Orbifold Blow-ups without breaking hypercharge

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Based on:
Outline

Motivation

Orbifold MSSMs
\[ \mathbb{Z}_6 \text{-II Mini-Landscape} \]
Full Blow-up

Non-local GUT Breaking
\[ \mathbb{Z}_2 \times \mathbb{Z}_2 \text{ Orbifold} \]
Examples

Conclusion
Motivation

- Heterotic orbifold MSSMs
- Study their connection to Calabi-Yau compactifications
- What is generic to orbifold MSSMs?
Orbifold MSSMs
$\mathbb{Z}_6$-II Mini-Landscape

$\mathcal{O}(100)$ $\mathbb{Z}_6$-II orbifold models with

- $\text{SU}(3) \times \text{SU}(2) \times \text{U}(1)_Y$ times hidden sector
- 3 generations of quarks and leptons + vector-like exotics
- exotics decouple
- (potentially) realistic flavor structure, e.g. heavy top


- see talks by:
  R. Kappl, H. P. Nilles, S. Ramos-Sanchez and M. Ratz
Relation to other Constructions

- Can these models be obtained from a CY construction?
  
  ⇒ No, at least not easily!

  ⇒ talks by M. Trapletti and S. Groot Nibbelink

- $\mathbb{Z}_6$-II Mini-Landscape at special (symmetry enhanced) point in moduli space:
  
  - Wilson line breaks GUT to SM (locally) at fixed points
  - In full blow-up, SM gauge group (e.g. hypercharge) broken at these fixed points
  - (fixed points with only SM charged states ⇒ blow-up mode breaks SM)

- Important: full blow-up of Mini-Landscape models not necessary
Can MSSM orbifold models have a corresponding CY description in principle?

or

Can MSSM orbifold models be blown-up completely?
Non-local GUT Breaking
Non-local GUT Breaking

- One possibility: GUT broken to SM non-locally: freely acting orbifold
- In this talk: $\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold with freely acting twists
  R. Donagi and K. Wendland 2008
- Gauge coupling unification and $M_{GUT}$ vs. $M_{string}$
  (anisotropic compactification $\Rightarrow$ talk by R. Kappl on gauge-top unification)
  A. Hebecker and M. Trapletti 2004
**Z₂ × Z₂ Orbifold with Freely Acting Twist**

(1-1) \( \mathbb{Z}_2 \times \mathbb{Z}_2 \) orbifold by Donagi, Wendland:

- \( T^6 = T^2 \times T^2 \times T^2 \) spanned by orthogonal lattice \( e_i, \ i = 1, \ldots, 6 \)
- \( \mathbb{Z}_2 \times \mathbb{Z}_2 \) generated by

\[
\begin{align*}
v_1 &= \left(0, \frac{1}{2}, -\frac{1}{2}\right) \\
v_2 &= \left(-\frac{1}{2}, 0, \frac{1}{2}\right)
\end{align*}
\]

- freely acting twist: \( \tau = \left(\frac{1}{2}e_2, \frac{1}{2}e_4, \frac{1}{2}e_6\right) \)

R. Donagi and K. Wendland 2008
$\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold with freely acting twist

$T^6$ torus
$\mathbb{Z}_2 \times \mathbb{Z}_2$ Orbifold with Freely Acting Twist

twist $v_1$ acting on $T^6$ torus

$\mathbb{Z}_2 \times \mathbb{Z}_2$ Orbifold with Freely Acting Twist

Twist $\nu_1$ acting on $T^6$ torus

$\Rightarrow$ 16 fixed points
$\mathbb{Z}_2 \times \mathbb{Z}_2$ Orbifold with Freely Acting Twist

twist $v_2$ acting on $T^6$ torus
\( \mathbb{Z}_2 \times \mathbb{Z}_2 \) Orbifold with Freely Acting Twist

twist \( v_2 \) acting on \( T^6 \) torus

\( \Rightarrow \) 16 fixed points
$\mathbb{Z}_2 \times \mathbb{Z}_2$ Orbifold with Freely Acting Twist

twist $v_1 + v_2$ acting on $T^6$ torus
\( \mathbb{Z}_2 \times \mathbb{Z}_2 \) Orbifold with Freely Acting Twist

Twist \( v_1 + v_2 \) acting on \( T^6 \) torus

⇒ 16 fixed points
freely acting twist \( \tau \) acting on \( T^6 \) torus

\[ \Rightarrow \text{half the number of fixed points: } \frac{(16 + 16 + 16)}{2} = 24 \]
 action of freely acting twist in 2d:

\[ T^2 / \mathbb{Z}_2 \]

\[ \Rightarrow \] half the number of fixed points: \( 4/2 = 2 \)
$\mathbb{Z}_2 \times \mathbb{Z}_2$ Orbifold with Freely Acting Twist

- setup:

$\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold with 6 generations of SU(5)

freely acting $\mathbb{Z}_2$

3 generations of SU(3) × SU(2) × U(1)

- where freely acting Wilson line induces GUT breaking
- Potentially: one SM singlet per fixed point $\Rightarrow$ full blow-up
Example 1

