Discrete Symmetries

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Strings and Particle Physics

String theory provides us with

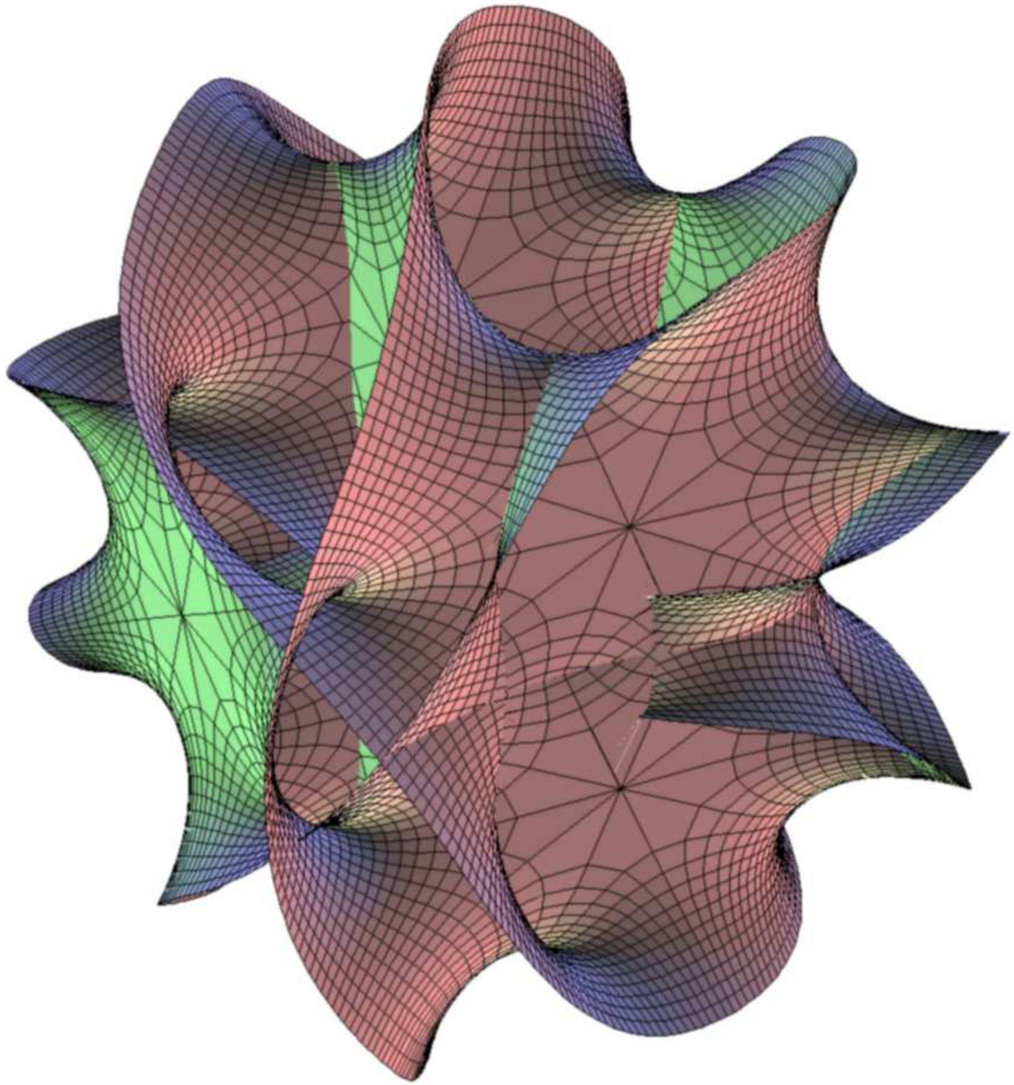
- gauge groups,
- matter multiplets for quarks and leptons,
- discrete $(R-)$symmetries.

The MSSM is not a generic prediction of string theory:

