Flipped SU(5) from Z_{12-I} orbifold with Wilson line

(String MSSM through flipped SU(5) from Z_{12} orbifold)

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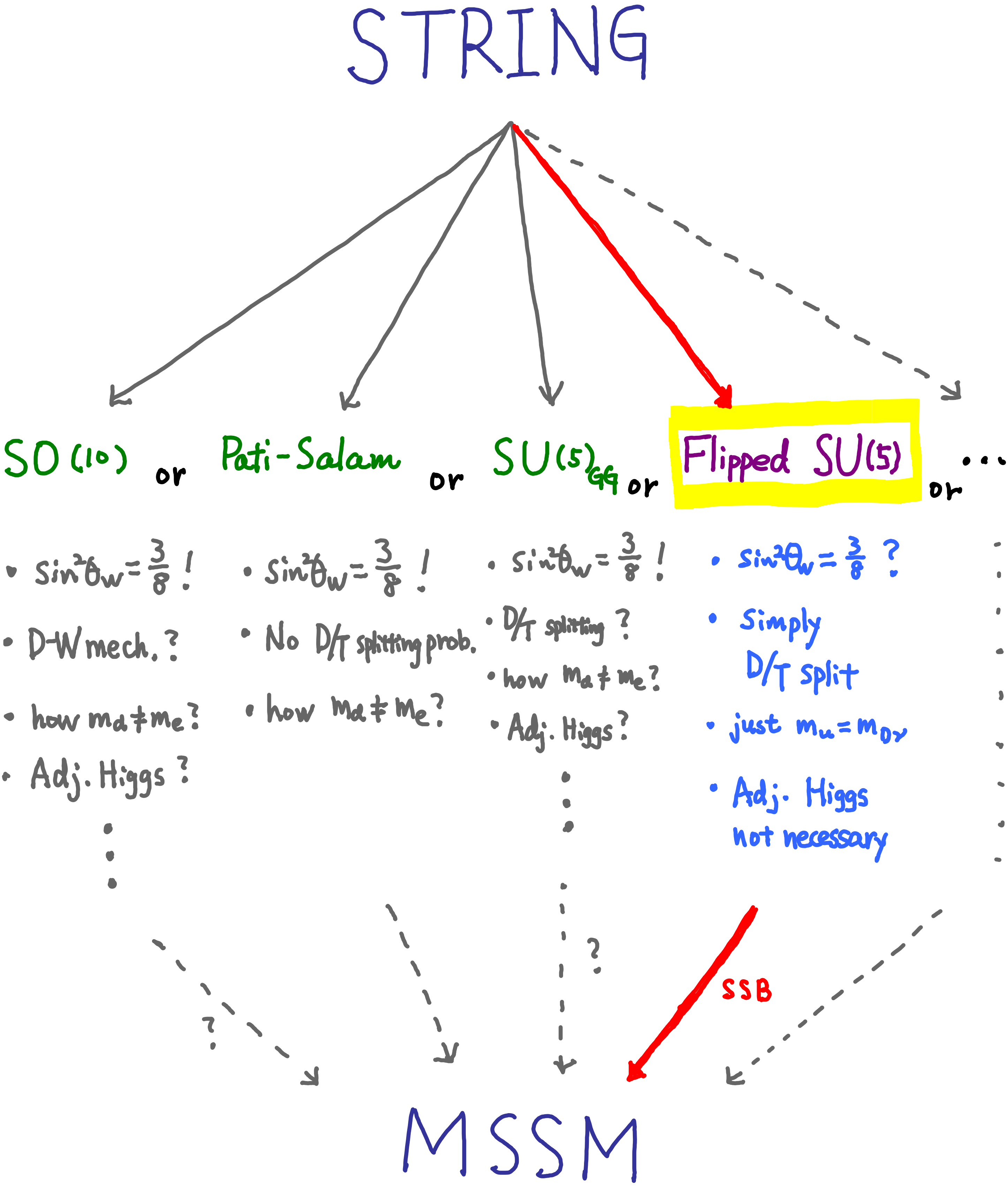
STRING
SO(10)
or
Pati-Salam
or
SU(5)$_{GG}$
or
Flipped SU(5)
or
...
• $\sin^2\theta_W = \frac{3}{8}$!
• D-W mech. ?
• how $m_d \neq m_e$?
• Adj. Higgs ?
• $\sin^2\theta_W = \frac{3}{8}$!
• No D/T splitting prob.
• how $m_d \neq m_e$?
• $\sin^2\theta_W = \frac{3}{8}$!
• D/T splitting ?
• how $m_d \neq m_e$?
• Adj. Higgs ?
• $\sin^2\theta_W = \frac{3}{8}$?
• Simply D/T split
• just $m_u = m_{D\nu}$
• Adj. Higgs not necessary
?
?
SSB
MSSM

Summary of our Results

1. $G = \underline{SU(5) \otimes U(1)_X} \otimes U(1)^3 \otimes$ Hidden gp.

with <u>3 families</u> of $\underbrace{\text{matter}}_{\text{MSSM}}$ + vec.-like Higgs $\{10_H, \overline{10}_H, 5_h, \bar{5}_h\}$

($U(1)_X$ charge assignments coincident with Flipped SU(5))

2. Yukawa Coupling Analysis showes

a. vec.-like (exotic) states Massive

b. Flipped SU(5) $\xrightarrow[\langle 10_H \rangle, \langle \overline{10}_H \rangle]{}$ MSSM

c. D/T splitting

d. Fermion masses

e. $\exists$ R-parity

if $\langle 1_0 \rangle \neq 0$

Current algebra in string theory determines U(1) charge normalization.

