Geography on Heterotic Orbifolds

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Based on work with S. Förste, P. Vaudrevange and A. Wingerter

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Outline

- Orbifold Compactification
- GUTs without GUT group
- Spinors of SO(10)
- An SO(10) Model with 3 Families
- Gauge group geography in extra dimensions
- Unification ($\sin^2 \theta_W$)
- Proton decay
- Yukawa textures and flavour symmetries
- Electroweak symmetry breakdown
- Outlook

Orbifold Compactification

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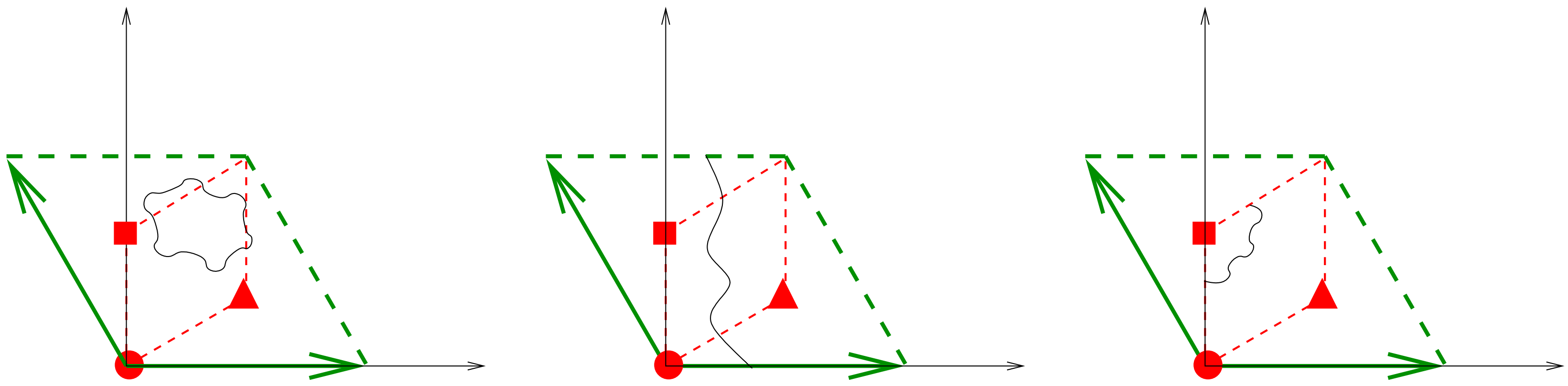
Fields can propagate

- Bulk ($d = 10$ untwisted sector)
- 3-Branes ($d = 4$ twisted sector fixed points)
- 5-Branes ($d = 6$ twisted sector fixed tori)

$\mathbb{Z}_3$ Example



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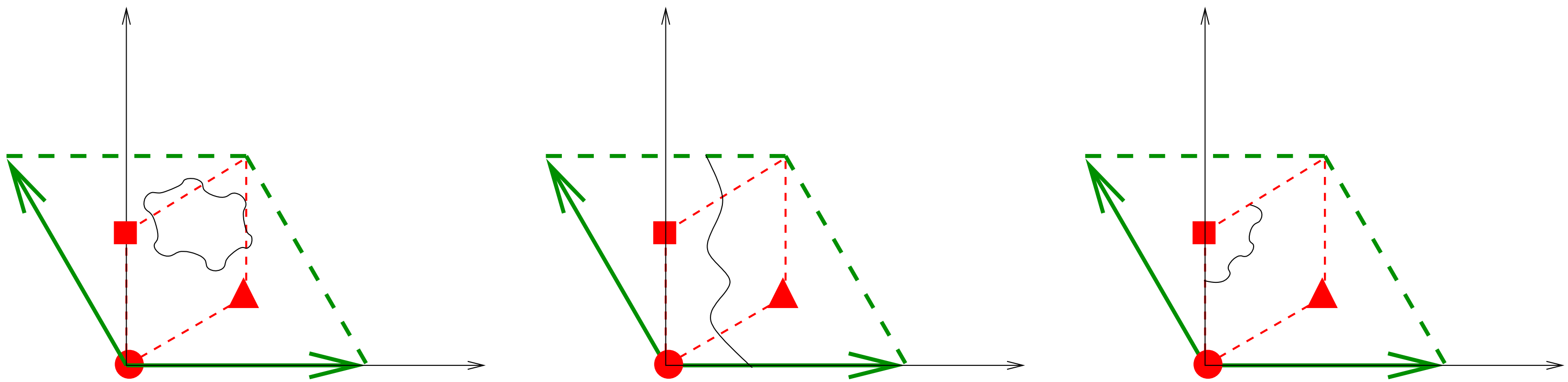

- Action of the space group on coordinates

$$X^i \longrightarrow (\theta^k X)^i + n_\alpha e^i_\alpha, \quad k = 0, 1, 2, \quad i, \alpha = 1, \ldots, 6$$

- Embed twist in gauge degrees of freedom

$$X^I \longrightarrow (\Theta^k X)^I \quad I = 1, \ldots, 16$$

Results from the $\mathbb{Z}_3$ Orbifold

Successful model building with

- three families of quarks and leptons
- gauge group $SU(3) \times SU(2) \times U(1)^n$
- doublet-triplet splitting
- mechanism for Yukawa suppression

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Leads to a picture of "GUTs without GUT group"

- Incomplete gauge and Higgs multiplets
- Transparent geometric interpretation

Things to improve

For models with $SU(3) \times SU(2) \times U(1)$ gauge group, the $\mathbb{Z}_3$ orbifold example is too rigid

- only fixed points and no fixed tori
- no "normal" grand unified picture (like $SO(10)$)
- no large string threshold corrections
- continuous Wilson lines too "destructive"
- value of $\sin^2\theta_W \neq 3/8$

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The only successful approach in the framework of the $\mathbb{Z}_3$ orbifold might be

- $SU(3)^3$ trinification (Choi, Kim, 2003; Kim, 2004)

Some basic observations

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Can we incorporate this into a string theory description?