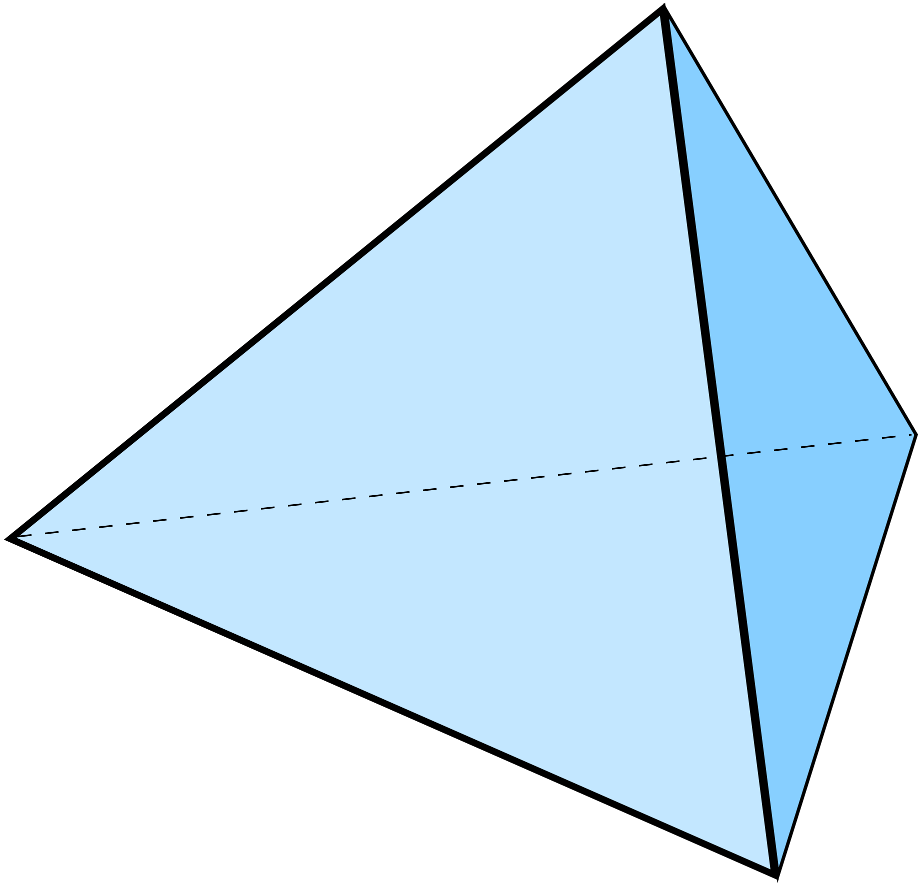
- need exploration of the "Landscape" at non-generic points with higher symmetries
- that provide enhanced discrete $(R-)$symmetries.

The geometry of compactified space (and its symmetries) is a crucial ingredient for successful model building.

Calabi Yau Manifold



Orbifold



Work with Fernando

CERN-TH.4611/86

ORBIFOLDS AND WILSON LINES

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CERN, 1211 Geneva 23, Switzerland

ABSTRACT

We study the consequences of the presence of gauge background fields on the torus underlying orbifold compactification of the heterotic string. It is pointed out that such Wilson lines provide us with a mechanism for controlling the number of chiral matter states both from twisted and untwisted sectors, as well as breaking the symmetry group. Starting from the Z orbifold, we can construct a variety of four-dimensional string models with three families of quarks and leptons and different gauge groups such as E_6, $SU(3)^3$, $SU(6) \times U(1)$ or $SU(5) \times [SU(2) \times U(1)]^2$.

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Preprints and Handwriting

where $n_i = 0, \pm 1$. Different values of n_i lead to different twisted sectors. Since in the Z orbifold there are 27 twisted sectors, corresponding to the 27 fixed points, this means that turning on the three independent Wilson lines will make all the twisted sectors unequivalent. This is a consequence of the fact that different fixed points are invariant up to different lattice vectors. Invariance under $\tau \to \tau + 3$ on these sectors imposes the constraints [6]

$$3\left(V^I + n_i a_i^I\right)^2 = 2m \qquad m \in \mathbb{Z} \tag{7}$$

There is then a modular-invariance constraint for every twisted sector. The mass formulae for the twisted sectors are modified by the shifts in the $E_8 \times E_8$ lattice as well as by the modded oscillators' contribution to the zero point energy. In our case we have

A three family model ...

