Proton hexality in local grand unification

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Outline

- Evidence for grand unification and
- the role of global symmetries

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- GUTs and proton hexality
- the fate of global symmetries
- ultraviolet completion
- strings and local grand unification
- bottom up approach
- top down attempts

Proton stability

In the standard model Baryon number $U(1)_B$ is not a good symmetry

- Baryon and lepton number are anomalous
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Baryon number violation is needed for baryogenesis.

- Grand unification addresses these questions
- proton decay via dimension-6 operators
- GUT scale has to be sufficiently high

GUTs need SUSY

Grand unification most natural in the framework of SUSY

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But there is a problem

- dimension-4 and -5 operators
- more symmetries needed
- matter parity (or R-parity)
- baryon triality, proton hexality

(Ibanez, Ross, 1991; Dreiner, Luhn, Thormeier, 2005)

The fate of global symmetries

Global symmetries are very useful for

- absence of FCNC (solve flavour problem)
- Yukawa textures à la Frogatt-Nielsen
- solutions to the μ problem
- axions and the strong CP-problem
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But they might be destroyed by gravitational effects:

- we need a UV-completion of the theory
- with a consistent incorporation of gravity

String theory as UV-completion

What do we get from string theory?

- supersymmetry
- extra spatial dimensions
- (large unified) gauge groups
- consistent theory of gravity
- many discrete symmetries
- no global continuous symmetries

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String theory serves as a UV-completion with a consistent incorporation of gravity,
and thus provides exact global symmetries.

Local Grand Unification

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- complete multiplets for fermion families
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- partial Yukawa unification

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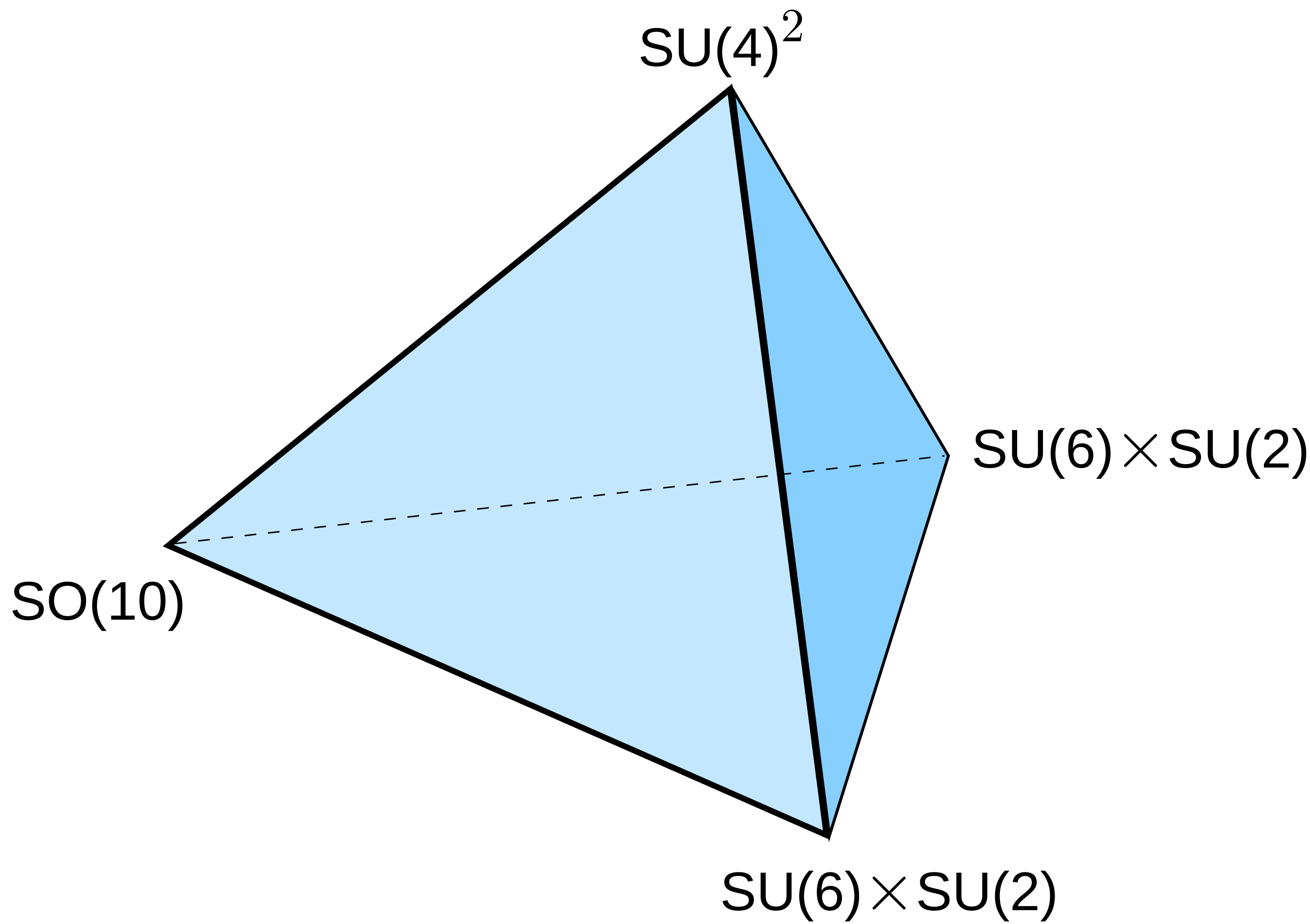
Key properties of the theory depend on the geography of the fields in extra dimensions.

