E_6 orbifold GUT with gauge-Higgs unification

山下　敏史

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based on a work in preparation

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Overview

Hosotani mech. in GUTs

- Hosotani breaking of the $SU(5)_{GG}$

  ⇒ "grand gauge-Higgs unification"

  K.Kojima, K.Takenaga & T.Y. (2011)

  ⇓ SUSY

  adjoint

  - ✓ natural Doublet-Triplet (DT) splitting
  - ✓ general & *testable* prediction T.Y. (2011)

We may get a hint of the GUT-breaking @LHC.

（別のお仕事）

Overview

Hosotani mech. in GUTs

- rank reduction by the Hosotani mechanism

K.Kojima, K.Takenaga & T.Y. in preparation

  - a more straightforward application of the gauge-Higgs unification
  - a kind of the orbifold GUTs (the $SU(5)_{GG}$ is broken by the BCs)

- extra $U(1)$s often remain in the orbifold GUTs

  ↳ Hosotani mech.

（今回のお話）

reviews

- Hosotani mechanism
- flipped $SU(5)$
- E_6 group

Hosotani mechanism

Y.Hosotani (1983-)

- overview

5D theory

compactification

4D theory

w/ KK modes

gauge field

$A_M = (A_\mu, A_5)$

A_μ gauge field

A_5 scalar field

Higgs

- flat pot. @tree
- eff. pot. via loop

flipped $SU(5)$

S.M.Barr (1982)

- $SU(5)_F \times U(1)_F \subset SO(10)$

  $\xrightarrow{\langle \mathbf{10}_H \rangle}$ $G_{\rm SM}$

  - matter content

    - Higgs fields: $\mathbf{10}_H$, $\bar{\mathbf{5}}_H$ (SM Higgs field)
    - fermions: $\mathbf{10}_i$, $\bar{\mathbf{5}}_i$, $\mathbf{1}_i$ $(i=1,2,3)$

      d^c q n^c | u^c l | e^c

      embedded, w/ the $SU(2)_R$ flipped

      missing partner (MP) mechanism

  - DT splitting: $\mathbf{10}_H \mathbf{10}_H \mathbf{5}_H$ ➡ the triplet mass

E_6 group

S.M.Barr (1982)

- maximal subgroups

$$SO(10)\times U(1) \qquad SU(6)\times SU(2) \qquad SU(3)^3$$

- decomposition

27: $\quad 16_1 + 10_{-2} + 1_4 \qquad (15,\ 1) + (\overline{6},\ 2) \qquad \underline{(3,\ \overline{3},\ 1)}$

$$\{10_1 + \overline{5}_{-3} + 1_5\}_1 \qquad (\{10+5\},\ 1)$$

$$+\{5_{-2} + \overline{5}'_2\}_{-2} + \{1'_0\}_4 \qquad +(\{\overline{5}+1\},\ 2)$$

E_6 model

K.Kojima, K.Takenaga & T.Y.

- candidate unified group
  - rank $G > 4$
  - $G / G_{\rm SM} \times U(1)^n$ contains $SU(3) \times SU(2)$ singlets.

- rank 5

  $SU(6)$: no singlets

  $SO(10)$: a singlet but in **10** from **45**

  ⇨ the $U(1)$ charge does not fit

  ⇨ to be further "flipped"

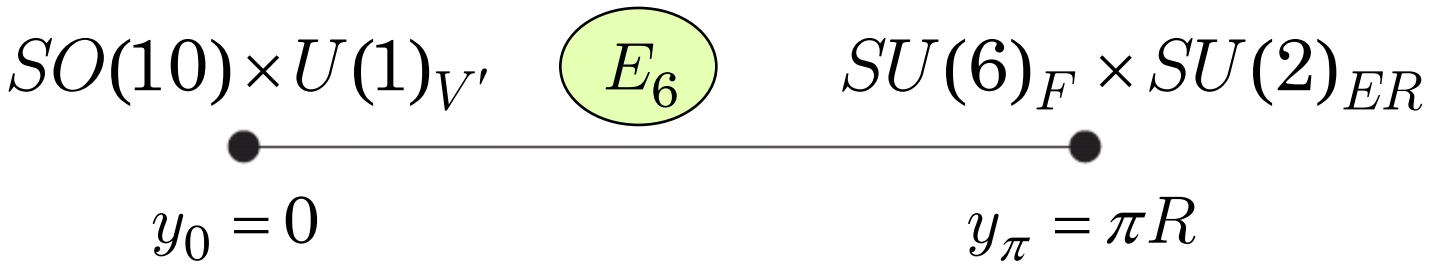
  E_6 is an interesting candidate.

  $SU(8) \to SU(5) \times SU(3)$ too T.Yanagida (1995)

E_6 model

K.Kojima, K.Takenaga & T.Y.