CERN-TH.4661/87

ORBIFOLD COMPACTIFICATIONS WITH THREE FAMILIES OF $SU(3) \times SU(2) \times U(1)^n$

L.E. Ibàñez, Jihn E. Kim*), H.P. Nilles and F. Quevedo

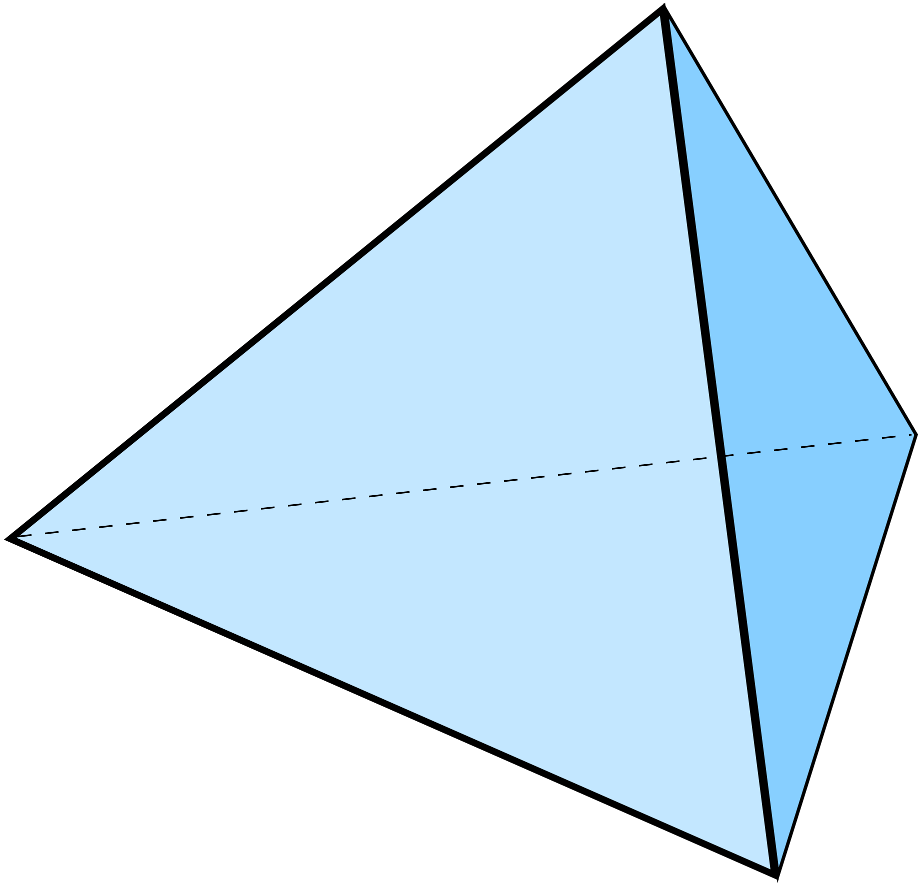
CERN — Geneva

ABSTRACT

We construct several $N = 1$ supersymmetric three-generation models with $SU(3) \times SU(2) \times U(1)^n$ gauge symmetry, obtained from orbifold compactification of the heterotic string in the presence of constant gauge-background fields. This Wilson-line mechanism also allows us to eliminate extra colour triplets which could mediate fast proton decay.

... with four authors

Orbifold



Localization

Quarks, Leptons and Higgs fields can be localized:

- in the Bulk ($d = 10$ untwisted sector,)
- on 3-Branes ($d = 4$ twisted sector fixed points),
- on 5-Branes ($d = 6$ twisted sector fixed tori).

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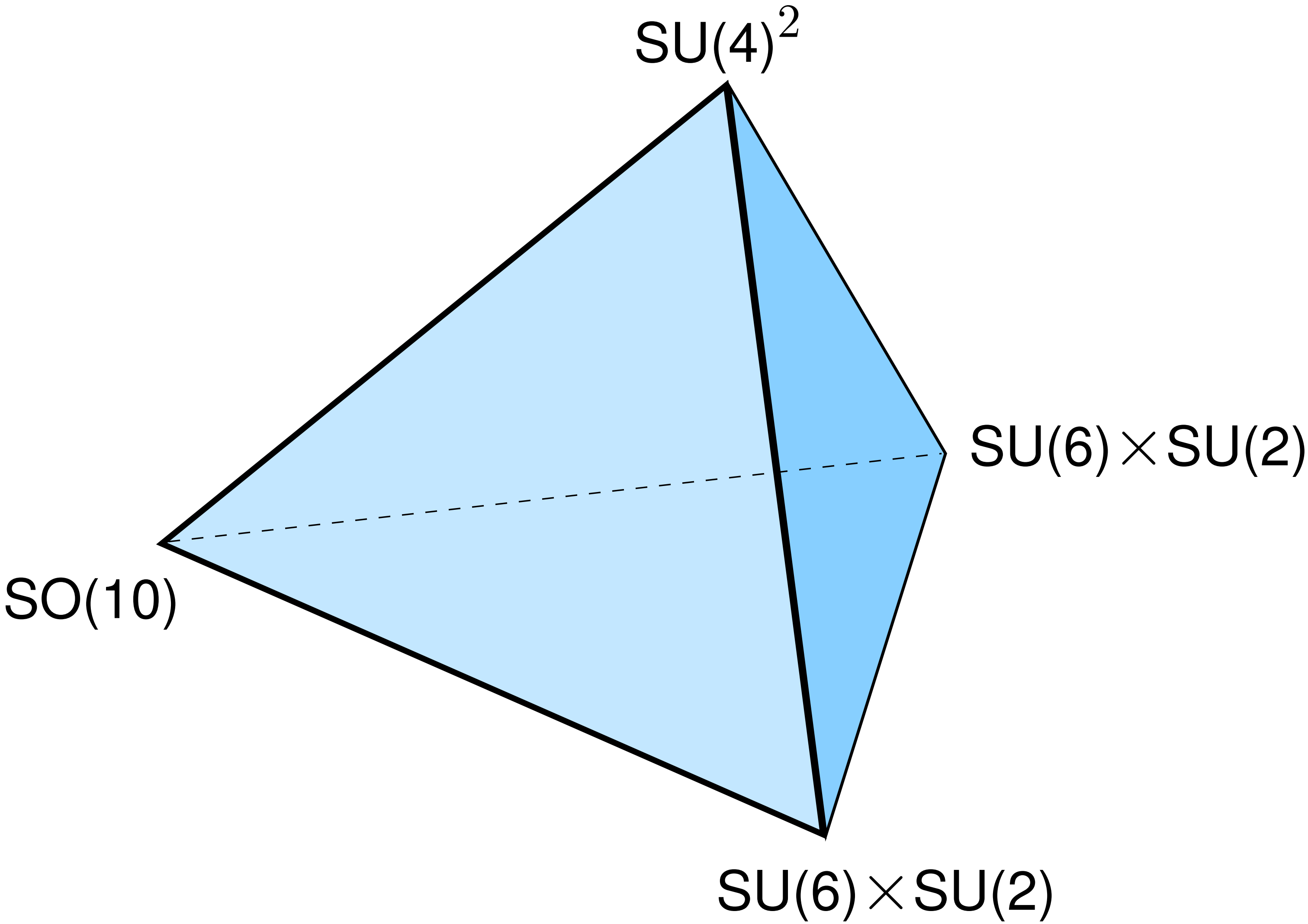
But there is also a "localization" of gauge fields:

