Discrete Flavor Symmetry in String Model

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Introduction

- String → Standard Model
  - String theory
    -- A candidate which describe quantum gravity and unify four forces
    -- Is it possible to realize phenomenological properties of Standard Model ?
  - (Supersymmetric) Standard Model
    -- We have to realize all properties of Standard model

      Four-dimensions,
      N=1 supersymmetry,
      Standard model group(SU(3)*SU(2)*U(1)),
      Three generations,
      Quarks, Leptons and Higgs,
      No exotics,
      Yukawa hierarchy, → The key is **non-Abelian discrete symmetry**
      Proton longevity,
      R-parity,
      Doublet-triplet splitting,
      Moduli stabilization,
      ...

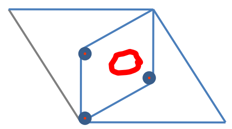
- String → Standard Model ----- String compactification : 10-dim → 4-dim

  Orbifold compactification, Calabi-Yau, Intersecting D-brane, Magnetized D-brane, F-theory, M-theory, ...

- Orbifold compactification

  Dixon, Harvey, Vafa, Witten '85,'86
  Ibanez, Kim, Nilles, Quevedo '87

  - SM or several GUT gauge symmetries
  - N=1 supersymmetry
  - Chiral matter spectrum



- MSSM searches in orbifold vacua :
  Embedding higher dimensional GUT into string

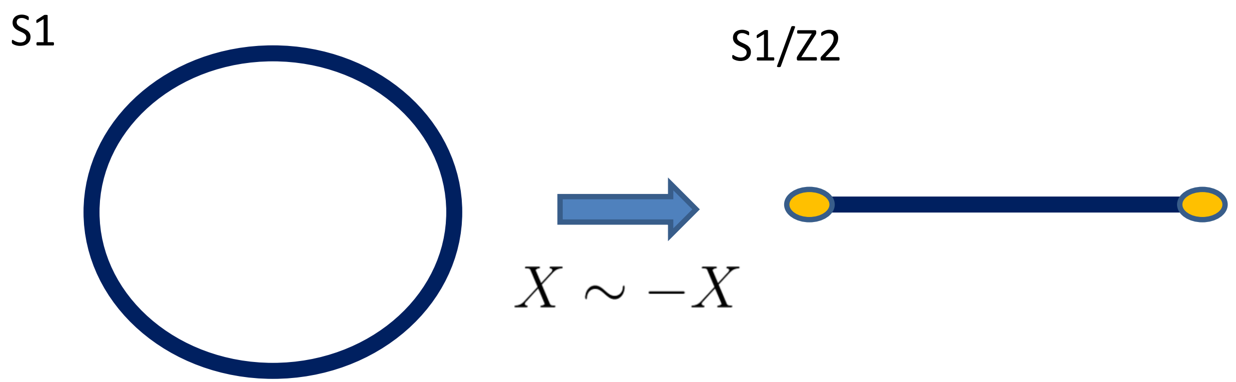
  Three generations,
  Quarks, Leptons and Higgs,
  No exotics,
  Top Yukawa,
  Proton longevity,
  R-parity,
  Doublet-triplet splitting,
  ...

  Kobayashi, Raby, Zhang '04
  Buchmuller, Hamaguchi, Lebedev, Ratz '06
  Lebedev, Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter '07
  Kim, Kyae '07
  ......

Discrete flavor symmetry in heterotic orbifolds

- Orbifold compactification of heterotic string theory

Kobayashi, Nilles, Plöger, Raby, Ratz '07



- Boundary condition

$$X^i(\sigma + \pi) = (\theta^k X)^i + n_a e_a^i$$

- String coupling selection rule

Conjugacy class : (θ, me)

$$\prod_j (\theta, m^j e) = (1, (1-\theta)\Gamma)$$

- 1 dimensional orbifold : S1/Z2

-- String coupling selection rule

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$$

-- Relabeling fixed points

$$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

These Abelian discrete symmetries generate the non-Abelian discrete symmetry

$$D_4 = (Z_2 \times Z_2) \rtimes Z_2$$

- 2 dimensional orbifold : T2/Z3

  -- String coupling selection rule

$$\begin{pmatrix} \omega & 0 & 0 \\ 0 & \omega & 0 \\ 0 & 0 & \omega \end{pmatrix}, \begin{pmatrix} 1 & 0 & 0 \\ 0 & \omega & 0 \\ 0 & 0 & \omega^{-1} \end{pmatrix}$$

  -- Relabeling fixed points

$$\begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

These Abelian discrete symmetries generate the non-Abelian discrete symmetry

$$\Delta(54) = (Z_3 \times Z_3) \rtimes S_3$$

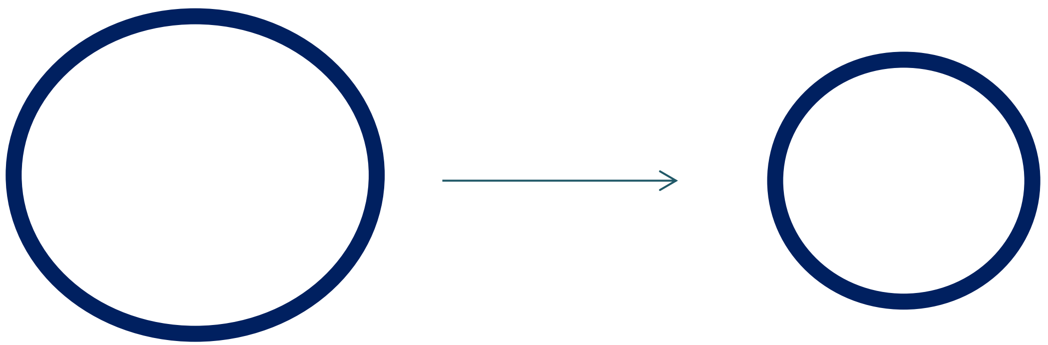
Non-Abelian discrete symmetries have a stringy origin, which are determined by the structure of the extra dimension space