This geometrical set-up called local grand unification, and can be realized in the framework of the "heterotic braneworld".

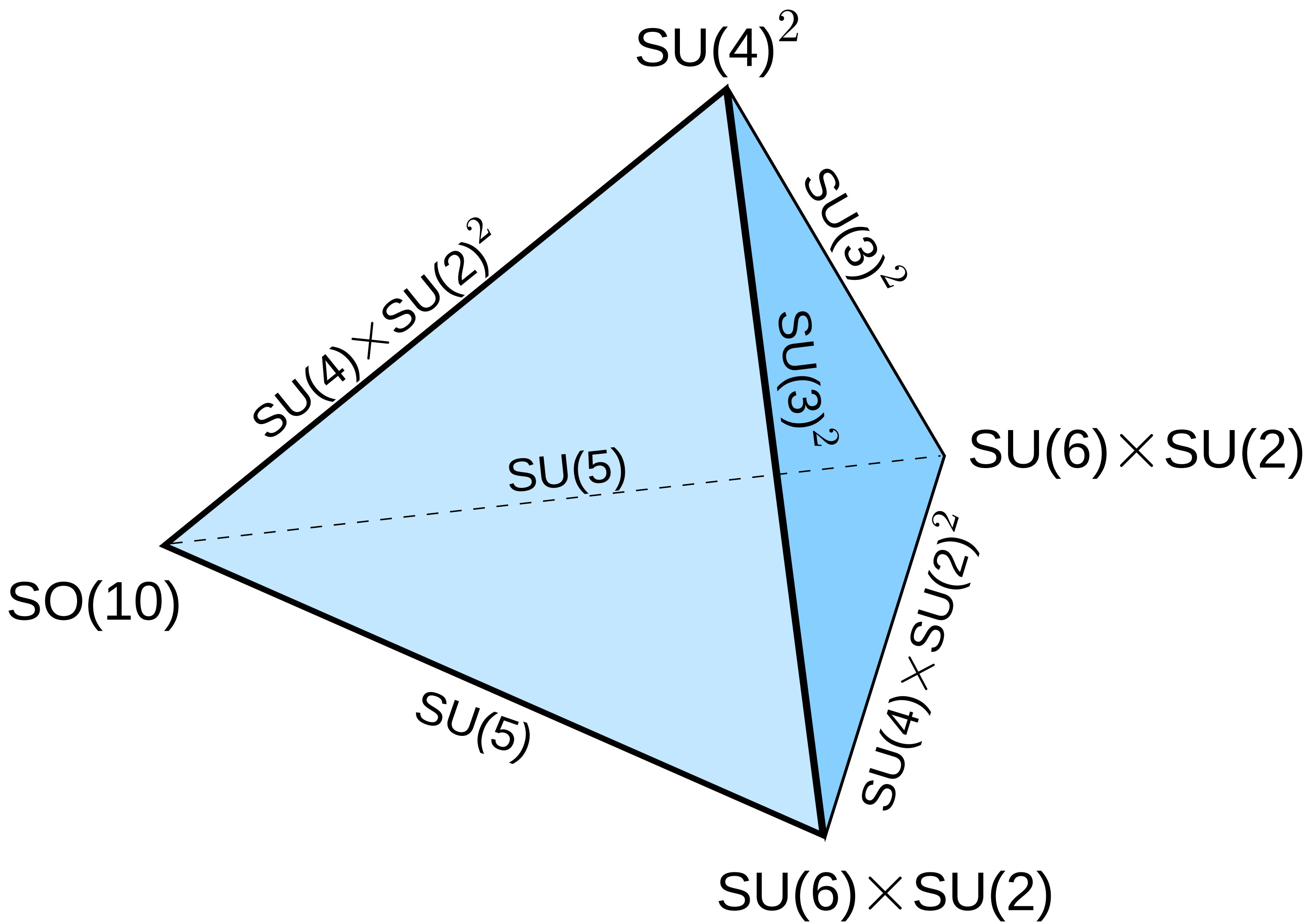
(Förste, HPN, Vaudrevange, Wingerter, 2004; Buchmüller, Hamaguchi, Lebedev, Ratz, 2004)

