Phenomenology of Resolving Orbifold Singularities

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Based on work with:
S. Groot Nibbelink, M. Ratz, F. Rühle, M. Trapletti, P.K.S. Vaudrevange
0911.4905, 1007.0203, work in progress

SUSY 2010, Bonn, 27.08.2010

Motivation

- Aim: find realistic string vacua
- Heterotic Orbifolds : Mini-Landscape with ≈ 200 MSSM models

O. Lebedev, H. P. Nilles, S. Raby, S. Ramos-Sánchez, M. Ratz, P.K.S. Vaudrevange, A. Wingerter, 2006-2008

- Calabi-Yau compactification with vector bundles
- Can we connect these two approaches?
- How close can we get to the MSSM?

Heterotic Model Building

Heterotic Orbifold Models

- Toroidal Orbifolds: $\mathcal{O} = \mathbb{C}^3/S$
- Spacegroup S. Here:

$$S = \Lambda_6^{\text{fac}} \rtimes (\mathbb{Z}_2 \times \mathbb{Z}_2) \rtimes \mathbb{Z}_{2,\text{free}}$$
$$= \Lambda_6^{\text{nonfac}} \rtimes (\mathbb{Z}_2 \times \mathbb{Z}_2)$$

- embed S into gauge dofs, $g \longmapsto V_g$
  - $g \in S$ has fixed point/plane $\rightarrow$ local shift
  - $g \in S$ free $\rightarrow$ Wilson line
- Untwisted States: SUGRA + SYM + moduli (+ chiral)
- Twisted States: chiral

Calabi–Yau Models

- Heterotic SUGRA on smooth Calabi–Yau threefold
- Wrap Vector Bundle with structure group $\tilde{G} \subset E_8 \times E_8$
- Gauge group G = commutant of $\tilde{G}$
  Here: Abelian bundle, $\tilde{G} = U(1)^r$ (stable)
- **248** branched into ad(G) and chiral matter
- multiplicity given by bundle cohomology encoded in multiplicity operator

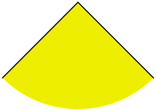
$$N = \int_X \left\{ \frac{1}{6} \left(\frac{\mathcal{F}}{2\pi} \right)^3 - \frac{1}{24} \,\mathrm{tr} \left(\frac{\mathcal{R}}{2\pi} \right)^2 \frac{\mathcal{F}}{2\pi} \right\}$$

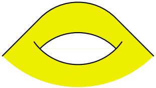
Orbifold vs. Calabi–Yau

- We can obtain a Calabi–Yau threefold by resolving the singularities of our orbifold

  talks by Nana Cabo Bizet and Stefan Groot Nibbelink
- different phases of one (fundamental) theory
- can transfer CFT consistency conditions from orbifold to SUGRA model on Calabi–Yau
- correspondence between these models

Orbifold vs. Calabi–Yau

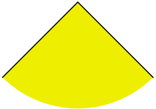


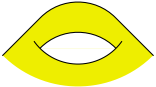


Orbifold	Calabi–Yau
local twist V_{loc}	Abelian bundle $\mathcal{F} = E_r V_r^I H^I$
Wilson Line	Wilson Line
D-flatness	DUY equation
$\sum_i q_i \lvert\Psi_i\rvert^2 + \xi = 0$	$\sum_r V_r^I \mathrm{Vol}(E_r) + \tilde{\xi}^I = 0$
one 'anomalous' $U(1)$	many 'anomalous' $U(1)$'s

talk by Nana Cabo Bizet

Orbifold vs. Calabi–Yau





Orbifold	Calabi–Yau	
untwisted states	SUGRA + SYM	
	chiral states	$W \supset e^{-\mathrm{Vol}(C)}\Psi_1\Psi_2$
twisted states	blow up modes, axions	$\Psi_r = e^{b_r + \mathrm{i}\beta_r}$

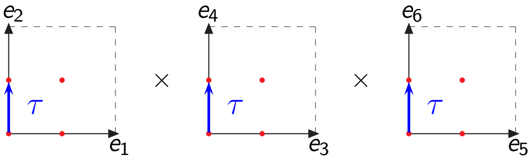
MSSM model on resolved Orbifold

$\mathbb{Z}_{2,\text{free}}$

$\mathbb{Z}_2 \times \mathbb{Z}_2$ Orbifold has freely acting $\mathbb{Z}_{2,\text{free}}$ symmetry

