Heterotic Asymmetric Orbifold and E6 GUT Model

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Abstract : We discuss string GUT scenario, realizing the standard model of the particle physics from string theory via supersymmetric grand unified theory (SUSYGUT) with adjoint Higgs fields. We especially construct E6 SUSYGUT models in heterotic string theory. We use diagonal embedding method to realize an adjoint Higgs field and utilize lattice engineering technique for the model building. In the framework of Z12 heterotic asymmetric orbifold construction, we obtain two more three-family E6 models with an adjoint Higgs field.

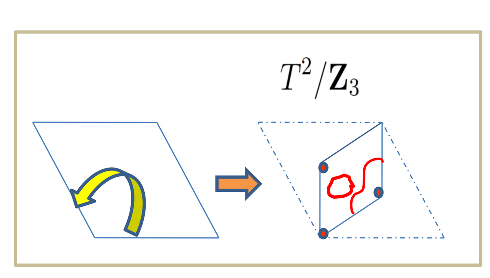
Motivation

- String → Standard Model
  - String theory
    - -- A candidate which describe quantum gravity and unify four forces
    - -- Is it possible to realize phenomenological properties of SM ?
    - -- Strings have many vacua
  - Minimal Supersymmetric Standard Model (MSSM) -- A candidate BSM
    - -- Non-Abelian gauge symmetries (SU(3) x SU(2) x U(1))
    - -- Three chiral generations (Quarks, Leptons)
    - -- Yukawa hierarchy
    - -- N=1 SUSY …
- String GUT scenario

  String → GUT → MSSM

  4D SUSY-GUT with adjoint representation Higgs
  (Adjoint Higgs VEV breaks GUT symmetry, not by extra dim. effects)

- String Compactification
  - String Model Building
    -- Heterotic string, F theory, M theory ,Intersecting D-brane,..)
  - (Symmetric) orbifold compactification
    -- Advantage : Realize E6 GUT gauge symmetry
    : N=1 supersymmetry
    -- Disadvantage : No adjoint representation Higgs



  - Asymmetric orbifold compactification, Diagonal embedding method
    -- Advantage : modding out the permutation symmetry of the models
    Ex.) $G_1 \times G_1 \times G_1 \to G_3$
    : We can obtain adjoint representation Higgs !

E6 GUT

- $E_6 \times U(1)_A (\times SU(2)_H)$ GUT model — Maekawa, Yamashita ('01-'04)
  - -- Unify all SM particles into GUT matter multiplets (E6)
  - -- Realistic Yukawa hierarchies (E6)
  - -- Realize doublet-triplet splitting (U(1)A)
  - -- Solve SUSY flavor problem (SU(2)H)

Generic interaction : Include all terms allowed by symmetry
→ Matter contents determine the models

Anomalous U(1) symmetry : Often appear in low energy effective theory of string theory.
→ Can we realize these GUT models in string theory ?

- E6 Unification — Bando, Kugo (1999)
  - All quarks and leptons are unified into $\Psi_i(\mathbf{27})$ $(i=1,2,3)$

$$\Psi_i(\mathbf{27}) = \mathbf{16}_i[\mathbf{10}_i + \bar{\mathbf{5}}_i + \mathbf{1}_i] + \mathbf{10}_i[\mathbf{5}_i + \bar{\mathbf{5}}'_i] + \mathbf{1}_i[\mathbf{1}_i]$$

$$\mathbf{10}(Q, U^c_R, E^c_R) \quad \bar{\mathbf{5}}(L, D^c_R)$$

$\bar{\mathbf{5}}_i : 3$, $\bar{\mathbf{5}}'_i : 3$, $\mathbf{5}_i : 3$

  - Yukawa structure
    -- Low energy $\bar{\mathbf{5}}$ are from 1, 2 generations $\Psi_1(\mathbf{27}), \Psi_2(\mathbf{27})$

$$\bar{\mathbf{5}}^{\rm low}_1 \sim \bar{\mathbf{5}}_1 \leftarrow \Psi_1(\mathbf{27}) \longrightarrow \mathbf{10}_1$$
$$\bar{\mathbf{5}}^{\rm low}_2 \sim \bar{\mathbf{5}}'_1 \qquad \Psi_2(\mathbf{27}) \longrightarrow \mathbf{10}_2$$
$$\bar{\mathbf{5}}^{\rm low}_3 \sim \bar{\mathbf{5}}_2 \qquad \Psi_3(\mathbf{27}) \longrightarrow \mathbf{10}_3$$