Localized gauge symmetries



(Förste, HPN, Vaudrevange, Wingerter, 2004)

Standard Model Gauge Group



Symmetries

String theory gives us

- gauge symmetries
- discrete global symmetries from geometry and stringy selection rules (Kobayashi, HPN, Plöger, Raby, Ratz, 2006)
- accidental global $U(1)$ symmetries in the low energy effective action

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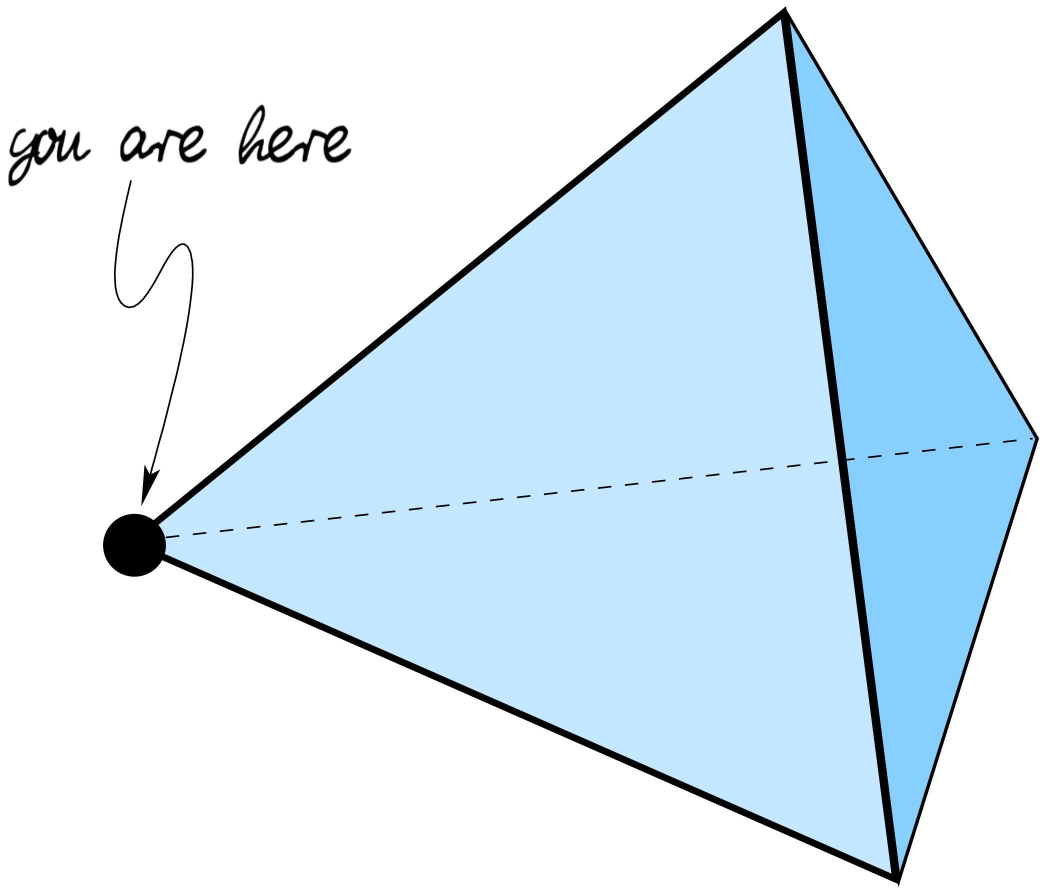
Location matters