R. Donagi, K. Wendland '08; A. Hebecker, M. Trapletti '04

$$\tau = \frac{1}{2}(e_2 + e_4 + e_6)$$



- $\pi_1(X/\mathbb{Z}_{2,\text{free}}) = \mathbb{Z}_{2,\text{free}}$
- wrap quantized Wilson line aroud the cycle
  $\Rightarrow$ break SU(5) $\rightarrow \mathcal{G}_{\text{SM}}$ by fluxless $\mathcal{A}$-field
  - no new chirality $\rightarrow$ $\mathrm{U}(1)_\mathrm{Y}$ preserved in blow-up
  - gauge coupling unification
  - doublet-triplet splitting

Orbifold MSSM

$$
\begin{aligned}
V_1 &= \left(\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{1}{4}, -\tfrac{3}{4}, -\tfrac{3}{4}, \tfrac{1}{4}, \tfrac{1}{4}\right)\left(1, 0, 0, 0, 0, 0, 0, 0\right)\\
V_2 &= \left(\tfrac{3}{4}, \tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{1}{4}, \tfrac{1}{4}, -\tfrac{3}{4}, \tfrac{1}{4}, \tfrac{1}{4}\right)\left(1, 0, 0, 0, 0, 0, 0, 0\right)\\
W_2 = W_4 = W_6 = 2W_{\text{free}} &= \left(-\tfrac{5}{4}, \tfrac{3}{4}, -\tfrac{3}{4}, \tfrac{9}{4}, -\tfrac{7}{4}, -\tfrac{3}{4}, \tfrac{5}{4}, -\tfrac{3}{4}\right)\left(-\tfrac{1}{4}, \tfrac{11}{4}, \tfrac{3}{4}, -\tfrac{3}{4}, -\tfrac{7}{4}, -\tfrac{3}{4}, \tfrac{5}{4}, \tfrac{3}{4}\right)\\
W_3 &= \left(-1, -1, 0, -2, 0, -2, 2, -3\right)\left(-\tfrac{7}{4}, -\tfrac{1}{4}, \tfrac{3}{4}, -\tfrac{1}{4}, -\tfrac{5}{4}, \tfrac{1}{4}, \tfrac{1}{4}, \tfrac{5}{4}\right)\\
W_5 &= \left(\tfrac{1}{4}, \tfrac{9}{4}, -\tfrac{13}{4}, \tfrac{11}{4}, \tfrac{3}{4}, \tfrac{11}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}\right)\left(\tfrac{3}{4}, \tfrac{1}{4}, -\tfrac{11}{4}, -\tfrac{3}{4}, -\tfrac{3}{4}, -\tfrac{1}{4}, -\tfrac{5}{4}, \tfrac{3}{4}\right)
\end{aligned}
$$

- $G = [SU(5) \times U(1)^4] \times [SU(4) \times SU(4) \times U(1)^2]$
- SM spectrum + decoupled exotics
- phenomenologically interesting vacuum configurations