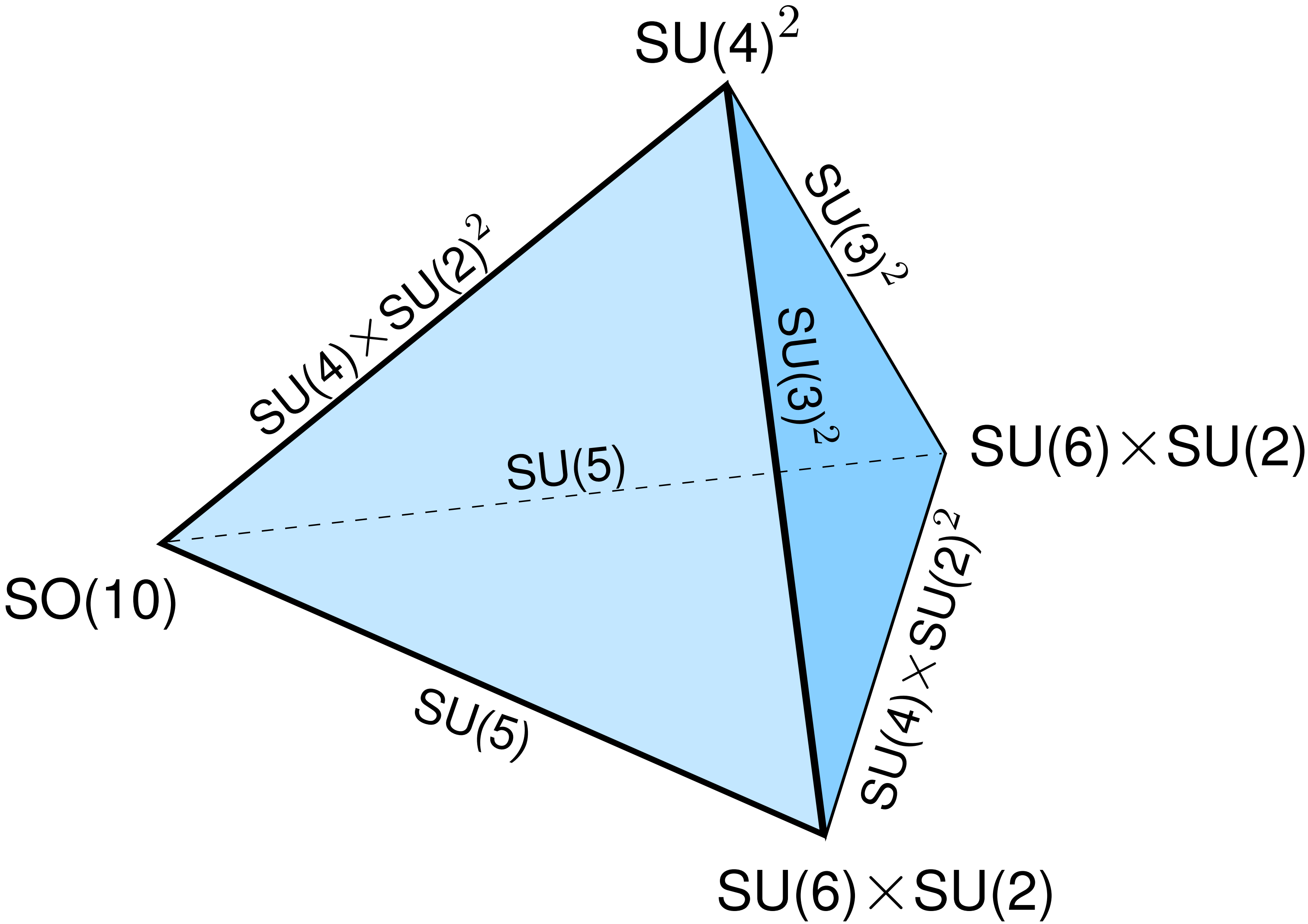
- e.g. $E_8 \times E_8$ in the bulk,
- smaller gauge groups on various branes.