    -- Mixing of $\bar{\mathbf{5}}$ realize hierarchies

Up type Yukawa

$$(Y^H)_{ij}\mathbf{10}_i\mathbf{10}_j\mathbf{5}_h$$

$$(Y_u) = (Y^H) \sim \begin{pmatrix} \lambda^6 & \lambda^5 & \lambda^3 \\ \lambda^5 & \lambda^4 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

Down-type, Charged lepton Yukawa (Mild hierarchy)

$$(Y^H)_{ij}\mathbf{10}_i\bar{\mathbf{5}}_j\bar{\mathbf{5}}_h \longrightarrow (Y^H)'_{ij}\mathbf{10}_i\bar{\mathbf{5}}^{\rm low}_j\bar{\mathbf{5}}_h$$

$$(Y^H)'_{ij} = (Y_d) = (Y_e)^{\rm T} \sim \begin{array}{c} \\ \mathbf{10}_1 \\ \mathbf{10}_2 \\ \mathbf{10}_3 \end{array} \begin{array}{ccc} \bar{\mathbf{5}}^{\rm low}_1 & \bar{\mathbf{5}}^{\rm low}_2 & \bar{\mathbf{5}}^{\rm low}_3 \\ \lambda^6 & \lambda^{5.5} & \lambda^5 \\ \lambda^5 & \lambda^{4.5} & \lambda^4 \\ \lambda^3 & \lambda^{2.5} & \lambda^2 \end{array}$$

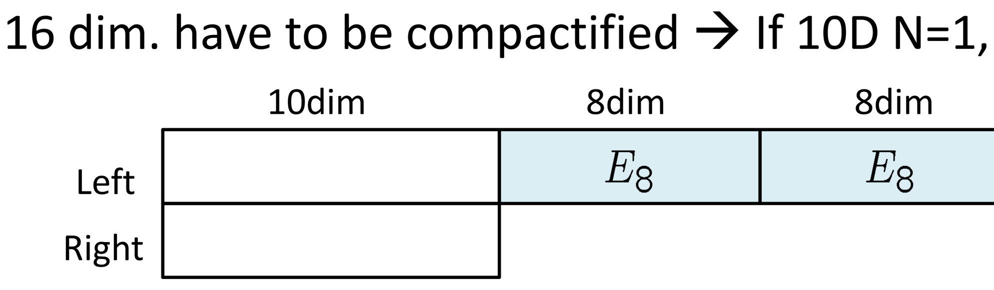
Requirements for String Model Building

- Requirements for string model building :
  - 4D $\mathcal{N}=1$ SUSY,
  - E6 unification group,
  - Net 3 chiral generations ($\mathbf{27}$, $\overline{\mathbf{27}}$),
  - Adjoint Higgs fields ($\mathbf{78}$),
  - SU(2)H or SU(3)H family symmetry,
  - Anomalous U(1)A gauge symmetry,
  - Adjoint Higgs fields charged under the anomalous U(1)A gauge symmetry.