Five golden rules

- Family as spinor of SO(10)
- Incomplete multiplets
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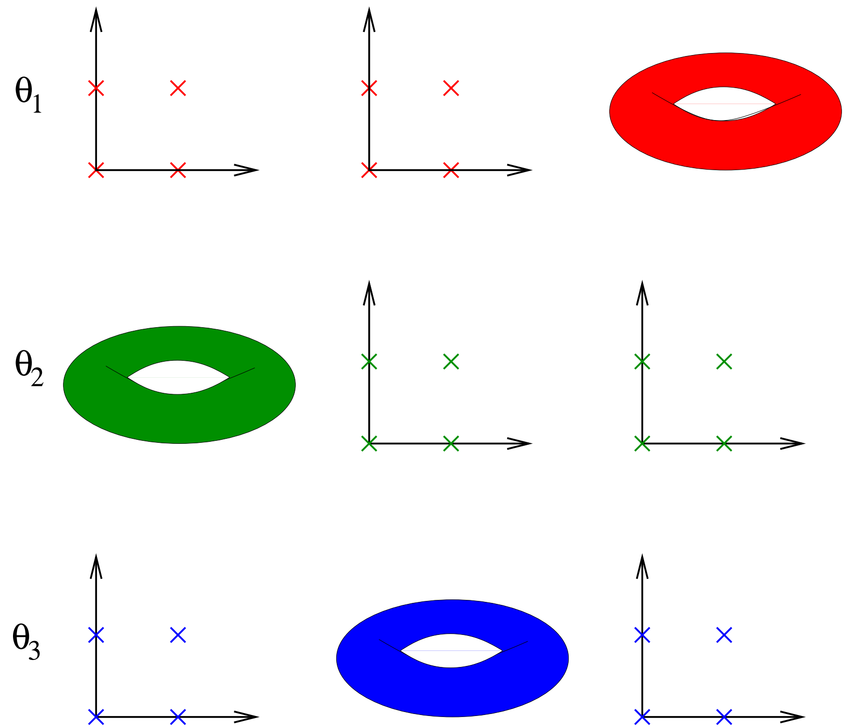
We need more general constructions to identify remnants of $SO(10)$ in string theory .....

