Heterotic MSSM on an orbifold resolution

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Based on:

JHEP03(2009)005 [arXiv:0901.3059 [hep-th]],

Phys. Lett. B **683** (2010) 340 [arXiv:0911.4905 [hep-th]],

and work in progress (for far too long)

In collaboration with:

Michael Blaszczyk, Michael Ratz, Fabian Rühle, Michele Trapletti, Patrick Vaudrevange

Overview

1. Introduction and motivation
2. $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold
3. MSSM orbifold from freely acting involution
4. Resolution of orbifold
5. MSSM in blow-up
6. Novel states on the blow-up
7. Conclusions

Introduction and motivation

Our aims is to find the Standard Model from $E_8 \times E_8$ Heterotic Strings :

- which can naturally incorporate properties of GUT theories ,
  Dixon,Harvey,Vafa,Witten'86, Ibanez,Mas,Nilles,Quevedo'88
- and can lead to the Supersymmetric Standard Model (MSSM) .
  Braun,He,Ovrut,Pantev'05, Donagi,Bouchard'05, Buchmuller,Hamaguchi,Lebedev,Ratz'05, Lebedev,Nilles,Raby,Ramos-Sanchez,Ratz,Vaudrevange,Wingerter'06

To have both computable control and to be make generic predictions

1. we start form a heterotic MSSM orbifold model,
   Blaszczyk,SGN,Ratz,Rühle,Trapletti,Vaudrevange'10
2. and then resolve the orbifold to obtain more generic predictions.

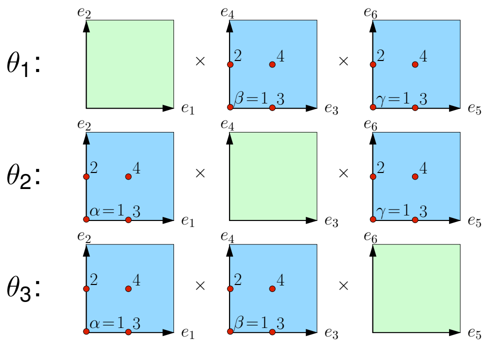
To avoid that the hyper charge gets broken in the blow-up, there should not be any hyper charge flux. SGN,Held,Rühle,Trappletti,Vaudrevange'08

$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold

Consider the $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold where the $\mathbb{Z}_2$'s act as pure reflections

$$\theta_1(z_1, z_2, z_3) = (z_1, -z_2, -z_3), \quad \theta_2(z_1, z_2, z_3) = (-z_1, z_2, -z_3)$$

- which has $3 * 16 = 48$ fixed two-tori:



- and 64 $\mathbb{Z}_2 \times \mathbb{Z}_2$ fixed points where the fixed two-tori intersect.

An MSSM orbifold

We construct an SU(5) GUT orbifold model with:

- six generations of $\mathbf{10} + \overline{\mathbf{5}}$ that come from twisted sectors only.
- SU(5) $\rightarrow$ SM breaking by Wilson line associated with a $\mathbb{Z}_{2,\text{free}}$ freely acting involution: Blaszczyk,SGN,Ratz,Rühle,Trapletti,Vaudrevange'10

$$\tau(z_1, z_2, z_3) = (z_1 + \frac{i}{2}, z_2 + \frac{i}{2}, z_3 + \frac{i}{2})$$

This involutions has the following consequences:

- The fixed tori get identified in pairs, Donagi,Wendland'08 so that the number of generations becomes three.
- However its non-local breaking does not lead to a flux: The hyper charge remains unbroken. Donagi,Ovrut, et al'99,'05, Hebecker,Trapletti'05

Some features of the MSSM orbifold model

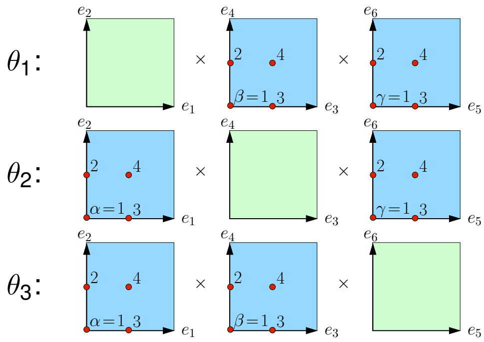
Because of the non-local breaking of the GUT group there are

- only universal “power-like” gauge threshold corrections,
- and no ”split” multiplets.

Quasi-realistic VEV configurations are possible such that
Blaszczyk,SGN,Ratz,Rühle,Trapletti,Vaudrevange'10

- $B - L$ is broken to a $\mathbb{Z}_2$ matter parity, and all exotic are decoupled,
- mass matrices have a D_4 flavor symmetry, allow for a large top Yukawa coupling.
- But the model has a μ-problem.