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These symmetries can be trusted as we are working within a consistent theory of gravity.

Applications of global symmetries

Applications of discrete and accidental global symmetries:

- (nonabelian) family symmetries (and FCNC)

  (Ko, Kobayashi, Park, Raby, 2007)

- Yukawa textures (via Frogatt-Nielsen mechanism)
- a solution to the μ-problem

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

- creation of hierarchies

  (Kappl, HPN, Ramos-Sanchez, Ratz, Schmidt-Hoberg, Vaudrevange, 2008)

- proton stability via “Proton Hexality”

  (Dreiner, Luhn, Thormeier, 2005; Förste, HPN, Ramos-Sanchez, Vaudrevange, 2010)

- approximate global $U(1)$ for a QCD accion

  (Choi, Kim, Kim, 2006; Choi, HPN, Ramos-Sanchez, Vaudrevange, 2008)

MSSM

The minimal particle content of the susy extension of the standard model includes chiral superfields

- Q, $\bar{U}$, $\bar{D}$ for quarks and partners
- L, $\bar{E}$ for leptons and partners
- H_d, H_u Higgs supermultiplets

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with superpotential

$$W = QH_d\bar{D} + QH_u\bar{U} + LH_d\bar{E} + \mu H_u H_d.$$

Also allowed (but problematic) are dimension-4 operators

$$\bar{U}\bar{D}\bar{D} + QL\bar{D} + LL\bar{E}.$$

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But there are in addition dimension-5 operators that might mediate too fast proton decay

$$QQQL + \bar{U}\bar{U}\bar{D}\bar{E}$$

and we might need alternative symmetries like
baryon triality or proton hexality.

(Ibanez, Ross, 1991; Dreiner, Luhn, Thormeier, 2005)

Proton Hexality

	Q	$\bar{U}$	$\bar{D}$	L	$\bar{E}$	H_u	H_d	$\bar{\nu}$
$6\,Y$	1	-4	2	-3	6	3	-3	0
$\mathbb{Z}_2^{\text{matter}}$	1	1	1	1	1	0	0	1
B_3	0	-1	1	-1	2	1	-1	0
P_6	0	1	-1	-2	1	-1	1	3

Proton hexality is exactly what we need:

- dangerous dimension 4 and 5 operators forbidden
- neutrino Majorana masses allowed (LLH_uH_u)

GUTs and Hexality

Combination of GUTs and proton hexality is perfect

But GUTs and Hexality are incompatible

(Luhn, Thormeier, 2007)

Excluded are basically all GUTs

- $SU(4) \times SU(2) \times SU(2)$
- $SU(5)$ even when flipped
- $SO(10)$

Example:
the 10-dimensional representation of SU(5) includes $\bar{U}$, Q and $\bar{E}$ and they cannot all have the same charge under hexality.

Bottom up approach

Are there ways out? We could try to enhance the gauge group and get P_6 from an additional $U(1)_X$ as e.g.