$\mathbb{Z}_2 \times \mathbb{Z}_2$ Orbifold Example



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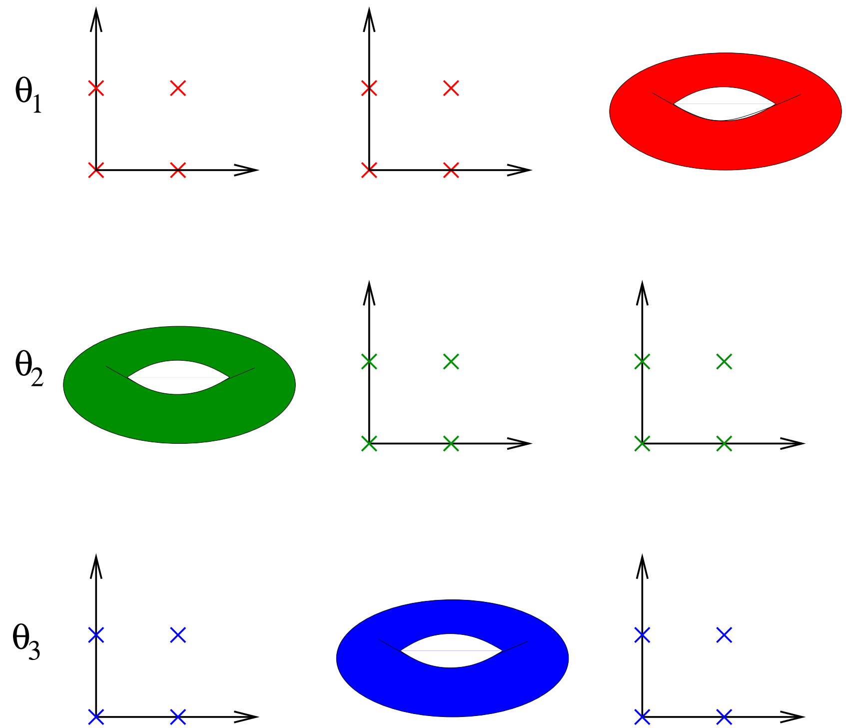
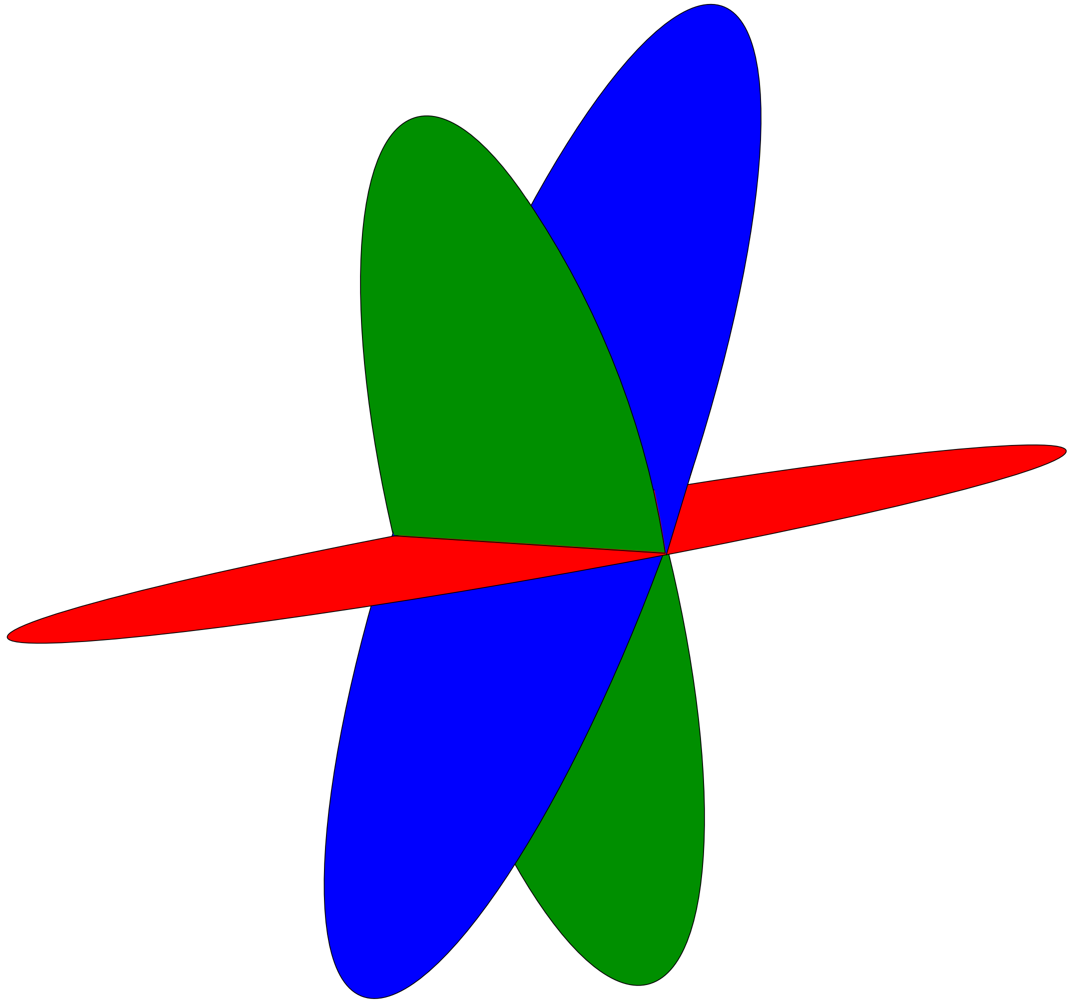
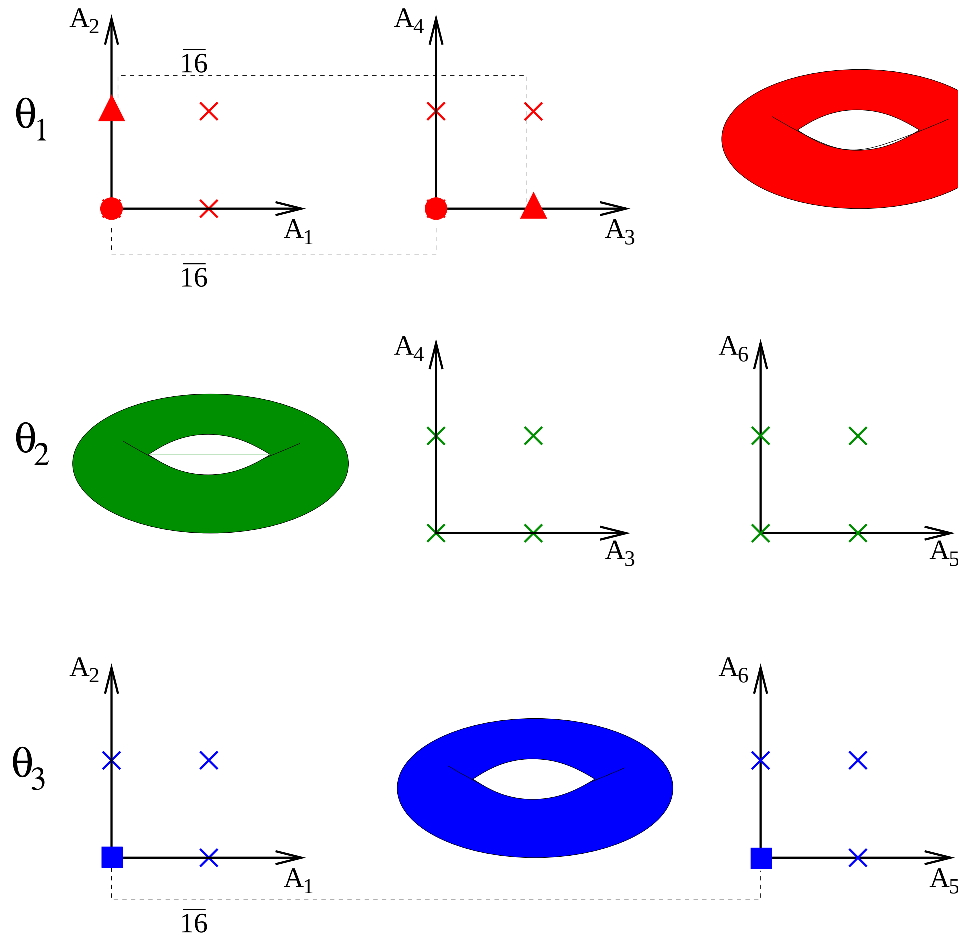