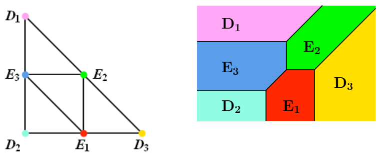
Resolutions of the $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ singularities



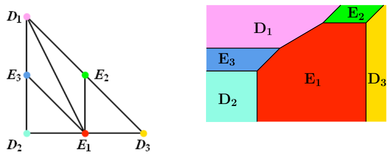
- Each of the $3 * 16 = 48$ fixed two-tori gives an exceptional divisor E_r in blow-up,
- The 64 $\mathbb{Z}_2 \times \mathbb{Z}_2$ fixed points do not give additional exceptional divisors, but each of them has 4 inequivalent resolutions.

Non-compact $\mathbb{C}^3/\mathbb{Z}_2 \times \mathbb{Z}_2$ resolutions

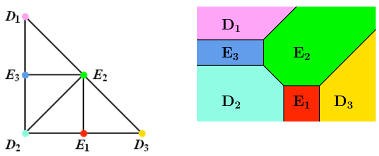
The toric and web diagrams for the four $\mathbb{Z}_2 \times \mathbb{Z}_2$ fixed point resolutions:



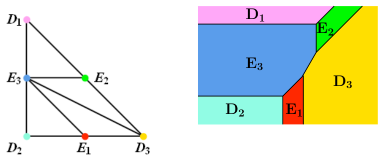
triangulation “S”



triangulation “E_1”



triangulation “E_2”



triangulation “E_3”

Intersection numbers (same triangulations everywhere)

Int($S_1 S_2 S_3$) \ Triangulation	"E_1"	"E_2"	"E_3"	"S"
$E_{1,\beta\gamma} E_{2,\alpha\gamma} E_{3,\alpha\beta}$	0	0	0	1
$E_{1,\beta\gamma} E_{2,\alpha\gamma}^2$, $E_{1,\beta\gamma} E_{3,\alpha\beta}^2$	-2	0	0	-1
$E_{2,\alpha\gamma} E_{1,\beta\gamma}^2$, $E_{2,\alpha\gamma} E_{3,\alpha\beta}^2$	0	-2	0	-1
$E_{3,\alpha\beta} E_{1,\beta\gamma}^2$, $E_{3,\alpha\beta} E_{2,\alpha\gamma}^2$	0	0	-2	-1
$E_{1,\beta\gamma}^3$	0	8	8	4
$E_{2,\alpha\gamma}^3$	8	0	8	4
$E_{3,\alpha\beta}^3$	8	8	0	4
$R_1 R_2 R_3$	2			
$R_1 E_{1,\beta\gamma}^2$, $R_2 E_{2,\alpha\gamma}^2$, $R_3 E_{3,\alpha\beta}^2$	-2			

Huge number of resolutions

The intersection numbers of the divisors affect, e.g.

- the Bianchi consistency identities,
- the spectrum of massless states.

The intersection numbers are extremely sensitive to the triangulations of the 64 resolved fixed points.

The number of possible triangulations is huge:

$$\frac{4^{64}}{3!4!^3} \approx 4.10 \cdot 10^{33}$$

- How to determine the appropriate choice of triangulations?
- What does this mean physically?

MSSM in blowup

We have constructed an Abelian flux such the unbroken gauge group is $SU(5) \times SU(3) \times SU(2)$ on the resolution.

The massless spectrum reads: Blaszczyk,SGN,Rühle,Trapletti,Vaudrevange'10, SGN,Trapletti,Walter'06

#	irrep	#	irrep
6	$(\mathbf{10};\mathbf{1},\mathbf{1})$	70	$(\mathbf{1};\mathbf{1},\mathbf{1})$
12	$(\overline{\mathbf{5}};\mathbf{1},\mathbf{1})$	6	$(\mathbf{5};\mathbf{1},\mathbf{1})$

in the first E_8

#	irrep	#	irrep
16	$(\mathbf{1};\mathbf{3},\mathbf{1})$	16	$(\mathbf{1};\overline{\mathbf{3}},\mathbf{1})$
32	$(\mathbf{1};\mathbf{1},\mathbf{2})$	80	$(\mathbf{1};\mathbf{1},\mathbf{1})$

in the second E_8

The $\mathbb{Z}_{2,\text{free}}$ involution on a resolution requires identical gauge fluxes at resolved fixed tori that get identified.

The effect of this involution is that the GUT gauge group gets broken down to the SM group and the number of generations gets halved.

Novel states in blow-up

One expects that the orbifold spectrum contains that of the resolution:

- From the orbifold perspective the blow-up means giving VEVs to twisted states, so that part of the spectrum gets Higgsed away.

However, computations of the spectra on the resolution show that:

Name	Orbifold Mult.	Resolution Mult. "E_1"	"E_2"	"E_3"	"S"
s_1	16	16	-48	16	16
s_2	16	16	-48	16	16
s_3	16	16	16	-48	16
s_4	16	16	16	-48	16
s_5	16	-48	16	16	16
s_6	16	-48	16	16	16
s_7	48	-80	-80	-80	-80

Conclusions

We have constructed orbifold and resolution models with following properties:

- The model describes a three generation MSSM.
- To avoid that the hyper charge gets broken in full blow-up, the GUT gauge symmetry breaking is performed by a freely acting involution.

An interesting and surprising feature is the appearence of additional states on the resolutions which do not have orbifold analogs.