Heterotic MSSM on a Resolved Orbifold

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and work in progress

In collaboration with:

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

Overview

1. Introduction and motivation
2. A $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ MSSM orbifold
3. Orbifold resolutions
4. Novel resolution states
5. Smoothly from orbifolds to resolutions
6. Conclusions

Introduction and motivation

Our aims is to find models 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)
  $\Rightarrow$ on Calabi-Yaus Braun,He,Ovrut,Pantev'05, Donagi,Bouchard'05
  $\Rightarrow$ or on orbifold Buchmuller,Hamaguchi,Lebedev,Ratz'05, Lebedev,Nilles,Raby,Ramos-Sanchez,Ratz,Vaudrevange,Wingerter'06

To connect these very different approaches:
SGN,Held,Rühle,Trapletti,Vaudrevange'09, Blaszczyk,SGN,Rühle,Trapletti,Vaudrevange'10

1. we start from a heterotic MSSM orbifold model
2. and then resolve it to obtain more generic predictions

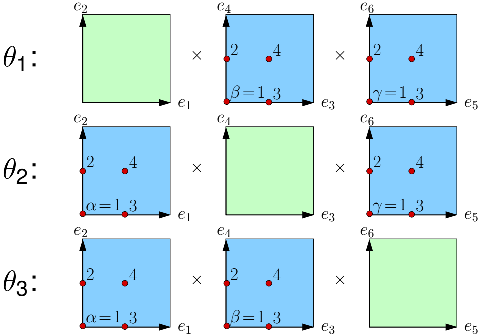
A $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold

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

Blaszczyk,SGN,Ratz,Rühle,Trapletti,Vaudrevange'10

- Six generations of $\mathbf{10} + \overline{\mathbf{5}}$ that come from twisted sectors only
- A $\mathbb{Z}_{2,\text{free}}$ freely acting involution breaks SU(5) $\to$ SM:

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

- Under it the fixed tori get identified in pairs: Donagi,Wendland'08
  $\Rightarrow$ the number of generations becomes three
- Its non-local breaking cannot lead to a flux: Hebecker,Trapletti'05
  $\Rightarrow$ the hyper charge remains unbroken Donagi,Ovrut, et al'99,'05,

For further details of this MSSM orbifold see talks by Michael Ratz and Michael Blaszczyk

Orbifold resolutions

Resolution of torodial orbifolds

A torodial orbifold is a flat space except for some singularities that locally look like non-compact orbifolds, e.g. $\mathbb{C}^2/\mathbb{Z}_N$

Such singularities can be resolved using toric geometry:
Erler,Klemm'92,SGN,Ha,Trapletti'07

- E.g. the $\mathbb{Z}_2$ orbifold action

$$\theta : (z_1, z_2, z_3) \to (z_1, -z_2, -z_3),$$

- can be replaced by a $\mathbb{C}^*$ action

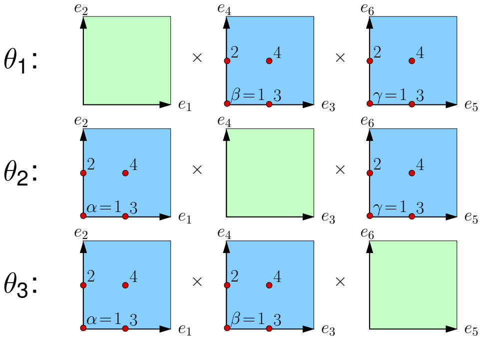
$$(z_1, z_2, z_3; x) \to (z_1, \lambda\, z_2, \lambda\, z_3; \lambda^{-2} x)$$

- This introduces an "exceptional" divisor $E := \{x = 0\}$.

The local resolutions can subsequently be glued together
Lust,Reffert,Scheidegger,Stieberger'06

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

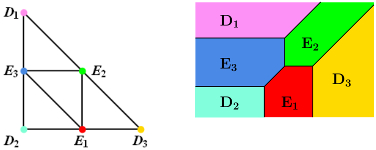
Denef,Douglas,Florea,Grassi,Kachru'05, Lust,Reffert,Scheidegger,Stieberger'06



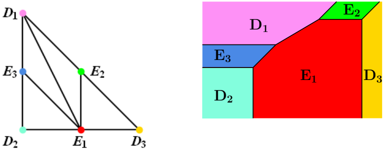
- The 48 fixed two-tori give 48 exceptional divisors E_r in blow-up
- The 64 $\mathbb{Z}_2 \times \mathbb{Z}_2$ fixed points do not give additional exceptional divisors, but each of them has 4 inequivalent resolutions:

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

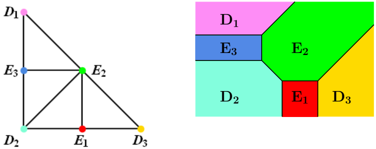
The toric and web diagrams for the four $\mathbb{Z}_2 \times \mathbb{Z}_2$ resolutions:



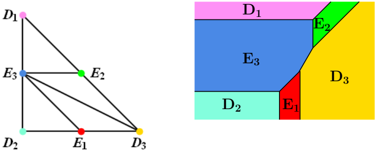
triangulation "S"



triangulation "E_1"



triangulation "E_2"



triangulation "E_3"

Resolution dependence of intersection numbers

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			

(same triangulation for all 64 $\mathbb{Z}_2 \times \mathbb{Z}_2$ resolutions)

Huge number of resolutions

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

SGN,Trapletti,Walter'07,SGN,Ha,Trapletti'07

- the Bianchi consistency identities
- structure of anomalous U(1)s
- the spectrum of massless states

For details see e.g. talk by

Nana Cabo Bizet

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 triangulation?
- What does this mean physically?

MSSM in blowup

We have constructed an Abelian flux such the unbroken gauge group on the resolution is:

$$SU(5) \times SU(3) \times SU(2)$$

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

#	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)

By $\mathbb{Z}_{2,\text{free}}$ involution breaks the GUT gauge group to the SM, and the number of generations gets halved

For further details see Michael Blaszczyk talk...

Novel resolution states

Novel states in blow-up

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

- The orbifold is a point of enhanced symmetry in the moduli space hence additional states may become massless there
- 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:

Blaszczyk,SGN,Rühle,Trapletti,Vaudrevange'10

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

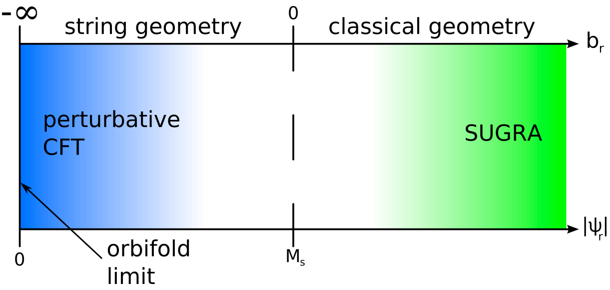
(the minus indicates that the complex conjugated state appears)

Smoothly from orbifold to resolutions

Moduli space

So far we have used analyses that are valid in very different regions of the moduli space:

- The supergravity description breaks down before $b_r \approx 0$
- The orbifold CFT regime is reached when $b_r \to -\infty$ Aspinwall'93



Twisted state VEV:

$$\Psi_r = M_s \, e^{2\pi(b_r + i\beta_r)}$$

is related to the Kahler parameter b_r

$\Rightarrow$ We need a description that is valid everywhere in moduli space...

Gauged linear sigma models

Gauged linear sigma models (GLSMs) might provide a description for the orbifold, large volume and intermediate regimes Witten'93, Distler,Karchu'94, Distler,Greene,Morrison'96

The coordinates are part of a 2D susy theory that is gauged:

$$(z_1, z_2, z_3; x) \to (z_1, e^{i\phi/2} z_2, e^{i\phi/2} z_3; e^{-i\phi} x)$$

Like in 4D an FI term is possible, resulting in the scalar potential

$$V = \frac{e^2}{2} \Big(\frac{|z_2|^2 + |z_3|^2}{2} - |x|^2 - b \Big)^2$$

The minimum of the potential determines the geometry:

- smooth geometry ($b > 0$): at least one of the $\langle z_i \rangle \neq 0$
- orbifold ($b < 0$): $\langle x \rangle \neq 0$ but a $\mathbb{Z}_2$ gauge sym. remains

GLSMs for heterotic orbifold resolutions

To be able to use GLSMs to describe heterotic orbifold models and their resolutions we need:

SGN'in progress

- A map between orbifold states that generate a blow-up and the consise definition of the corresponding GLSM
- Understand the properties of the various GLSM phases for heterotic model building
- Computational methods to determine the spectrum and masses in any point in the moduli space

Conclusions

We have constructed orbifold and resolution models with the following properties:

- Six generation orbifold GUT
- GUT breaking performed by a freely acting involution

  $\Rightarrow$ reducing the number of generations to three
- The hyper charge remains unbroken in blow-up

An interesting and surprising feature is the appearance of additional states on the resolutions without orbifold analogs

As the orbifold and supergravity regimes are far apart, we need a description that can interpolate between them