3 twisted sectors (with 16 fixed tori in each) lead to a geometrical picture of ....

Intersecting Branes

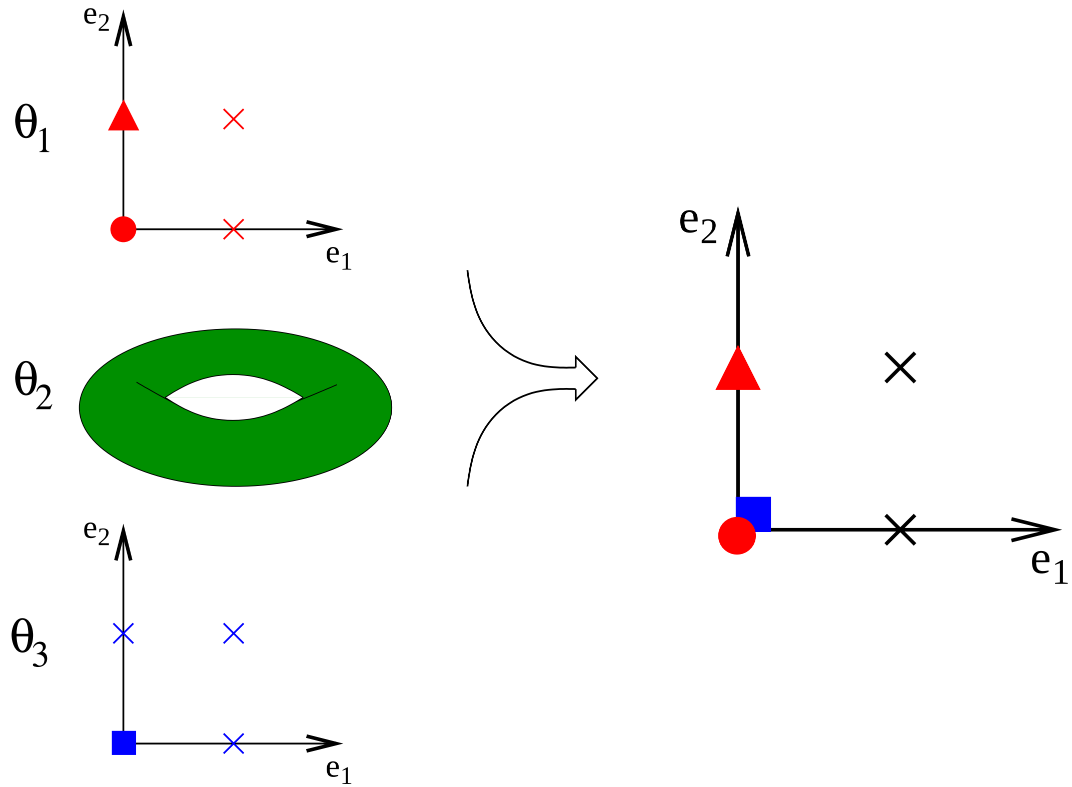


Three family $SO(10)$ toy model



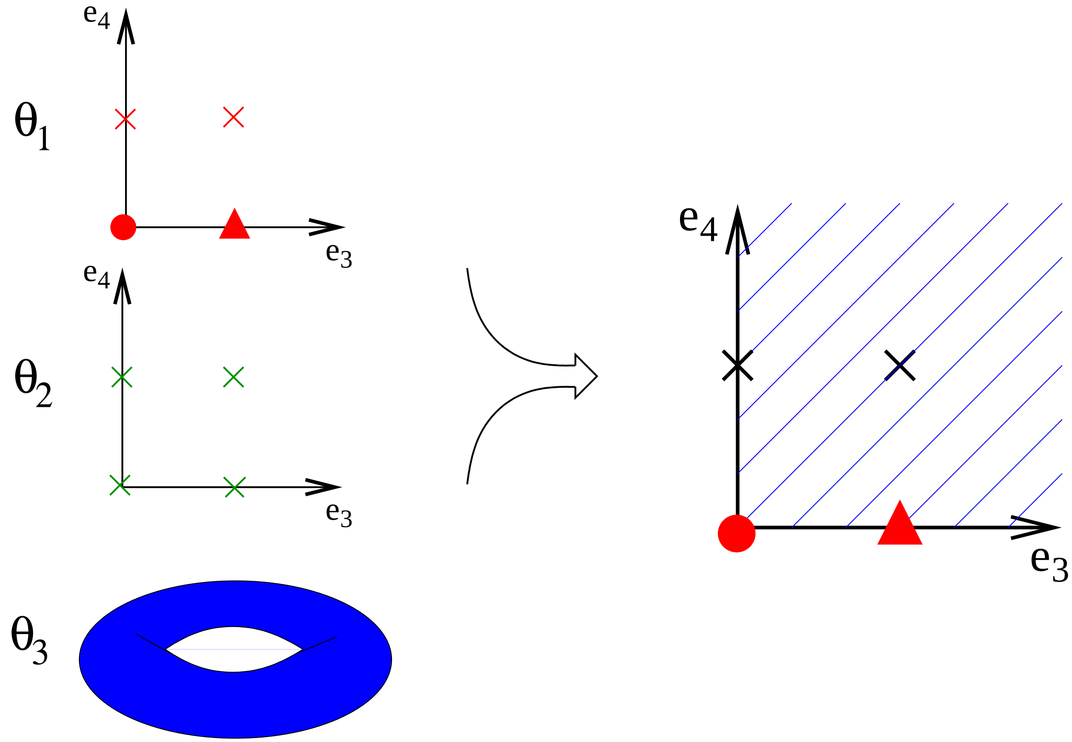
Localization of families at various fixed tori

Zoom on first torus ...



Interpretation as 6-dim. model with 3 families on branes

second torus ...



... 2 families on branes, one in (6d) bulk ...

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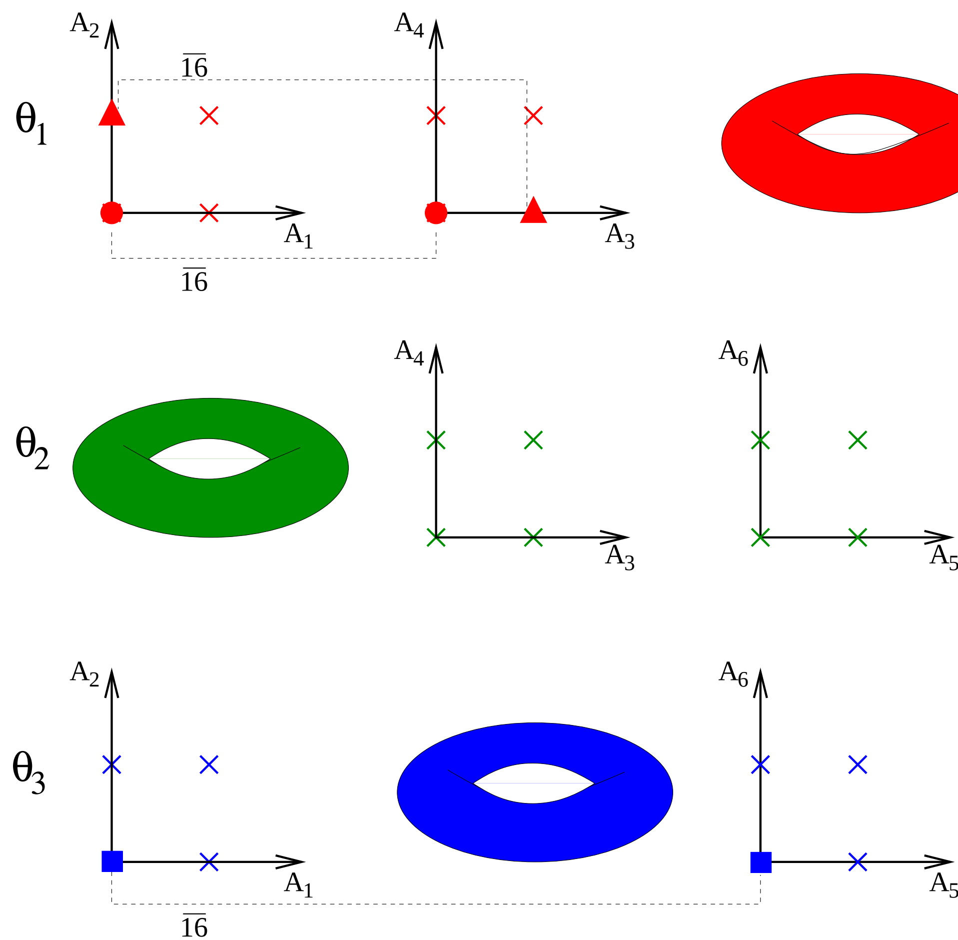