3. $\underline{\sin^2 \theta_W^0 = \frac{3}{8}}$ at the full unif. scale

Physical Massless States in Orbifold Compactification of the Heterotic String

1. Massless Conditions

- L-mover: $\frac{1}{2}|P+kV|^2 + \sum_j N_j^L \tilde{\phi}_j - \tilde{c} = 0$

  if $kW = 0$, $(P+kV)\cdot W = \text{integer}$

- R-mover: $\frac{1}{2}|s+k\phi|^2 + \sum_j N_j^R \tilde{\phi}_j - c = 0$

2. Multiplicity

degeneracy factor

$$P_k = \frac{1}{N}\sum_{l=0}^{N-1} \tilde{\chi}(\theta^k \theta^l)\, e^{2\pi i l \Theta_0}$$

$$\left(\Theta_0 = \sum_j (N_j^L - N_j^R)\hat{\phi}_j + \frac{k}{2}(V^2 - \phi_s^2) + (P+kV)\cdot V + (\tilde{s}+k\phi_s)\cdot\phi_s \right)$$

In the presence of Wilson line,

$$e^{2\pi i \Theta_0} \longrightarrow \frac{1}{N_W}\sum_{f=0}^{N_W-1} e^{2\pi i l \Theta_f}$$

$$\left(\Theta_f = \Theta_0 [V \to V_f] \right)$$

The Model

Z_{12-I} orbifold compactification

$$\vec{\phi}_s = \left(\frac{5}{12}, \frac{4}{12}, \frac{1}{12}\right) \quad : \sim SO(8)\times SU(3) \text{ lattice}$$

$\sim Z_3$: Wilson Line of order 3 can be set on this sub-lattice.

$$V = \left(\frac{3}{12}\ \frac{3}{12}\ \frac{3}{12}\ \frac{3}{12}\ \frac{3}{12}\ ;\ \frac{5}{12}\ \frac{6}{12}\ 0\right)\left(\frac{2}{12}\ \frac{2}{12}\ 0;\ 0^5\right)'$$

$$a_3 = \left(\ 0^5\ ;\ 0\ \frac{-4}{12}\ \frac{4}{12}\right)\left(0\ 0\ \frac{4}{12};\ 0^5\right)'$$

$$= a_4 \quad (a_1 = a_2 = a_5 = a_6 = 0)$$

$$Q_X = (\underbrace{-2\ -2\ -2\ -2\ -2}_{SU(5)\otimes U(1)_X}\ ;\ \underbrace{0^3}_{(\otimes [U(1)]^3)}\ )(\underbrace{0^2\ 0}_{SU(2)'}\ ;\ \underbrace{0^5}_{\otimes SO(10)'})'$$

$SU(5)\otimes U(1)_X$ $(\otimes [U(1)]^3)$ $\quad SU(2)' \otimes SO(10)'$ $(\otimes [U(1)^2])$

* Simple roots satisfying $P\cdot V = P\cdot a_3 = 0$ $\quad (1\ -1;\ 0^6)'$: $SU(2)'$

$(\underline{1\ -1\ 0\ 0\ 0}\ ;\ 0^3)$: $SU(5)$, $SO(10)'$ $\begin{cases} (\ 0\ 0\ ;\ 1\ -1\ 0^3)' \\ (\ \ \text{"}\ \ ;\ 0^3\ 1\ 1)' \end{cases}$

Field Spetrum (Result)

matter — EW Higgs

U : $2\times\{\,\bar{5}_{-3},\ 10_{1},\ 1_{5}\,\} + 1\times 5_{-2}$

+ neutral Singlet + CTP

$\left\{\begin{array}{l} 10_1 = \begin{pmatrix} d^c & Q \\ & \nu^c \end{pmatrix} \\ \bar{5}_{-3} = \begin{pmatrix} u^c \\ L \end{pmatrix} \\ 1_5 = e^c \end{array}\right.$

T_6 : $4\times 10_{1} + 3\times\overline{10}_{-1}$

$+\ 2\times\{\,\bar{5}_{-3},\ 5_{3}\,\} + 2\times\{\,1_{5},\ 1_{-5}\,\}$

+ neutral Singlets + CTP

$\left\{\begin{array}{l} 5_{-2} = \begin{pmatrix} D \\ h_d \end{pmatrix} \\ \bar{5}_{2} = \begin{pmatrix} \bar{D} \\ h_u \end{pmatrix} \end{array}\right.$

matter

T_2 : $1\times\{\,\bar{5}_{-3},\ 1_{5}\,\}$ + neutral Singlets

(CTP: from T_{10})