- $SU(4) \times SU(2)_L \times SU(2)_R \times U(1)_X$
- broken to $SU(3) \times SU(2)_L \times U(1) \times Z_{12}$
- where Z_{12} acts a P_6 on the standard model sector

But this is not really a grand unified theory. Closer to GUTs might be

- $SO(10) \times U(1)_X$ broken to
- $SU(4) \times SU(2)_L \times SU(2)_R \times P_6$
- with $(4, 2, 1)_1$ and $(\bar{4}, 1, 2)_{-1}$

Split multiplets

In fact we could consider

$$SO(12) \to SO(10) \times U(1)_X \to SU(3) \times SU(2)_L \times U(1) \times P_6$$

This would mean that P_6 is a subgroup of $SO(12)$
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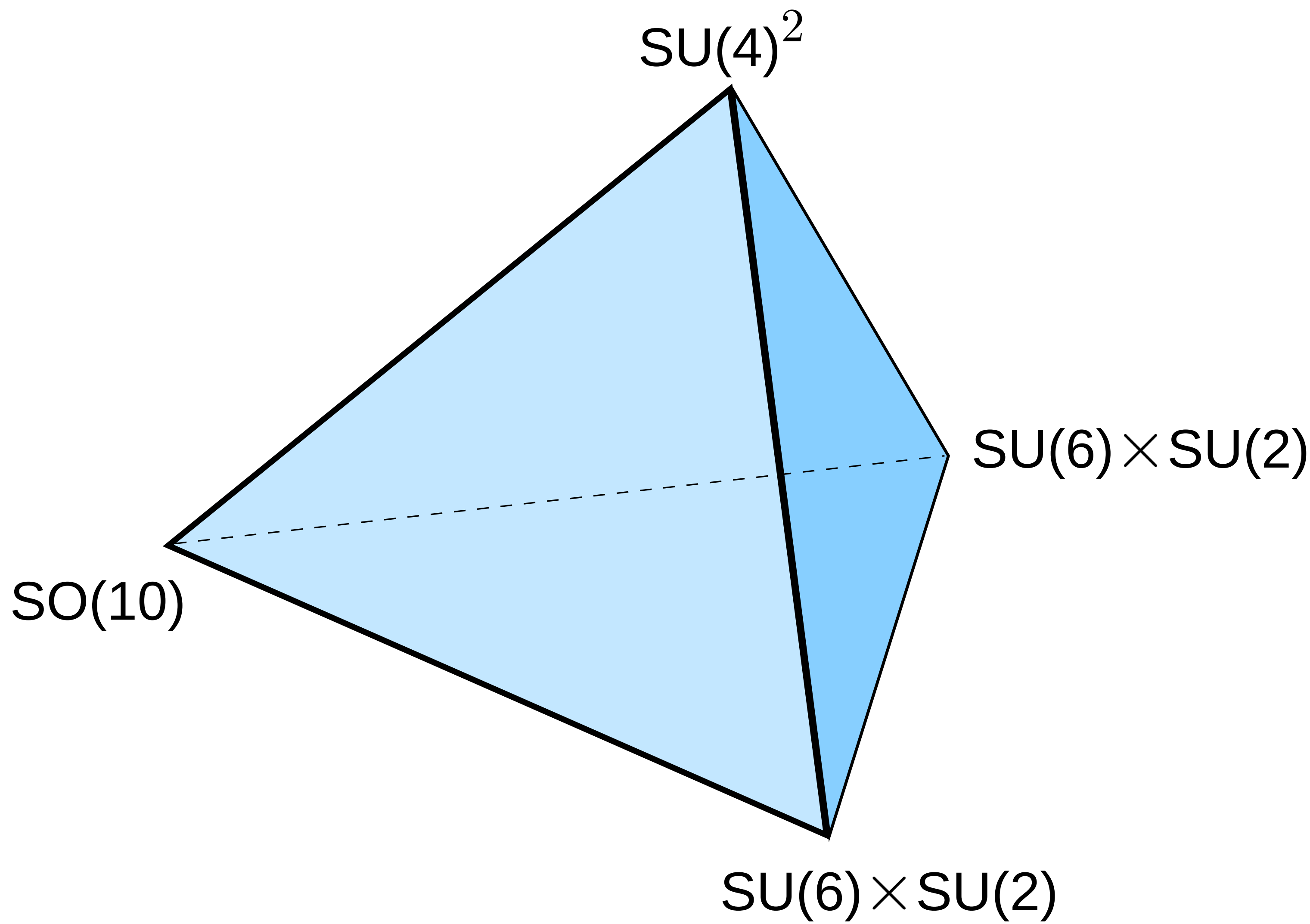
(in the same way as matter parity is a subgroup of $SO(10)$)

Consequences:

- we need representations of (ridiculously) high dimensionality to break $SO(12)$ (analogue of 126 of $SO(10)$ for matter parity)
- appearance of split multiplets

This is exactly what we get in the framework of
local grand unification in the braneworld picture.