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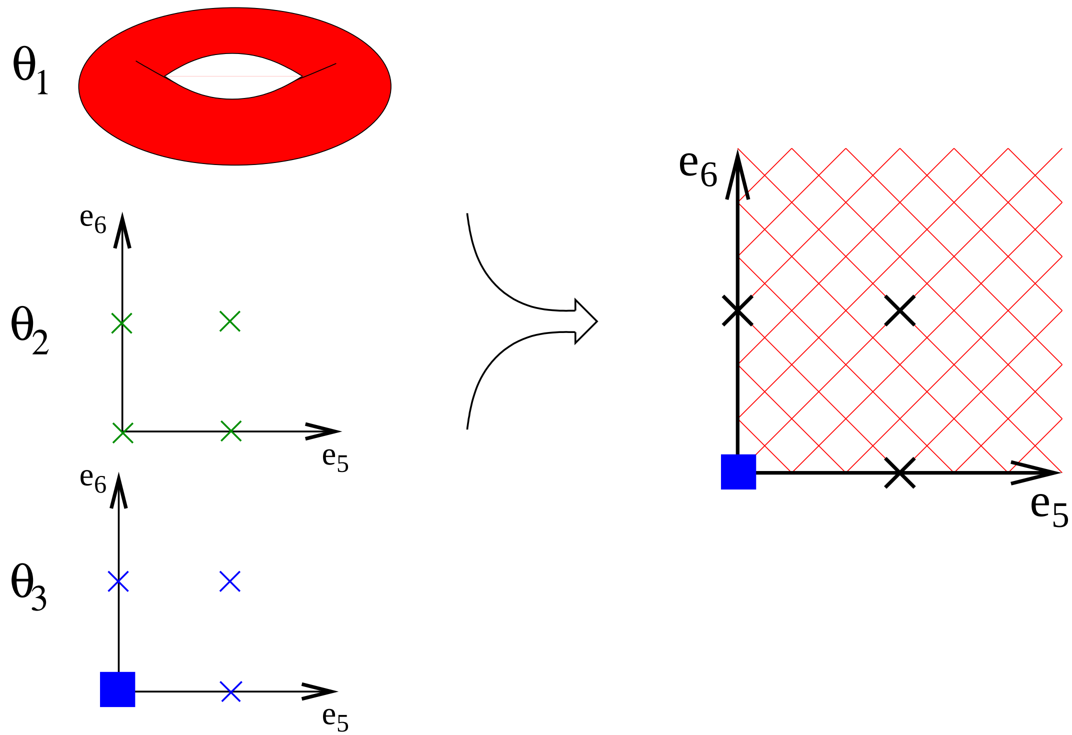

... 1 family on brane, two in (6d) bulk.

Model building

We can easily find

- models with gauge group $SU(3) \times SU(2) \times U(1)$
- 3 families of quarks and leptons
- doublet-triplet splitting

(Kobyashi, Raby, Zhang, 2004)

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Related heterotic constructions:

- fermionic formulation (talk of Faraggi)
- Calabi Yau compactification (talks of Ovrut, Honecker)

Model building (II)

Key properties of the models depend on geometry:

