Eclectic flavor symmetries from orbifolds

based on work with M. Kade, H.P. Nilles, S. Ramos-Sánchez, and P.K.S. Vaudrevange

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Seminar Series on String Phenomenology – 27.10.2020

Outline

String

- String setup
- How to get a flavor symmetry
- What are possible flavor symmetries
- How to use the flavor symmetries

Pheno

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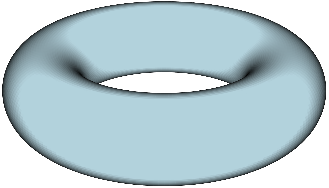
Setup

- Heterotic String Theory
- Toroidal orbifolds
- For now: 2 dimensional compact space



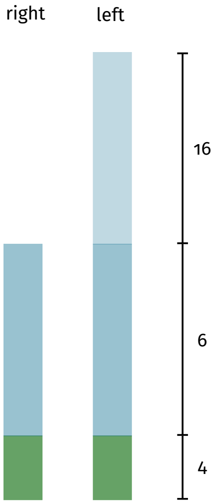


Figure: Space-time dimensions of a heterotic string.

Setup

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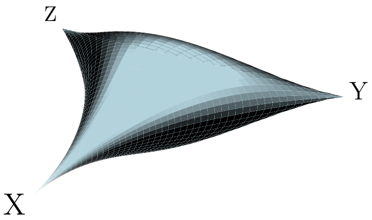
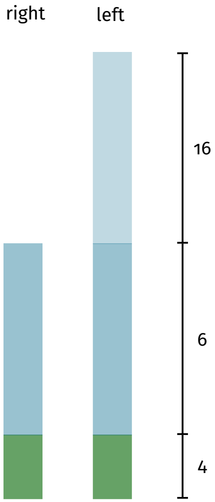
- Toroidal orbifolds
- For now: 2 dimensional compact space





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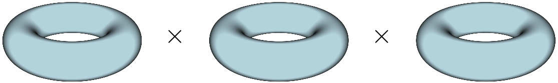


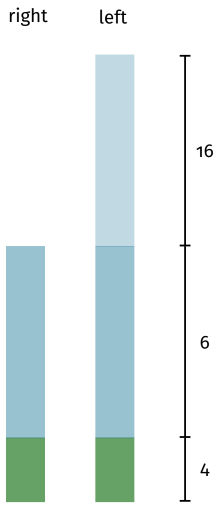
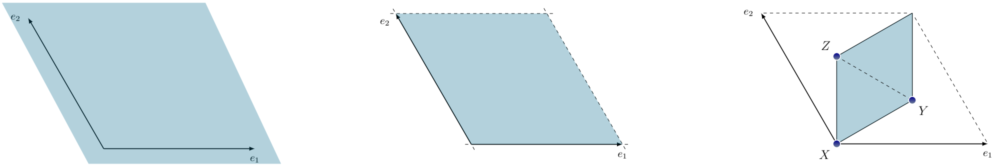


Figure: Space-time dimensions of a heterotic string.

Toroidal Orbifolds

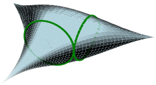
$$\mathbb{R}^2 \qquad \mathbb{T}^2 = \mathbb{R}^2/\Lambda \qquad \mathbb{T}^2/P = \mathbb{R}^2/(P,\Lambda)$$



S : Space group

P : Point group

Λ : Lattice



Closed string boundary condition:

$$X^i(\sigma+1,\tau) = g\, X^i(\sigma,\tau)$$

→ Strings characterized by $g \in S$

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An analogy

4D world: C, P, T

- Representations of the proper Poincaré group build up fundamental particle states
- C, P, T transformations interchange representations and conj. classes
- C, P, T are automorphisms of the proper Poincare group

Extra dim.: Flavor transformations

- Different types of strings correspond to conj. classes of the space group S
- Calculate the outer automorphisms of the space group S
- Interpret these automorphisms as flavor transformations

Automorphism a:

$$a \; : \quad S \overset{a}{\mapsto} S$$

[A. B. , H. P. Nilles, A. Trautner, P. Vaudrevange: 1901.03251, 1908.00805], [A. B. , M. Kade, H. P. Nilles, S. Ramos-Sánchez, P. Vaudrevange: 2008.07534]

Narain construction

Narain lattice:

Winding- and KK-momenta of a string lie in a Narain lattice of signature $(2_\mathrm{R}, 2_\mathrm{L})$

→ Use Narain lattice instead of usual target space lattice

The moduli:

