabilization of adjoint modes

Further prospects

- Extension to mixed SYM theories
- Moduli stabilization
- Effects of curved geometries
- D-brane interpretations and dual descriptions

Thank you!