Observed 4-dimensional gauge group is common subroup of the various localized gauge groups!

Localized gauge symmetries



Standard Model Gauge Group



Local Grand Unification

In fact string theory gives us a variant of GUTs:

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- split multiplets for gauge- and Higgs-bosons,
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Key properties of the theory depend on the geography of the fields in extra dimensions.

At specific "branes" we have

- enhancement of gauge symmetries,
- enhancement of discrete $(R-)$symmetries.

The Extended MiniLandscape

It all started with the Z_3 orbifold.

(Kim, Ibanez, Nilles, Quevedo, 1987)

- MiniLandscape with explicit models for $Z_6 II$

  (Lebedev, HPN, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, 2007-2009)

- local grand unification (by construction)
- gauge- and (partial) Yukawa unification
- models with matter-parity + solution to the μ-problem

  (Lebedev et al., 2007)

- explicit construction based on $Z_6 II$, $Z_2 \times Z_2$ and $Z_2 \times Z_4$

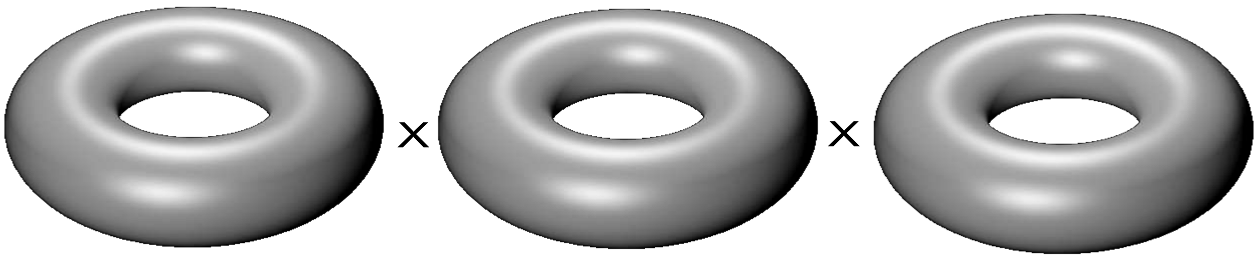
  (Blaszczyk, Groot-Nibbelink, Ratz, Ruehle, Trapletti, Vaudrevange, 2010;

  Mayorga-Pena, HPN, Oehlmann, 2012)

Structure of Sectors of $Z_2 \times Z_4$

The underlying $Z_2 \times Z_4$ orbifold has the following sectors:

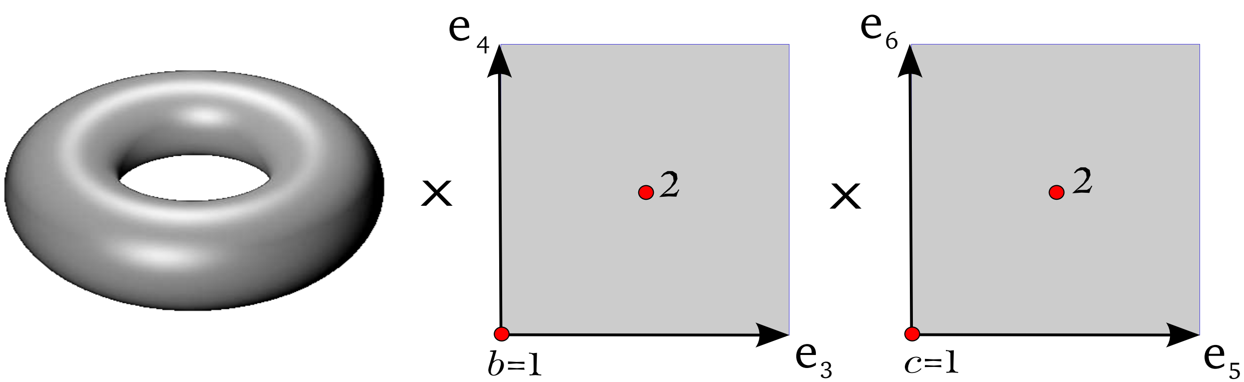
- the untwisted sector



Fields live in the bulk $d = 10$ with remnant $N = 4$ Susy (for tree level interactions)