T_4 : $3\times\bar{5}_{2} + 2\times 5_{-2}$ + neutral singlets

(CTP: from T_8)

T_1 : $2\times\{\,\bar{5}_{-1/2},\ 5_{1/2}\,\} + 7\times\{\,1_{5/2},\ 1_{-5/2}\,\}$

(CTP: from T_{11})

T_7 : $2\times\{\,\bar{5}_{-1/2},\ 5_{1/2}\,\} + 7\times\{\,1_{5/2},\ 1_{-5/2}\,\}$

(CTP: from T_5)

vec.-like

T_3 : No Massless States satisfying $(P+3V)a_3 = 0$

Yukawa Couplings

A vertex op. should satisfy $\langle \mathcal{O}_A \mathcal{O}_B \mathcal{O}_C \cdots \rangle$

1. Gauge Invariance

2. $\underbrace{\text{H-mom.}}_{\text{bosonic}}$ Conservation (discrete R-charge conservation)

$$\sum_{z} R_1(z) = -1 \ \text{mod.} 12, \quad \sum_{z} R_2(z) = 1 \ \text{mod.} 3, \quad \sum_{z} R_3(z) = 1 \ \text{mod.} 12$$

z = A, B, C, ...

where $R_i = (\tilde{r} + k\phi_s)_i - (N_i^L - N_{\bar{i}}^L)$, $i = 1, 2, 3$

$\tilde{r}$: (bosonic) shifted SO(8) weight satisfying the Mass shell condition

3. Space Group Selection Rules

$$\begin{cases} \sum_{z} k(z) = 0 & \text{mod.} 12 \\ \sum_{z} [k\, m_f](z) = 0 & \text{mod.} 3 \end{cases}$$

Allowed Yukawa Couplings

With the assumption $\langle 1_0 \rangle s \sim \Lambda$

a. $W \supset f_1[1_0 s] \cdot 5_{\frac{1}{2}} \overline{5}_{-\frac{1}{2}} + f_2[1_0 s] \cdot 1_{5/2} 1_{-5/2}$

$+ f_3[1_0 s] \cdot 10_1 \overline{10}_{-1} + f_4[1_0 s] \cdot 5_3 \overline{5}_{-3} + f_5[1_0 s] \cdot 1_5 1_{-5}$

$+ f_6[1_0 s]\, 5_{-2} \overline{5}_2 + \cdots$

All $\{5_{\frac{1}{2}}\ \overline{5}_{-\frac{1}{2}}\}$, $\{1_{5/2}, 1_{-5/2}\}$ in T_1, T_7,

$3 \times \{10_1, \overline{10}_{-1}\}$, $2 \times \{5_3, \overline{5}_{-3}, 1_5, 1_{-5}\}$ in T_6,

$2 \times \{5_{-2}, \overline{5}_2\}$ in T_4 can be heavy.

Thus,

Higgs

$U: 2 \times \{16\} + 5_{-2}$, $T_6: 10_1$, $T_2: \overline{5}_{-3} + 1_5$

(3 families of MSSM matter) $T_4: \overline{5}_2$

Higgs

$\Rightarrow$ Flipped SU(5) field spectrum

b.

$$W \supset f_7[1_0^D s]\left[10'_1\overline{10}'_{-1} + 10''_1\overline{10}''_{-1} + \cdots - f_8[1_0 s]\right]$$

$$\Rightarrow \quad \langle 10_1 \overline{10}_{-1} \rangle = M_G$$

c.

$$W \supset \overset{T_6}{\langle 10_1 \rangle}\,\overset{T_6}{10_1}\,\overset{\text{in } U}{5_h} + f_9[1_0 s]\,\overset{T_6}{\langle \overline{10}_{-1} \rangle}\,\overset{T_6}{\overline{10}_{-1}}\,\overset{\text{in } T_4}{\bar{5}_h}$$

$$(\langle \nu^c \rangle \quad d^c \quad D) \qquad\qquad (\langle \bar{\nu}^c \rangle \quad \bar{d}^c \quad \bar{D})$$

pair up to be heavy

(※ $\{Q, \bar{Q}\}$ in $10_1 \overline{10}_{-1}$ are eaten by the massive gauge sector.)

$\Rightarrow$ D/T splitting

d.

Cubic couplings

$10_1\ \overline{5}_{-3}\ \overline{5}_2$ $(T_6\ T_2^0 T_4^0)$: t quark

& Dirac τ neutrino

$10_1\ 10_1\ 5_{-2}$ $\begin{pmatrix} T_6\ T_6\ U_2 \\ U_1\ U_2\ U_3 \end{pmatrix}$: b-type quarks

But only if $\langle 1_0 \rangle$s $\neq 0$, all the components

in $(10_1)_i(\overline{5}_{-3})_j\overline{5}_2$, $(10_1)_i(10_1)_j 5_{-2}$, $(1_5)_i(\overline{5}_{-3})_j 5_2$

$\langle \overline{10}_{-1}\overline{10}_{-1}\rangle (10_1)_i (10_1)_j$ can be non-zero.

e.

R-parity (matter parity) relevant at low energy still can be defined.