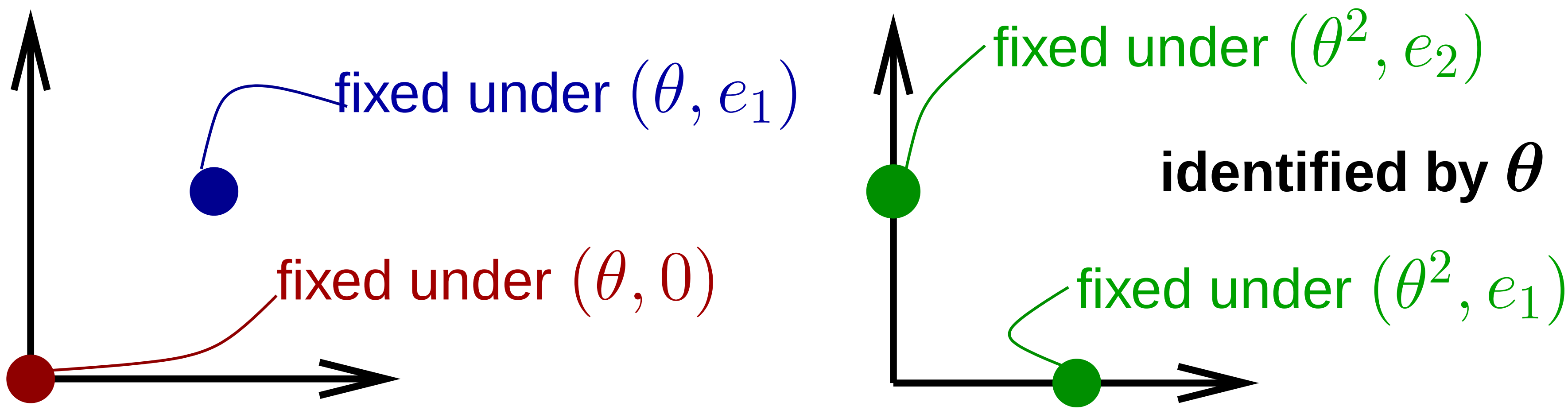
Localized gauge symmetries



(Förste, HPN, Vaudrevange, Wingerter, 2004)

A T_2/Z_4 toy example

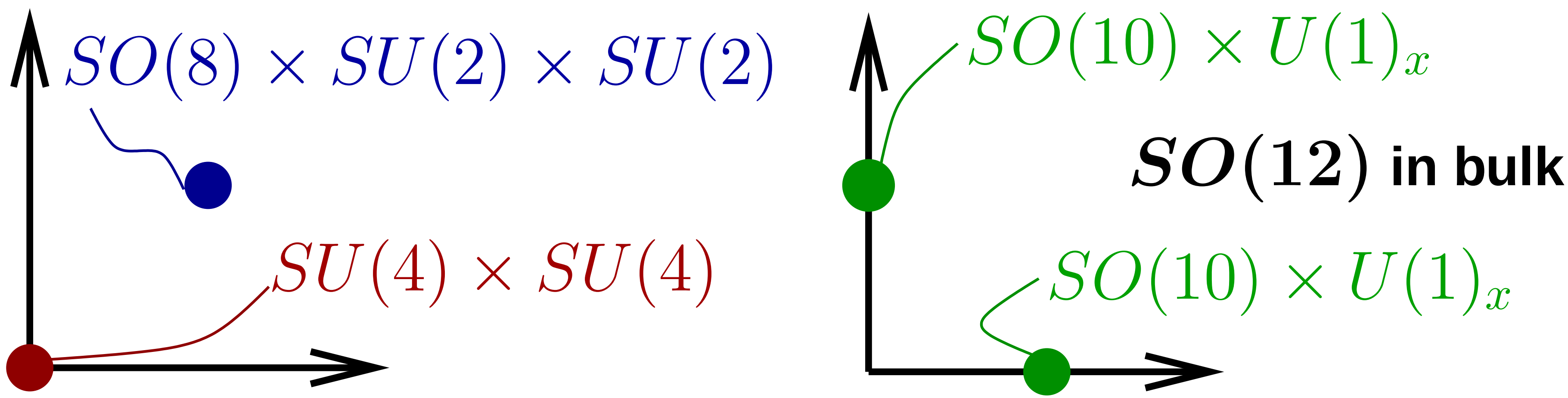
Consider the T_2/Z_4 orbifold, where we have two different types of fixed points