Complex structure : $U \;=\; \dfrac{G_{12}}{G_{11}} + \dfrac{\mathrm{i}}{G_{11}}\sqrt{\det G}$ geometrical

Kähler modulus : $T \;=\; B_{12} + \mathrm{i}\sqrt{\det G}$ stringy

Symmetry of the Narain torus: / $\mathbb{Z}_3$ Narain orbifold

$$\mathrm{O}(2,2,\mathbb{Z}) \;=\; \Big[\,\big(\overset{U=\mathrm{e}^{2\pi\mathrm{i}/3}}{\cancel{\mathrm{SL}(2,\mathbb{Z})_U}} \times \mathrm{SL}(2,\mathbb{Z})_T\big) \;\rtimes\; \big(\mathbb{Z}_2^{\mathrm{CP}} \times \cancel{\mathbb{Z}_2^{\mathrm{M}}}\big)\,\Big] \,/\, \cancel{\mathbb{Z}_2}$$

Orbifold: Elements of $\mathrm{O}(2,2,\mathbb{Z})$ that commute with orbifold action, i.e. point group P

[K. S. Narain et al.: Asymmetric Orbifolds], [Vaudrevange and Groot Nibbelink: 1703.05323]

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Types of flavor symmetries

We find two types of flavor symmetries:

A modular flavor symmetries

B traditional flavor symmetries

A Modular symmetries

Symmetry of the Narain torus: / $\mathbb{Z}_3$ Narain orbifold / twisted states:

$$U = \mathrm{e}^{2\pi\mathrm{i}/3}$$

$$\mathrm{O}(2,2,\mathbb{Z}) \;=\; \left[\,(\mathrm{SL}(\cancel{2},\mathbb{Z})_U \times \mathrm{SL}(2,\mathbb{Z})_T) \rtimes (\mathbb{Z}_2^{\mathrm{CP}} \times \cancel{\mathbb{Z}_2^{\mathrm{M}}})\,\right] / \cancel{\mathbb{Z}_2}$$

$$\Gamma_3' \simeq T'$$

Twisted string states transform trivially under

$$\Gamma(N) \;=\; \{\gamma \in \mathrm{SL}(2,\mathbb{Z})\,,\; \gamma = \mathbb{1} \mod N\}$$

but in a nontrivial representation $\rho(\gamma)$ under

$$\Gamma_N' \;=\; \mathrm{SL}(2,\mathbb{Z}) \big/ \Gamma(N)$$

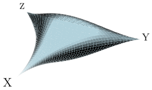
finite modular flavor symmetry

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \stackrel{\gamma}{\mapsto} (c\,T + d)^k\, \rho(\gamma) \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

Finite modular flavor symmetries:

N	2	3	4	5
Γ_N	S_3	A_4	S_4	A_4
Γ_N'	S_3	T'	$\mathrm{SL}(2,4)$	$\mathrm{SL}(2,5)$

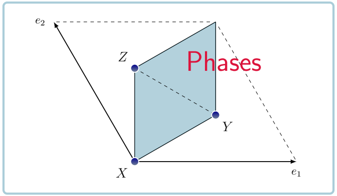
B Traditional symmetries

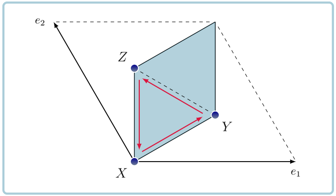


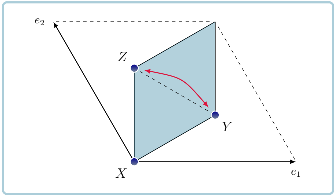
Flavor symmetry $\Delta(54)$

Selection rules: $\mathbb{Z}_3 \times \mathbb{Z}_3$

Geometrical symmetry: S_3







Translation (KK)

Translation (Winding)

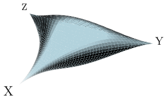
180° rotation

Classification traditional sym: [Olguin-Trejo, Pérez-Martínez, Ramos-Sánchez:1808.06622][Kobayashi et al.: hep-ph/0611020]

Pheno with $\Delta(54)$ flavor from orbifolds: [Carballo-Pérez, Peinado, Ramos-Sánchez: 1607.06812]

Resulting flavor symmetries

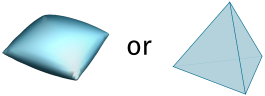
$\mathbb{T}^2/\mathbb{Z}_3$



flavor symmetry	
traditional	modular
$\Delta(54)$	$T' \rtimes \mathbb{Z}_2$
$\mathbf{3}$	$\mathbf{2'} \oplus \mathbf{1}$