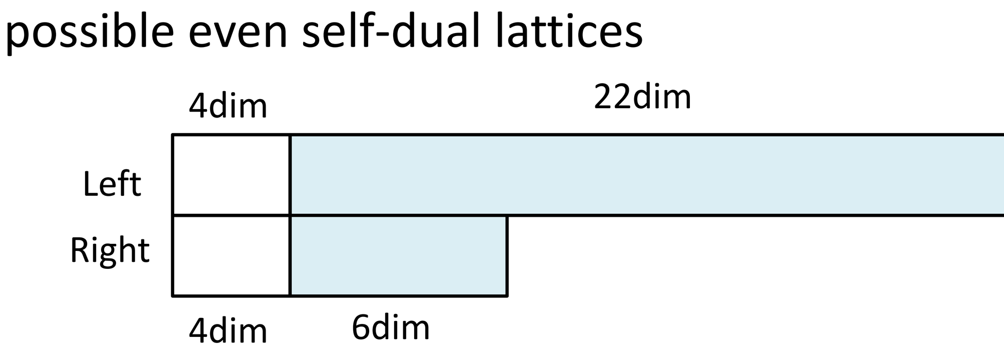
Minimum requirements for 4D-SUSYGUT models
↓
Embedding them into String !

Heterotic Asymmetric Orbifold

- Heterotic String
  - Degrees of freedom
    - --- Left mover 26 dim. Bosons
    - --- Right mover 10 dim. Bosons and fermions
  - Extra 16 dim. have to be compactified → If 10D N=1, E8 X E8 or SO(32)

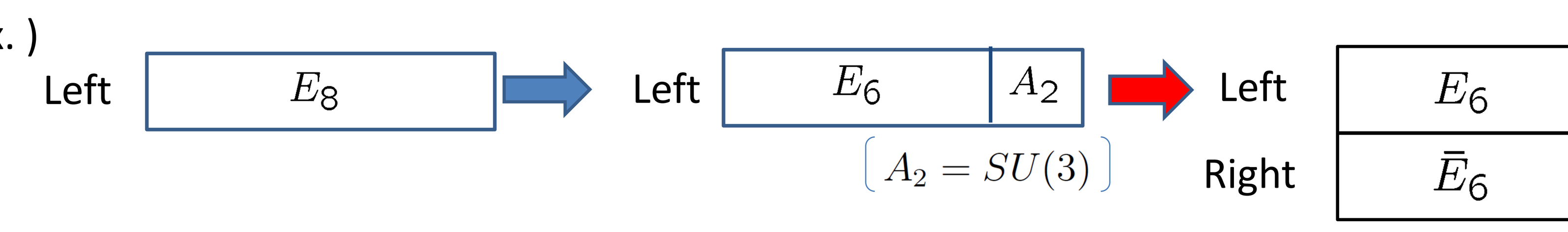


- Even Self-Dual Lattice (Narain Lattice)
  - Left-right combined momentum$(p_L||p_R)$ are quantized, and compose a lattice
  - Many possible even self-dual lattices



- Lattice Engineering Technique — Lerche, Schellekens, Warner '88
  - We can construct new even self-dual lattice from known one.

Ex.)



E_6 gauge symmetry ! ← $E_6 \times \bar{E}_6$ lattice

  - In repeating fashion, we can construct various (22,6) even self-dual lattices

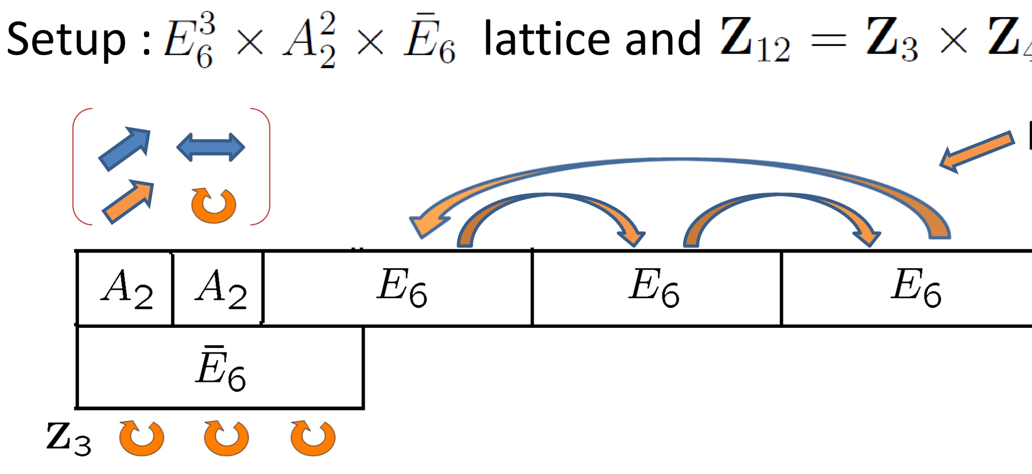
- Asymmetric Orbifold Compactification — Narain, Sarmadi, Vafa '87
  - Orbifold action $\theta = (\theta_L, \theta_R)$