- family symmetries
- texture of Yukawa couplings
- number of families
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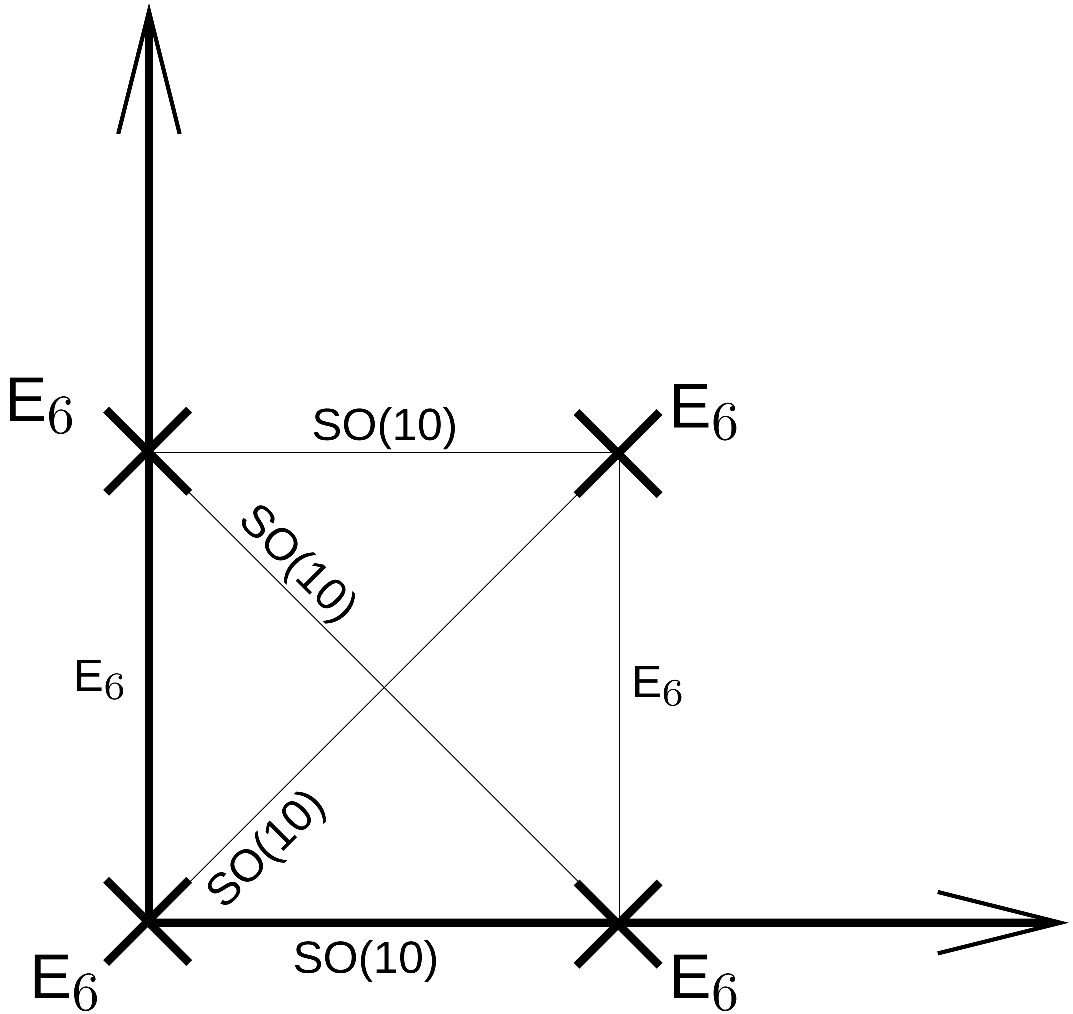
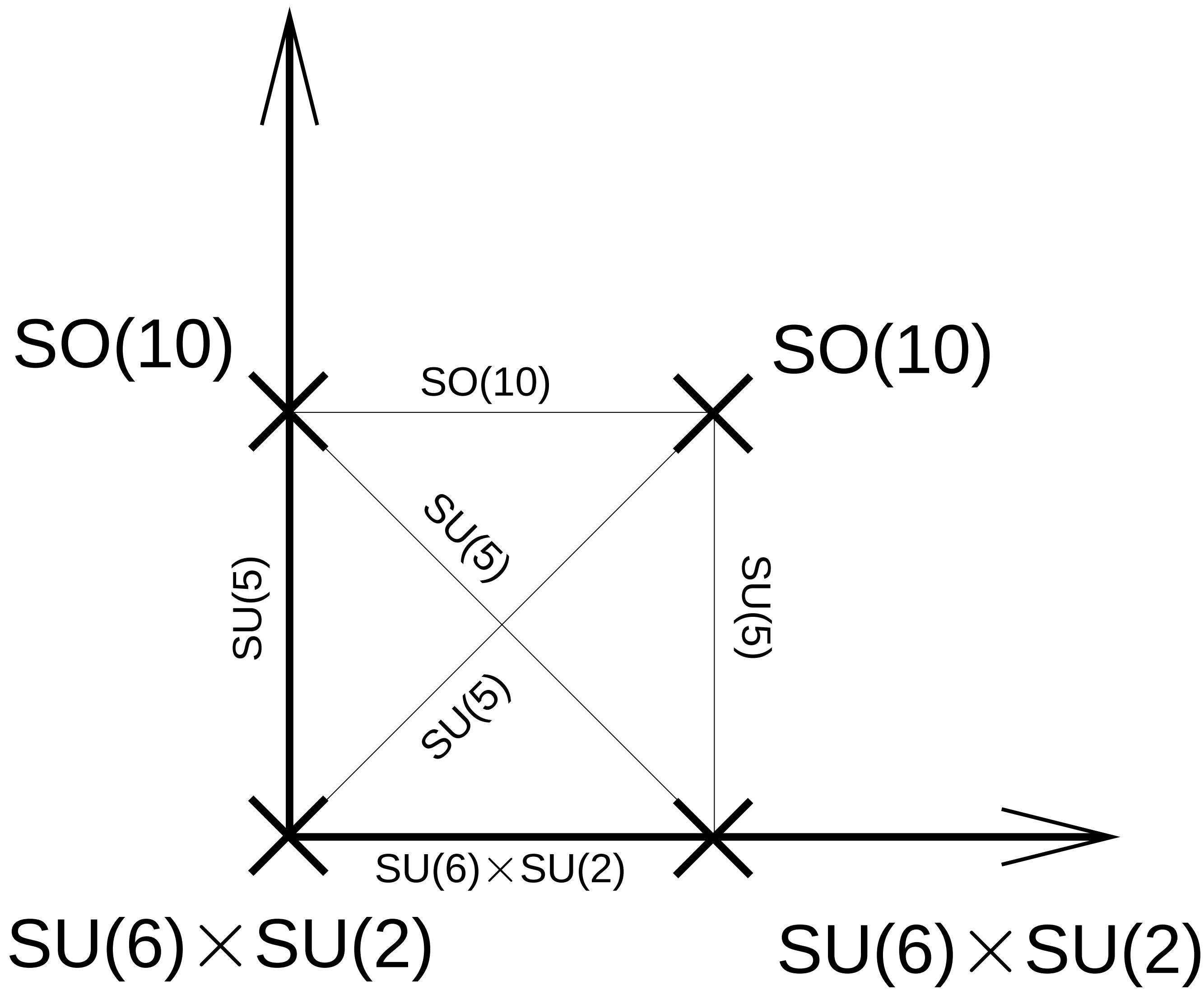
We need to exploit these geometric properties......