[B. , Nilles, Trautner, Vaudrevange: 1901.03251, 1908.00805]

$\mathbb{T}^2/\mathbb{Z}_2$



flavor symmetry	
traditional	modular
$\dfrac{D_8 \times D_8}{\mathbb{Z}_2}$	$(S_3 \times S_3) \rtimes \mathbb{Z}_4$
$\mathbf{4}$	$\mathbf{2} \oplus \mathbf{1} \oplus \mathbf{1}$

[B. , Kade, Nilles, Ramos-Sánchez, Vaudrevange: 2008.07534]

14 more . . .

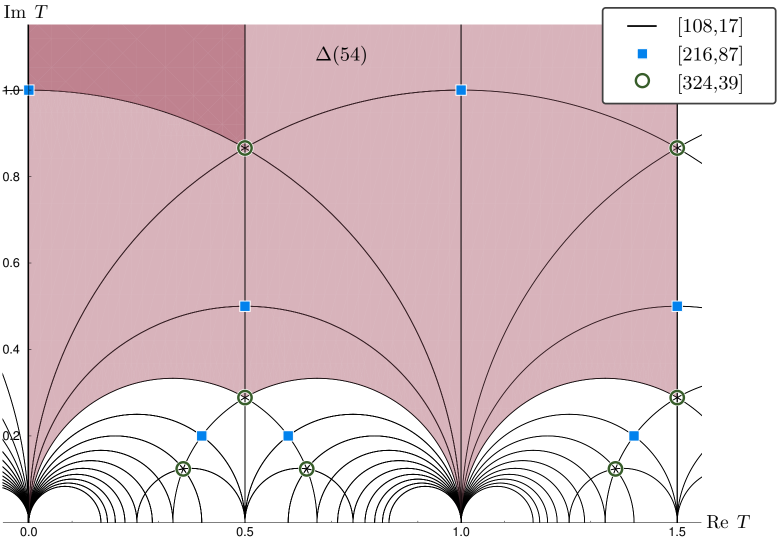
Traditional flavor symmetries: [Kobayashi, Nilles, Plöger, Raby, Ratz: hep-ph/0611020]

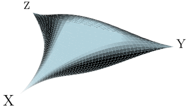
Eclectic flavor groups

$$
\begin{tikzcd}[column sep=small]
 & & \text{Normal subgroup of } G_{\text{ecl.}} & & \text{Consists only of outer automorphisms of } G_{\text{trad.}} \\
G_{\text{eclectic}} & = & G_{\text{traditional}} \arrow[u] \arrow[d] & \cup & G_{\text{modular}} \arrow[u] \arrow[d] \\
 & & \text{Broken by flavons} & & \text{Broken by } < T >
\end{tikzcd}
$$

[H. P. Nilles, S. Ramos-Sánchez, P. Vaudrevange: 2001.01736, 2004.05200, 2006.03059]

LINEARLY REALIZED FLAVOR SYMMETRIES – $\mathbb{T}^2/\mathbb{Z}_3$





Moduli space of the $\mathbb{T}^2/\mathbb{Z}_3$ Orbifold. $[108, 17]$ referrs to SMALLGROUP$(108, 17)$ of the SMALLGROUPS Library of GAP.

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Model building with modular flavor symmetries

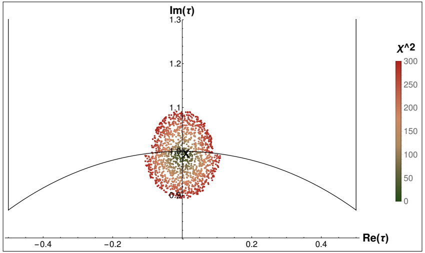
Are neutrino masses modular forms? #7

Ferruccio Feruglio (INFN, Padua and Padua U.) (Jun 27, 2017)

e-Print: 1706.08749 [hep-ph]

pdf DOI cite 92 citations

- Use modular forms as couplings in the superpotential
- Value of modulus is fitted to experimental values
- Very predictive, e.g. 7 out of 2 parameters



Conclusions

- Flavor symmetries can arise from outer automorphisms of the Narain space group
- We find modular as well as traditional flavor symmetries, combined in an eclectic flavor symmetry
- Finite modular symmetries can be very predictive; eclectic flavor symmetries are even more constraining
- String theory can provide some insights for bottom up model building

Thank you!