- setup on $S^1/\mathbb{Z}_2$ compactification



  - By these BCs, $E_6 \to SU(5)_F \times U(1)_F \times U(1)_{V'}$.
  - The A_5 has zero modes in $\mathbf{10} \in \mathbf{16} \in \mathbf{78}$.

    ⇨ <**10**$_A$> breaks $SU(5)_F \times U(1)_F \to G_{\rm SM}$

  - The $U(1)_{V'}$ is made anomalous to be broken.

    ⇨ GUT breaking w/o scalars

E_6 model

K.Kojima, K.Takenaga & T.Y.

- vacuum
  - w/o loss of generality, <**10**> = <N^c> + <D^c>

    ⇨ there are color-breaking vacua.
  - loop correction selects the vacuum

    $$-\frac{i}{2}\mathrm{Tr}\ \ln(D_M{}^2 - m^2)$$
  - E_6 is tough to treat, but it's possible to calculate the eff. pot. a la JHEP0402(2004)059. N.Haba & T.Y.
  - anomaly induces GS term: $\frac{1}{2}M_{\mathrm{GS}}(A^{V'}{}_{\mu})^2\delta(y)$

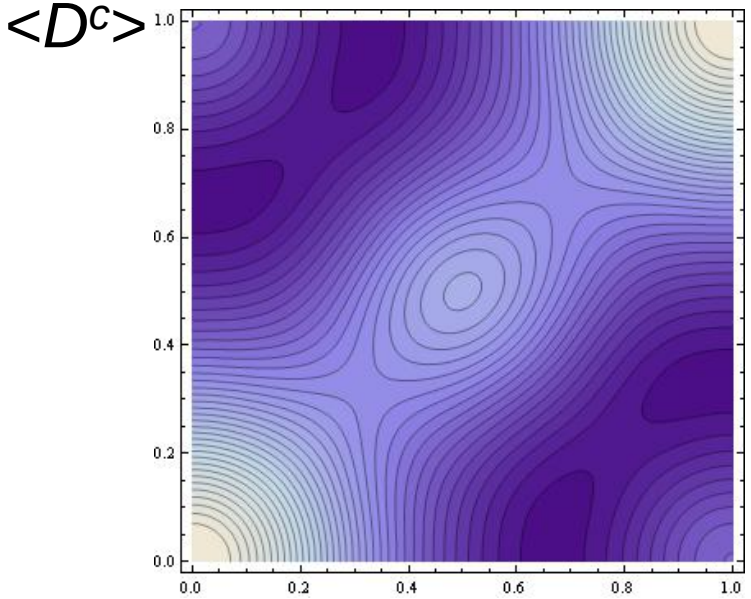
    ⇨ modifies BCs: makes it more messy

E_6 model

K.Kojima, K.Takenaga & T.Y.

- vacuum
  - 1 pair of adj. fermions w/ opposite periodicities & 1 vector like pair: $27^{(+,-)}$ & $27^{(-,+)}$

⇨ desired vacuum



Preliminary

(4 vacua are equivalent)

SUSY version

K.Kojima, K.Takenaga & T.Y.

Preliminary

- DT splitting
  - $\mathbf{10}_A\,\mathbf{10}_A\,\mathbf{5}_H$ is not allowed
    - ⇨ The mech. in 4D flipped $SU(5)$ not applied
  - ✓ another realization of the MP mech.

    Higgs: bulk $27^{(+,-)} \in \mathbf{10}_H \,\&\, \mathbf{5}_H$
    - ⇨ $\mathbf{10}_H\,\mathbf{10}_A\,\mathbf{5}_H$ gives a source of the splitting
  - ✓ color triplet in $\mathbf{10}_A$ is predicted to be light

    (tree: massless, loop: suppressed by m_{SUSY})
    - ⇨ LHC may discover it.

G.R. Dvali (1996)

SUSY version

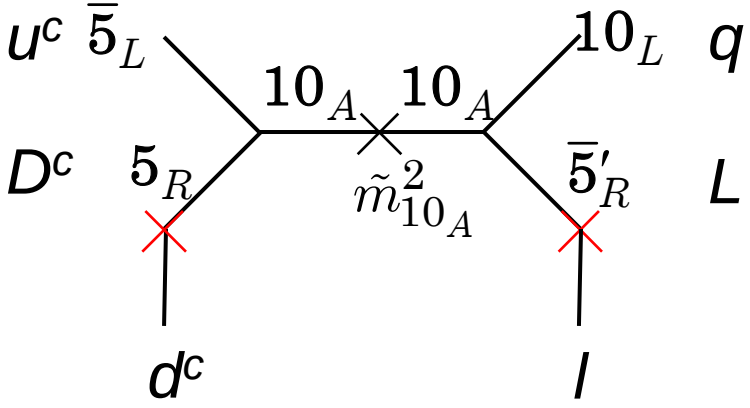
K.Kojima, K.Takenaga & T.Y.