see talk by Michael Ratz

Resolution MSSM bundle vectors

$V_{1,11}, V_{1,22}$	$(-\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})(0\ 0\ 0\ 0\ 0\ 0\ -1\ 0)$
$V_{1,12}, V_{1,21}$	$(-\frac{1}{2}\ 0\ \frac{1}{2}\ 0\ 0\ 0\ 0\ 0)(-\frac{3}{4}\ \frac{1}{4}\ \frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ \frac{1}{4})$
$V_{1,13}, V_{1,24}$	$(-\frac{1}{2}\ 0\ \frac{1}{2}\ 0\ 0\ 0\ 0\ 0)(\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ \frac{1}{4}\ -\frac{3}{4}\ \frac{1}{4})$
$V_{1,14}, V_{1,23}$	$(-\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})(0\ \frac{1}{2}\ \frac{1}{2}\ 0\ 0\ -\frac{1}{2}\ \frac{1}{2}\ 0)$
$V_{1,31}, V_{1,42}$	$(-\frac{1}{4}\ \frac{1}{4}\ -\frac{3}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})(-\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})$
$V_{1,32}, V_{1,41}$	$(-\frac{1}{2}\ 0\ -\frac{1}{2}\ 0\ 0\ 0\ 0\ 0)(0\ -\frac{1}{2}\ \frac{1}{2}\ 0\ 0\ -\frac{1}{2}\ \frac{1}{2}\ 0)$
$V_{1,33}, V_{1,44}$	$(\frac{1}{2}\ -1\ -\frac{1}{2}\ 0\ 0\ 0\ 0\ 0)(0\ 0\ 0\ 0\ 0\ 0\ 0\ 0)$
$V_{1,34}, V_{1,43}$	$(-\frac{1}{4}\ -\frac{3}{4}\ \frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})(-\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ -\frac{1}{4})$
$V_{2,11}, V_{2,22}, V_{2,31}, V_{2,42}$	$(\frac{1}{4}\ -\frac{1}{4}\ \frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})(0\ 0\ 0\ 0\ 0\ 0\ -1\ 0)$
$V_{2,12}, V_{2,21}, V_{2,32}, V_{2,41}$	$(0\ \frac{1}{2}\ -\frac{1}{2}\ 0\ 0\ 0\ 0\ 0)(-\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ -\frac{3}{4}\ -\frac{1}{4})$
$V_{2,13}, V_{2,24}, V_{2,33}, V_{2,44}$	$(0\ -\frac{1}{2}\ \frac{1}{2}\ 0\ 0\ 0\ 0\ 0)(\frac{1}{4}\ \frac{3}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4})$
$V_{2,14}, V_{2,23}, V_{2,34}, V_{2,43}$	$(\frac{1}{4}\ -\frac{1}{4}\ \frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})(0\ \frac{1}{2}\ \frac{1}{2}\ 0\ 0\ -\frac{1}{2}\ \frac{1}{2}\ 0)$
$V_{3,11}, V_{3,22}, V_{3,31}, V_{3,42}$	$(\frac{1}{2}\ \frac{1}{2}\ 1\ 0\ 0\ 0\ 0\ 0)(0\ 0\ 0\ 0\ 0\ 0\ 0\ 0)$
$V_{3,12}, V_{3,21}, V_{3,32}, V_{3,41}$	$(-\frac{1}{4}\ -\frac{1}{4}\ \frac{3}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})(-\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ -\frac{1}{4})$
$V_{3,13}, V_{3,24}, V_{3,33}, V_{3,44}$	$(-\frac{1}{2}\ -\frac{1}{2}\ 0\ 0\ 0\ 0\ 0\ 0)(\frac{3}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})$
$V_{3,14}, V_{3,23}, V_{3,34}, V_{3,43}$	$(-\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4}\ -\frac{1}{4})(-\frac{1}{2}\ 0\ 0\ -\frac{1}{2}\ -\frac{1}{2}\ 0\ 0\ \frac{1}{2})$

$$W_{\text{free}} = \left(-\frac{5}{8}, \frac{3}{8}, -\frac{3}{8}, \frac{9}{8}, -\frac{7}{8}, -\frac{3}{8}, \frac{5}{8}, -\frac{3}{8}\right)\left(-\frac{1}{8}, \frac{11}{8}, \frac{3}{8}, -\frac{3}{8}, -\frac{7}{8}, -\frac{3}{8}, \frac{5}{8}, \frac{3}{8}\right)$$

Resolution Model

$$G \;=\; [SU(5)\times U(1)^4]\times[SU(3)\times SU(2)\times U(1)^5]$$

chiral matter:

#	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	$(\mathbf{5};\mathbf{1},\mathbf{1})$

#	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	$(\mathbf{1};\mathbf{1},\mathbf{1})$

- Volumes positive at 1 loop

$\mathbb{Z}_4 \times \mathbb{Z}_{2,\text{free}}$

$\mathbb{Z}_4 \times \mathbb{Z}_{2,\text{free}}$ orbifold has better geometrical properties

- disentangled sectors
  $\longrightarrow$ consistency conditions easier to fulfill
- Volumes can all be LARGE
  $\longrightarrow$ SUGRA under control
- blowup topology unique, less discrete torsion
  $\longrightarrow$ easier matching of the models
- chiral untwisted sector
  $\longrightarrow$ distinguish families

MSSM models constructed, work in progress

Conclusion & Outlook

- better understandgin of model matching
- MSSM models on Orbifold and Resolution
- non local GUT breaking

- study more phenomenological properties
- more blow-up modes $\longrightarrow$ non-Abelian bundle
- focus closer on transition between models