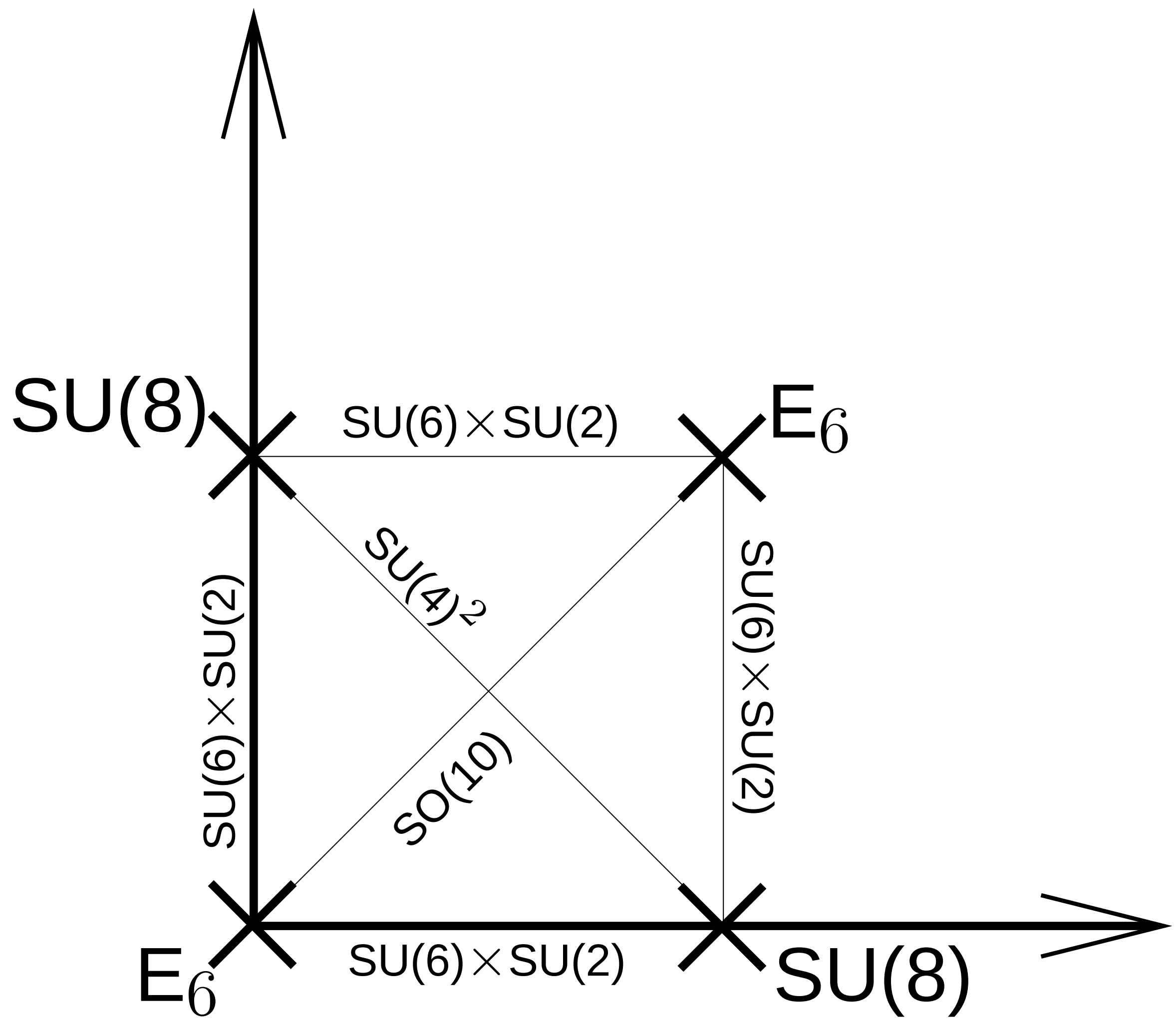
Gauge group geography SO(10)



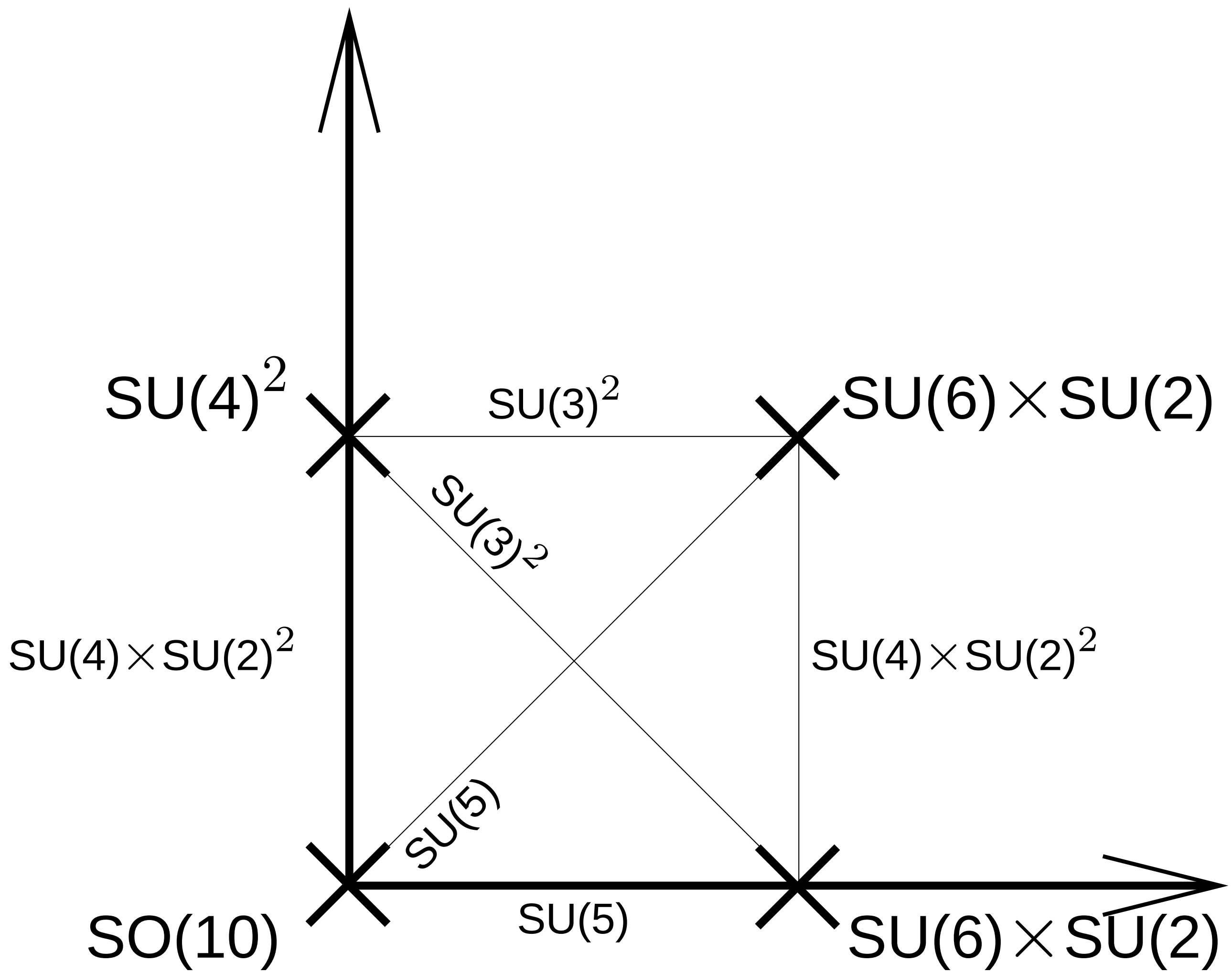
Gauge group geography SU(5)



Gauge group geography: Pati-Salam



Gauge geography: Standard Model



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There could still be remnants of $SO(10)$ symmetry

- 16 of SO(10) at some branes
- correct hypercharge normalization
- R-parity
- family symmetries

that are very useful for realistic model building ...