Gauge origin of discrete flavor symmetry

- symmetry enhance point in moduli space

Beye, Kobayashi, Kuwakino
arXiv:1406.4660 [hep-th]

S1



U(1) gauge symmetry → SU(2) gauge symmetry

S1/Z2

D4 discrete symmetry → U(1) gauge symmetry

◆ 1-dimensional orbifold model at symmetry enhance point

-- Currents

$$H' = i\partial X' = \frac{1}{\sqrt{2}}(E_+ + E_-)\,,$$

$$E'_\pm = e^{\pm i\alpha X'} = \frac{1}{\sqrt{2}}H \mp \frac{1}{2}(E_+ - E_-)$$

$$\left(\begin{aligned} H &= i\partial X \\ E_\pm &= e^{\pm i\alpha X} \end{aligned} \right)$$

-- Massless spectrum

Sector	Field	$U(1)$ charge	Z_4 charge
U	U	0	0
U	U_1	α	0
U	U_2	$-\alpha$	0
T	M_1	$\frac{\alpha}{4}$	$\frac{1}{4}$
T	M_2	$-\frac{\alpha}{4}$	$-\frac{1}{4}$

-- This model has symmetry : $U(1) \rtimes Z_2$

Z2 symmetry can be described by

$$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

-- Non zero VEV of Kahler moduli field breaks the U(1) symmetry to Z4 Abelian discrete symmetry

$$T = \frac{1}{\sqrt{2}}(U_1 + U_2)$$

$$\langle U_1 \rangle = \langle U_2 \rangle$$

Z4 symmetry can be described by

$$\begin{pmatrix} i & 0 \\ 0 & -i \end{pmatrix}$$

-- Symmetry breaking patterns are summarized as

$$SU(2) \xrightarrow[\text{orbifolding}]{} U(1) \rtimes Z_2 \xrightarrow[\langle T \rangle]{} D_4$$

◆ 2-dimensional orbifold model at symmetry enhance point

-- Massless spectrum

Sector	Field	$U(1)^2$ charge	Z_3^2 charge
U	U	$(0,0)$	$(0,0)$
U	U_1	$-\alpha_1$	$(0,0)$
U	U_2	$-\alpha_2$	$(0,0)$
U	U_3	$\alpha_1+\alpha_2$	$(0,0)$
T	M_1	$\frac{\alpha_1}{3}$	$(\frac{1}{3},\frac{1}{3})$
T	M_2	$\frac{\alpha_2}{3}$	$(-\frac{1}{3},0)$
T	M_3	$-\frac{\alpha_1+\alpha_2}{3}$	$(0,-\frac{1}{3})$

-- This model has symmetry : $U(1)^2 \rtimes S_3$

Z2 symmetry can be described by

$$\begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

-- Non zero VEV of Kahler moduli field breaks the U(1)^2 symmetry to Z3 x Z3 Abelian discrete symmetry

$$T = \frac{1}{\sqrt{3}}(U_1 + U_2 + U_3)$$

$$\langle U_1 \rangle = \langle U_2 \rangle = \langle U_3 \rangle$$

Z3 x Z3 symmetry can be described by

$$\begin{pmatrix} \omega & 0 & 0 \\ 0 & \omega^{-1} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \omega & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \omega^{-1} \end{pmatrix}$$

-- Symmetry breaking patterns are summarized as

$$SU(3) \xrightarrow[\text{orbifolding}]{} U(1)^2 \rtimes S_3 \xrightarrow[\langle T \rangle]{} \Delta(54)$$

Example model

- Heterotic asymmetric orbifold model
- SU(3) → U(1)^2 Xl S3 by orbifolding
- There-generation SUSY SM model

Gauge symmetry : $SU(3)_C \times SU(2)_L \times U(1)_Y \times SU(2)^2 \times SU(4) \times SU(5) \times U(1)^9$

Untwisted sector : 3 x 11 multiplets

Twisted sector : 1 x 114 multiplets

Three-generation quarks and leptons

Suitable U(1) hyper charges

Vector-like exotics

- This model realizes Δ(54) discrete flavor symmetry in low energy effective theory
- This gauge origin mechanism can also be applied to string models in non-geometric background

Summary and discussion

- A non-Abelian continuous gauge symmetry can be regarded as the origin of a non-Abelian discrete flavor symmetry in heterotic orbifolds
- This can be understood at symmetry enhance point in moduli space
- This mechanism can be applied to non-geometric string models

- Application of this mechanism to field theoretical models
  -- Higher-dimensional gauge theory on orbifolds
  -- Gauge extension of discrete flavor model
  -- New Z' bosons