under rotation of $\theta = \pi/2$ and shift of the lattice vectors.

A T_2/Z_4 toy example

For a suitable embedding of twist and shift in the gauge group $SO(12)$ we have the following local gauge group structure



This allows split representations compatible with P_6 and does not require huge representations for the breakdown of $SO(12)$.

The top-down picture

Can we incorporate this in globally consistent string models? The above example of P_6 from $SO(12)$

- has been realized in a $T_6/(Z_4 \times Z_4)$ orbifold
- with vectorlike exotics

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Models of the Mini-Landscape T_6/Z_6

- would have SU(6) instead of SO(12)
- are not too well suited
- but proton hexality could come from an accidental $U(1)$ symmetry

Lessons

Hexality can appear in the framework of the heterotic braneworld as

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- a subgroup of a anomalous gauge symmetry
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Note that we have consistent string models with exact global symmetries.

So we do not have to discuss things like “anomaly free discrete symmetries”, that might be useful in a bottom-up approach.

Accions

Absence of continuous global U(1) symmetries in string theory leads to a question towards the

- axion as a solution to the strong CP-problem

A gauge anomalous $U(1)$ symmetry might help, but there we expect

- a too large axion decay constant of order of string scale

Again additional accidental gobal U(1) symmetries (arising as a consequence of discrete symmetries) might help,

(Choi, Kim, Kim, 2007; Choi, HPN, Ramos-Sanchez, Vaudrevange, 2009)

but we need to control the accion scale F_a.

Multi-Axion Systems

Consider a system with two $U(1)$ symmetries: $U(1)_P \times U(1)_Q$ and suppose that they are broken spontaneously.

$$F_{a_1} \;=\; -\, v_1 \,\frac{q_P^1\, q_Q^2 - q_Q^1\, q_P^2}{q_f^2}\,, \qquad F_{a_2} \;=\; v_2 \,\frac{q_P^1\, q_Q^2 - q_Q^1\, q_P^2}{q_f^1}\,.$$

The relevant accion decay constant will then be

$$F_a = \left(\left(\frac{1}{F_{a_1}}\right)^2 + \left(\frac{1}{F_{a_2}}\right)^2\right)^{-1/2} \;=\; \frac{v_1\, v_2\, (q_P^1\, q_Q^2 - q_Q^1\, q_P^2)}{\sqrt{(q_f^1\, v_1)^2 + (q_f^2\, v_2)^2}}\,.$$

and it is dominated by the smallest VEV!

The Accion Program

- identify a model with an accidental (colour)-anomalous $U(1)^*$
- identify a vacuum configuration where the VEVs driven by the Fayet-Iliopoulos term do not break $U(1)^*$
- search for a vacuum configuration where $U(1)^*$ is broken by a VEV in the axion window (some other gauge $U(1)$'s might be broken here as well)
- check that higher order non-renormalizable terms that break $U(1)^*$ explicitely are sufficiently suppressed to avoid a too “large” axion mass.

(Choi, HPN, Ramos-Sanchez, Vaudrevange, 2009)

can be accomodated in the Heterotic Brane World.

Conclusion

String theory might provide us with a consistent UV-completion of the MSSM including

- Local Grand Unification and
- discrete (accidental) symmetries.

Geography of extra dimensions plays a crucial role:

Local Grand Unification is the right way to proceed.

We seem to live at a special place in the extra dimensions!

Where do we live?