Twisted sectors

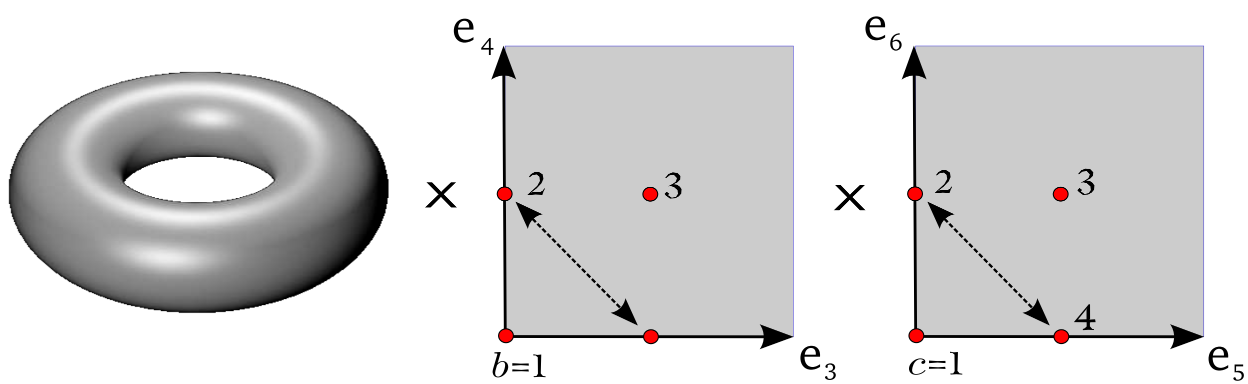
Twisted sectors correspond to the $Z_2(\theta)$ and $Z_4(\omega)$ twists



The ω sector has 2 x 2 = 4 fixed tori, corresponding to

- "5-branes" confined to $d = 6$ space time ($N = 2$ Susy).

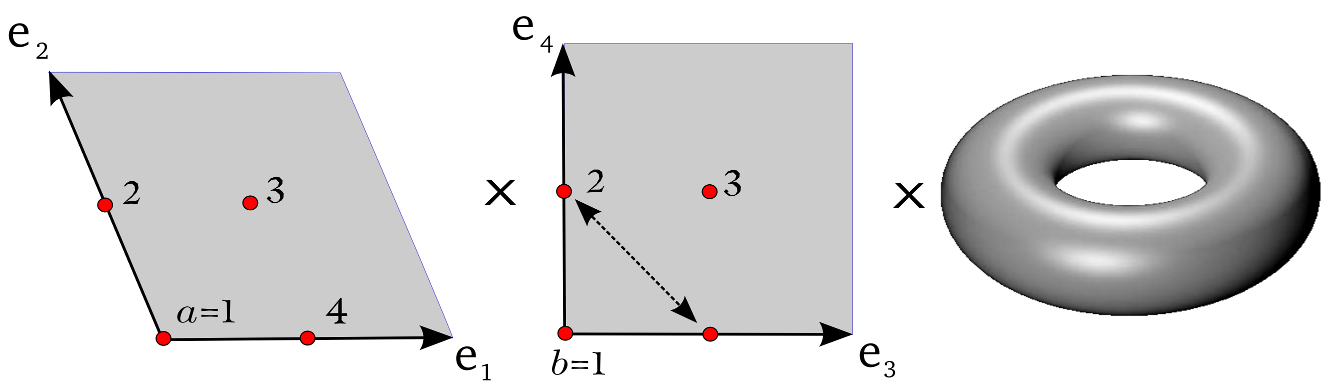
ω^2 twisted sector



The ω^2 twisted sector contains fixed tori correponding to

- "5-branes" confined to 6 space-time dimension (with remnants of $N = 2$ Susy).