- **Shifts and Wilson lines**

\[
V_1 = \left( \frac{1}{4}, -\frac{1}{4}, -\frac{1}{4}, \frac{1}{4}, -\frac{3}{4}, -\frac{3}{4}, \frac{1}{4}, \frac{1}{4}, 1, 0^7 \right)
\]

\[
V_2 = \left( \frac{3}{4}, 1, -\frac{1}{4}, \frac{1}{4}, -\frac{3}{4}, \frac{1}{4}, \frac{1}{4}, 1, 0^7 \right)
\]

\[
A_1 = 0
\]

\[
A_2 = \left( -\frac{5}{4}, \frac{3}{4}, -\frac{3}{4}, \frac{9}{4}, -\frac{7}{4}, -\frac{3}{4}, \frac{5}{4}, \frac{3}{4}, -\frac{1}{4}, \frac{11}{4}, \frac{3}{4}, \frac{3}{4}, -\frac{7}{4}, -\frac{3}{4}, \frac{5}{4}, \frac{3}{4} \right)
\]

\[
A_3 = \left( -1, -1, 0, -2, 0, -2, 2, -3, -\frac{7}{4}, -\frac{1}{4}, \frac{3}{4}, -\frac{1}{4}, -\frac{5}{4}, 1, 1, 5 \right)
\]

\[
A_5 = \left( \frac{1}{4}, \frac{9}{4}, -\frac{13}{4}, \frac{11}{4}, \frac{11}{4}, -\frac{1}{4}, \frac{1}{4}, \frac{11}{4}, -\frac{3}{4}, \frac{3}{4}, -\frac{3}{4}, \frac{1}{4}, -\frac{5}{4}, \frac{3}{4} \right)
\]

\[
A_6 = A_4 = A_2
\]
Example 1

- 4d gauge group: \( \text{SU}(5) \times \text{U}(1)^4 \times [\text{SU}(4)^2 \times \text{U}(1)^2] \)
- massless spectrum

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- 6 generations of SU(5) \( \Rightarrow \) 3 generations SM by freely acting Wilson line \( A_\tau = \frac{1}{2} A_2 \)
- one blow-up mode per fixed-point \( \Rightarrow \) potentially full blow-up
- however: unbroken \( \text{U}(1)_{B-L} \) at low energies
  (cf. M. Ambroso and B. Ovrut 2009)
Example 2

Shifts and Wilson lines

\[
\begin{align*}
V_1 &= \left( \frac{1}{2}, \frac{1}{2}, 0^{14} \right) \\
V_2 &= \left( \frac{5}{4}, \frac{1}{4}, \frac{1}{4}, \frac{1}{4}, \frac{1}{4}, \frac{1}{4}, 1, 1, 1, 1, 1, 0^6 \right) \\
A_1 &= 0 \\
A_2 &= \left( -1, -1, 0, -1, -\frac{1}{2}, -\frac{1}{2}, -\frac{1}{2}, -\frac{1}{2}, -\frac{1}{4}, -\frac{1}{4}, -\frac{1}{4}, -\frac{1}{4}, -\frac{3}{4}, -\frac{1}{4}, -\frac{1}{4}, -\frac{3}{4}, 1, 1, 1, -\frac{3}{4}, -\frac{1}{4} \right) \\
A_3 &= \left( 1, -1, 0, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{4}, \frac{1}{4}, \frac{1}{4}, \frac{1}{4}, -\frac{3}{4}, \frac{1}{4}, \frac{1}{4}, \frac{1}{4}, \frac{1}{4}, -\frac{1}{4}, -\frac{1}{4}, -\frac{1}{4} \right) \\
A_5 &= \left( -\frac{1}{2}, \frac{1}{2}, -\frac{1}{2}, -\frac{1}{2}, -\frac{1}{2}, -\frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}, 0, 0, 0, \frac{1}{2}, \frac{1}{2} \right) \\
A_6 &= A_4 = A_2
\end{align*}
\]
Example 2

- 4d gauge group: $\text{SU}(5) \times \text{U}(1)^4 \times [\text{SU}(4)^2 \times \text{U}(1)^2]$ 
- massless spectrum

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- freely acting Wilson line $A_T = \frac{1}{2} A_2 \Rightarrow 3$ generations SM
- properties (preliminary)
  - vector-like exotics decouple (at trilinear order)
  - Higgs-pair from untwisted sector: potentially $\mu \sim \langle W \rangle \sim m_{3/2}$
  - $D_4$ family symmetry: third generation: singlet; first/second: doublet
  - heavy top / all extra U(1)'s broken (at high scale)
  - however: 3 empty fixed points $\Rightarrow$ blow-up mode? $\Rightarrow$ full blow-up?
Conclusion
Summary

- $\mathbb{Z}_6$-II Mini-Landscape at special (symmetry enhanced) point, but full blow-up not necessary
- $\mathbb{Z}_2 \times \mathbb{Z}_2$ with freely acting twist $\Rightarrow$ non-local GUT breaking
- Examples: promising models (potentially also in full blow-up)