Preliminary

- proton decay
  - ➢ from the color triplet Higgs:

    negligible, since the μ term is small
  - ➢ from the color triplet in $\mathbf{10}_A$:

    depending on matter sector, dangerous

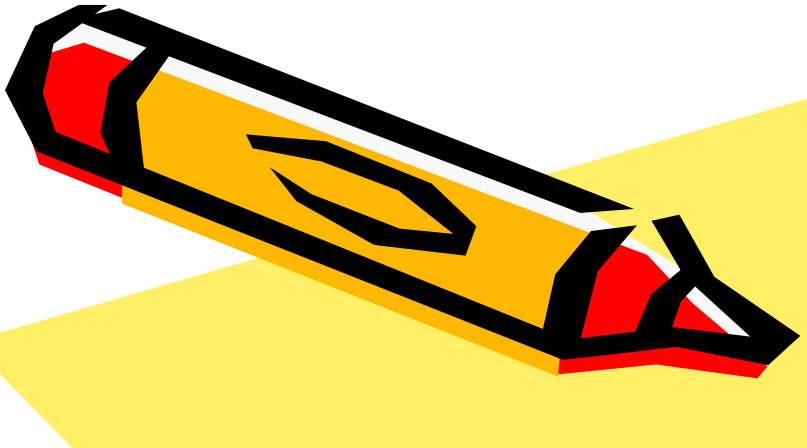


heavy-light mixing should be tiny.

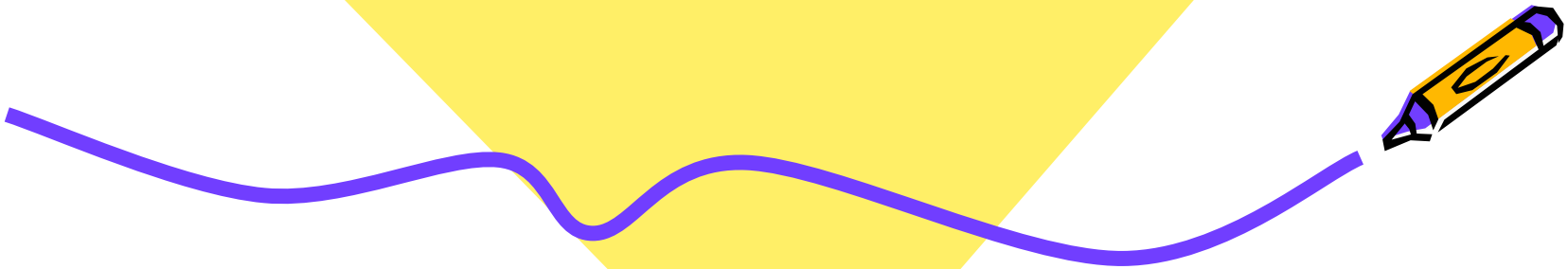
summary

Hosotani mech. for rank reduction in GUT

- no candidate in the groups w/ rank 5
- E_6 model via the flipped $SU(5)$
  - ✓ 1-loop eff. pot. is calculated.
    - ⇨ desired vacuum w/ appropriate bulk matter
- SUSY version
  - ✓ DT splitting by another realization of MP mech..
  - ✓ low energy prediction: light color triplet
    - ⇨ PD gives a constraint.



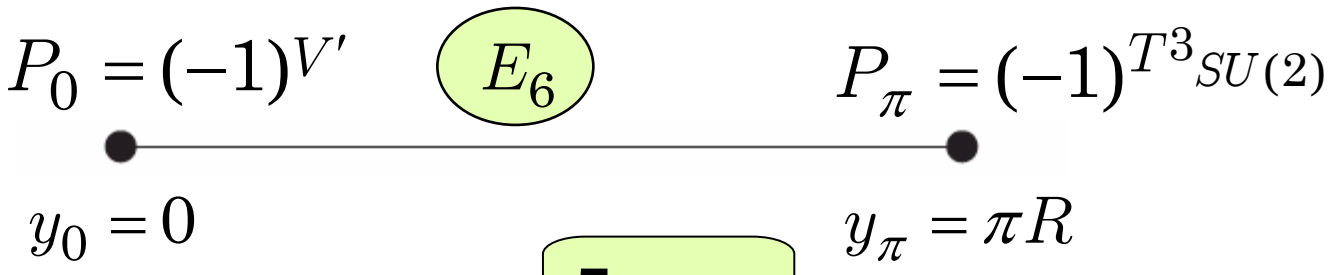
Backup



BCs & zero mode

K.Kojima, K.Takenaga & T.Y.

- boundary conditions



- zero modes

5 repr.

$$27^{(+,+)}: \quad 5_L + \bar{5}_R + 1_R \qquad H_u$$

$$27^{(+,-)}: \quad \bar{5}'_L + 1'_L + 10_R \qquad H_d$$

$$27^{(-,+)}: \quad 10_L + \bar{5}'_R + 1'_R$$

$$27^{(-,-)}: \quad \bar{5}_L + 1_L + 5_R$$

each gen.

⇨ anomaly