Proton decay

- R-parity from SO(10) memory avoids dangerous dimension-4 operators
- No proton decay via dimension-5 operators because of doublet-triplet splitting
- Avoid SO(10) brane for first family: suppressed p-decay via dimension-6 operators

Thus the proton could be practically stable!

Unification

- SO(10) memory provides a reasonable value of $\sin^2\theta_W$ and a unified definition of hypercharge

- presence of fixed tori allows for large threshold corrections at the high scale to match string and unification scale

- Yukawa unification from SO(10) memory for third family (on an SO(10) brane)

- no Yukawa unification for first and second family required

Yukawa textures and family symmetries

- Yukawa couplings depend on location of Higgs and matter fields
- Exponential suppression if fields at distant branes
- neutrino masses need some bulk mixing (one might need anti-families)
- GUT relations could be partially present, depending on the nature of the brane (e.g. SO(10) brane)
- family symmetries arise if different fields live on the same brane

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- smooth breakdown of gauge group

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Continuous Wilson lines require specific embeddings of twist in the gauge group

(Ibanez, HPN, Quevedo, 1987)

- are too destructive in the Z_3 case
- are more promising for Z_2 twists

An example

We consider a model that has E_6 gauge group in the bulk of a “6d orbifold”.

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- $SU(4) \times SU(2) \times SU(2) \rightarrow SU(3) \times SU(2) \times U(1)$ via a continuous Wilson line

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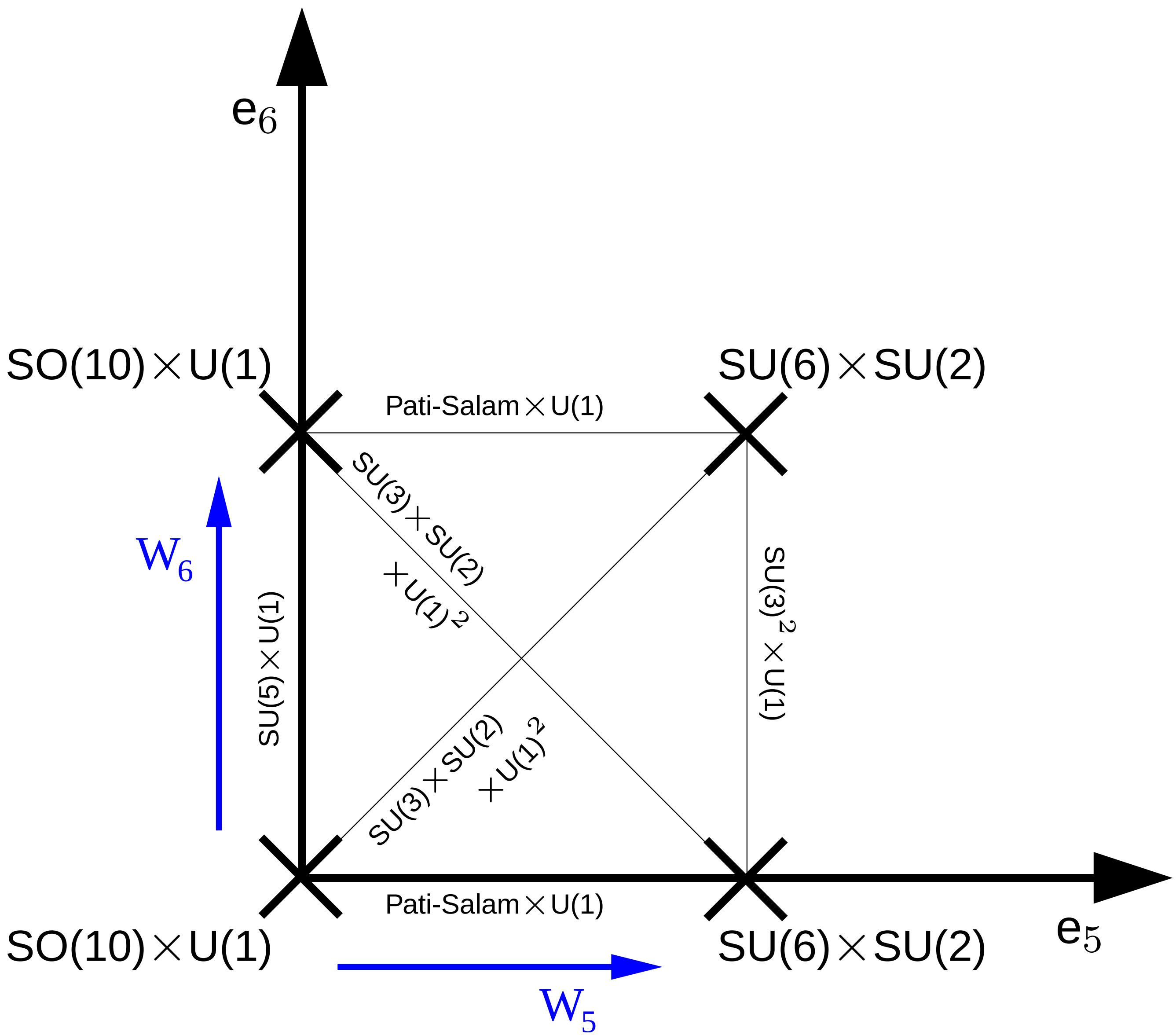
Pati-Salam breakdown



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Ultimately the mechanism should be used for the description of the
Higgs mechanism of electroweak symmetry breakdown

- $SU(3) \times SU(2) \times U(1)_{\mathrm{Y}} \rightarrow SU(3) \times U(1)_{\mathrm{EM}}$

in the standard model

Conclusion

Heterotic string compactifications might lead to models that incorporate all the successful ingredients of grand unified theories, while avoiding the problematic ones.

- spinor representations of SO(10)
- geometric origin of (three) families
- incomplete multiplets
- supersymmetric unification
- R-parity
- “absence” of proton decay
- gauge-Yukawa unification (partial GUT relations)
- discrete family symmetries