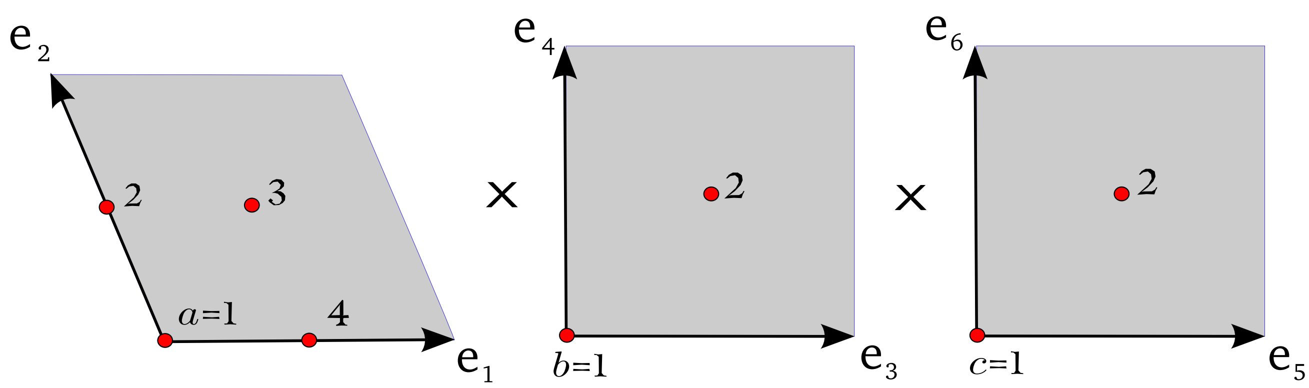
θ twisted sector



The θ twisted sector contains 4 x 3 fixed tori as well:

- "5-branes" confined to 6 space-time dimension (with remnants of $N = 2$ Susy).

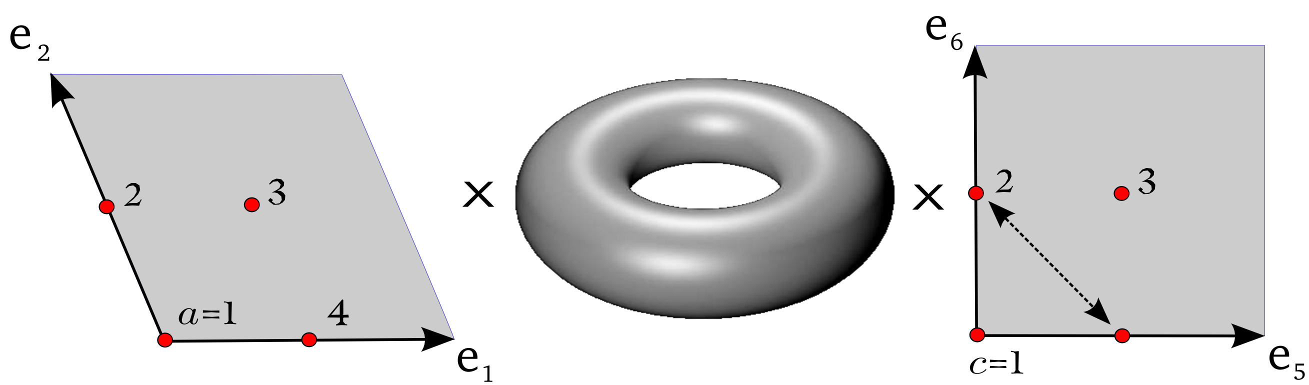
$\theta\omega$ twisted sector



The $\theta\omega$ twisted sector contains 4 x 2 x 2 fixed points:

- "3-branes" confined to 4 space-time dimension (sector with remnant of $N = 1$ Susy).

$\theta\omega^2$ twisted sector



The $\theta\omega^2$ twisted sector contains 4 x 3 fixed tori:

- "5-branes" confined to 6 space-time dimension (with remnants of $N = 2$ Susy).

Where do we find quarks, leptons and Higgs bosons in the models of the MiniLandscape?

The specific role of $R-$symmetries

Successful models of the “MiniLandscape” have

- exactly two Higgs doublets (no triplets). Other potential Higgs pairs removed with other vector-like exotics,
- μ protected by an $R-$symmetry.

(Lebedev et al., 2008; Kappl et al., 2009)

The specific role of $R-$symmetries

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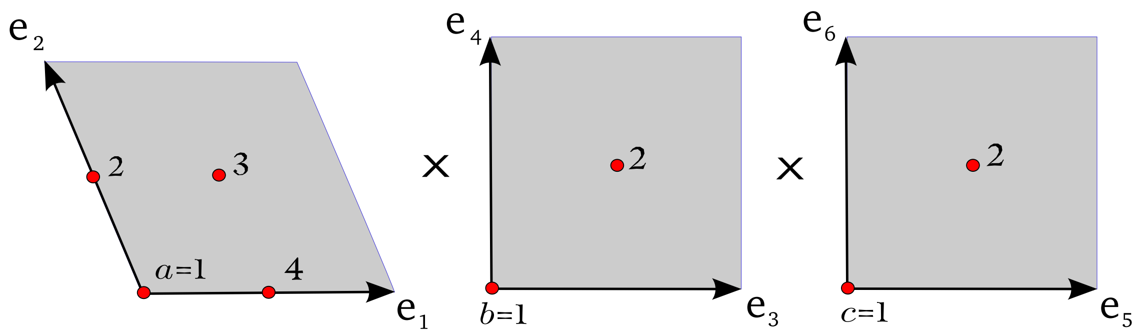
This last pair is localized in the untwisted sector (bulk):

- $R-$symmetry from Lorentz group in extra dimensions,
- solution to μ problem (Minkowski vacuum),
- gauge-Higgs unification.