Modding out the lattice in left-right independent way
$\theta = (\theta_L, \theta_R) \quad \theta_L \neq \theta_R$

$X_L \to \theta_L X_L$
$X_R \to \theta_R X_R$
$\Psi_R \to \theta_R \Psi_R$

Our Setup

- Setup : $E_6^3 \times A_2^2 \times \bar{E}_6$ lattice and $\mathbf{Z}_{12} = \mathbf{Z}_3 \times \mathbf{Z}_4$ orbifold action



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Result

New Models !!

- 3-generation E_6 models
  - Net three chiral genetaions
  - One adjoint Higgs field
  - Model 1 : Same mass spectrum as the known model
  - Model 2,3 ; New models !
  - No anomalous U(1) and family symmetries

	Model 1	Model 2	Model 3
	$E_6 \times SU(2) \times U(1)^3$	$E_6 \times SU(2) \times U(1)^3$	$E_6 \times U(1)^4$
U	$(\mathbf{1},\mathbf{1},+6,0,0)_L$ $(\mathbf{78},\mathbf{1},0,0,0)_L$	$(\mathbf{1},\mathbf{1},+6,\pm3,0)_L$ $(\mathbf{78},\mathbf{1},0,0,0)_L$	$(\mathbf{1},-6,0,0,0)_L$ $(\mathbf{1},+3,\pm6,0,0)_L$ $(\mathbf{78},0,0,0,0)_L$
T_1	$(\mathbf{27},\mathbf{1},+1,0,\pm1)_L$	—	$(\mathbf{27},-1,-1,+1,0)_L$
T_2	$(\overline{\mathbf{27}},\mathbf{1},-1,\pm1,0)_L$	$(\overline{\mathbf{27}},\mathbf{1},+2,0,-2)_L$	$(\overline{\mathbf{27}},+1,0,0,\pm1)_L$
T_3	$2(\mathbf{1},\mathbf{1},-3,0,\pm3)_L$	$(\mathbf{1},\mathbf{1},-3,\pm3,-3)_L$	$(\mathbf{1},+3,-3,+3,0)_L$ $(\mathbf{1},+3,+3,-3,0)_L$
T_4	$(\mathbf{27},\mathbf{1},-2,0,0)_L$	$(\mathbf{27},\mathbf{1},-2,\pm1,0)_L$	$(\mathbf{27},+2,0,0,0)_L$ $(\mathbf{27},-1,\pm2,0,0)_L$
T_5	$(\mathbf{27},\mathbf{1},+1,0,\pm1)_L$	$(\mathbf{27},\mathbf{1},+1,\pm1,+1)_L$	$(\mathbf{27},-1,+1,-1,0)_L$
T_6	$(\mathbf{1},\mathbf{2},0,0,\pm3)_L$ $(\mathbf{1},\mathbf{1},+3,\pm3,0)_L$	$(\mathbf{1},\mathbf{2},0,\pm3,0)_L$ $(\mathbf{1},\mathbf{1},-6,0,+6)_L$	$(\mathbf{1},-3,0,0,\pm3)_L$ $(\mathbf{1},0,+6,-2,0)_L$ $(\mathbf{1},0,-6,+2,0)_L$