Discrete Family Symmetries

The first two families live at fixed points:



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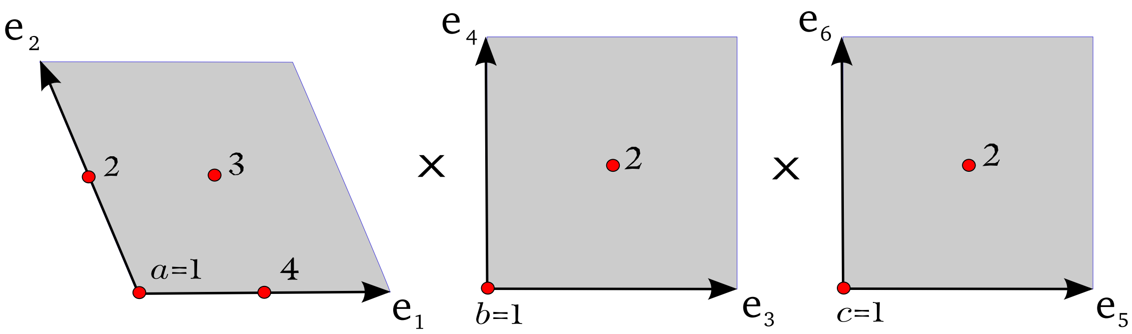

- they exhibit a D_4 family symmetry
- subgroup of $SU(2)$ flavour symmetry
- its origin is the interplay of geometry and selection rules

(Kobayashi, Nilles, Ploger, Raby, Ratz, 2007)

$R-$symmetries

$R-$symmetry can be understood as an extension of Susy

- $N = 1$ Susy with $U(1)_R$ forbids gaugino masses, μ-term and trilinear soft terms (A)
- broken to discrete symmetry like Z_2 matter parity to guarantee proton stability

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The superpotential transforms nontrivially under any $R-$symmetry

- gravitino mass as signal of $R-$symmetry breakdown and Susy breakdown,
- connects $\mu-$term with Susy breakdown and provides a solution to the $\mu-$problem.

$R-$symmetries from strings

The origin of $R-$symmetries is two-fold:

- string selection rules, (Cabo -Bizet et al., 2013; Kappl et al., 2014)
- Lorentz group of extra dimensions

$$SO(9,1) \to SO(3,1) \times SO(6).$$

Connections to $N-$extended Susy:

- torus compactification from 10 to 4 leads to $N = 4$ Susy,
- $R-$symmetry $SU(4)_R \sim SO(6)$ (completely geometric),
- fixed tori from $d = 6$ could lead to $N = 2$ extended Susy,
- $R-$symmetry $SU(2)_R$ (which is partially geometric).

Properties of $R-$symmetry

Connection between $R-$symmetry and holonomy group of compact manifold:

- $SU(3)$ holonomy $(\Gamma^{ijk}H_{ijk})$,
- its relation to the superpotential
- and gaugino condensates of hidden gauge group.
- Maximal geometric group is $SU(4)_R$ descending from $d = 10$ and thus completely of geometric origin.
- From $d = 6$ we can have $U(2)_R \times U(2)_R$ partially from geometry and partially from selection rules,
- similar to the situation of normal discrete symmetries (e.g. D_4 flavour symmetry discussed earlier).

The power of $R-$symmetries

More $R-$symmetries imply better protection than just Susy alone. This is of particular importance for

- the solution of the $\mu-$ problem,
- connection of $\mu-$term to gravitino mass and Susy breakdown via nonperturbative effects,
- the question of proton stability (protected by discrete symmetries),
- pattern of soft Susy breaking terms in various sectors of extended Susy. (Krippendorf, Nilles, Ratz, Winkler, 2012-13)

$R-$symmetries are abundant in orbifold compactifications of string theories and slightly broken away from orbifold point.

Messages

- The MSSM is (unfortunately) not a generic prediction of the string landscape
- compact manifolds with specific discrete properties can provide approximate discrete $(R-)$symmetries.
- Origin of flavour symmetries and $R-$symmetries from geometry and selection rules.
- Discrete $R-$symmetries are important for
  - solution of the μ problem
  - the question of proton stability
  - pattern of soft terms for "Natural Susy".
- Approximate discrete symmetries allow hierarchies via a Frogatt-Nielsen mechanism.

Congratulations......

... hope for the future ...

Joy, Joie, Freude, Fernando