A Zip-code for Quarks, Leptons and Higgs Bosons

Paul-Konstantin Oehlmann

In collaboration with D. K. Mayorga and H. P. Nilles
Based on Arxiv:1209.6041, ArXiv:1305.0566

21. Susy Conference, ICTP Trieste

August, 27, 2013

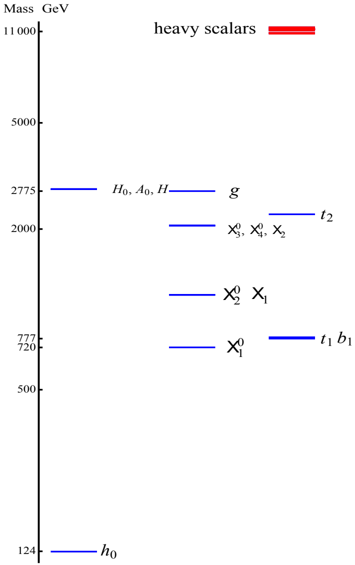
The $\mathbb{Z}_{6-\text{II}}$ Mini-Landscape

$\sim$ 200 realistic MSSM models based on the $\mathbb{Z}_{6-\text{II}}$ orbifold geometry have been constructed in computer based searches Lebedev,Nilles,Raby,Ramos-Sanchez,Ratz,Vaudrevange,Wingerter '06-08

Main features

1. The Higgs system
   - Higgs doublets are untwisted (Gauge-Higgs-Unification) Fairlie, *et. al.*'79
   - Shift symmetry in Kahler potential solves vacuum instability Hebecker, *et. al.*'12
   - μ-term forbidden by R-Symmetry Lebedev *et al.*, 2008; Kappl *et al.*, 2009
2. The Top-Quark
   - Top-Quark is untwisted with tree level Higgs Yukawa coupling
     $\hookrightarrow$ Gauge-Top-Unification Hosteins, Kappl, Ratz, Schmidt-Hoberger *et. al.*'07
   - Third family is a patchwork, completed by fields from different locations.
3. The light families
   - Twisted fields localized at fixed points
   - Form a complete **16** of SO(10)

SUSY Breaking Pattern

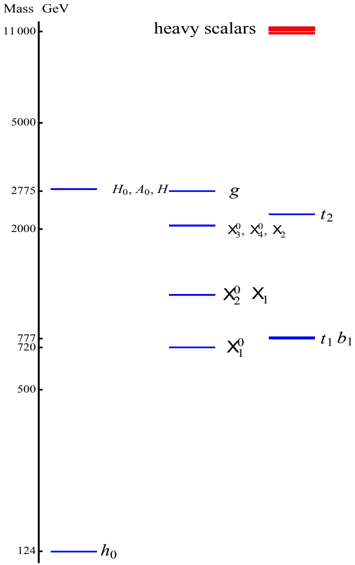


Dilaton stabilization needs:

1. Hidden sector gaugino condensation, favored [Lebedev *et. al.*'07]
2. Down-lifting of vacuum energy

$\Rightarrow$ $m_{3/2}$ in multi-TeV range

SUSY Breaking Pattern



Dilaton stabilization needs:

1. Hidden sector gaugino condensation, favored [Lebedev *et. al.*'07]
2. Down-lifting of vacuum energy

$\Rightarrow m_{3/2}$ in multi-TeV range

- Fields at Fixed Points feel only $\mathcal{N} = 1$ SUSY
  $\rightarrow$ Scalar masses $\sim m_{3/2}$
- Fields in Bulk and Fixed Tori feel remnants of $\mathcal{N} = 4, 2$ SUSY
  $\rightarrow$ Superpartner masses suppressed by $\log(M_{\rm Pl}/m_{3/2})$

  $\rightarrow$ Natural SUSY [Krippendorf *et. al.*'12]

Motivation

- How general are these results?
- What can be expected in different geometries?

A Zip-code for Quarks, Leptons and Higgs Bosons

Outline:

1. $\mathbb{Z}_2 \times \mathbb{Z}_4$ Orbifold Geometry
2. $\mathbb{Z}_2 \times \mathbb{Z}_4$ Phenomenology and Examples
3. Conclusion

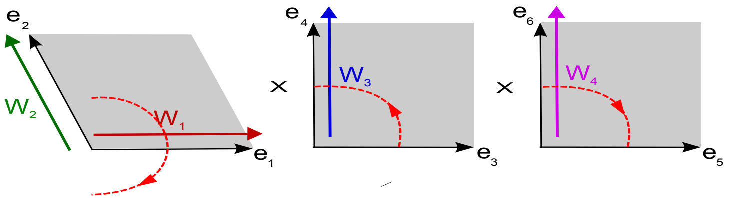
$\mathbb{Z}_2 \times \mathbb{Z}_4$ Geometry

Orbifold identification under twist $\theta(k_1, k_2)$

$$\theta(k_1, k_2) = \text{Diag}(e^{2\pi i\,(k_1 v_2^i + k_2 w^i)})$$

Geometric Definitions

- Choose factorizable lattice $SU(2)^2 \times SO(4) \times SO(4)$
- Choose the shifts $v_2 = (0, \frac{1}{2}, -\frac{1}{2}, 0) \quad v_4 = (0, 0, \frac{1}{4}, -\frac{1}{4})$
  - 8 sectors: $T_{(k_1,k_2)}$ $k_1 = 0, 1$ and $k_2 = 0, , 3$
  - 4 Wilson lines of order two: W_1, W_2, W_3, W_4



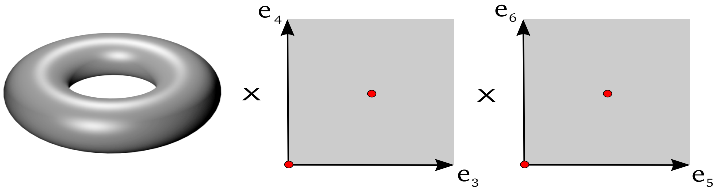
$\mathbb{Z}_2 \times \mathbb{Z}_4$ Geometry

Orbifold identification under twist $\theta(k_1, k_2)$

$$\theta(k_1, k_2) = \mathrm{Diag}(e^{2\pi i\,(k_1 v_2^i + k_2 w^i)})$$

Twisted Sectors

- $T_{(0,1)}/T_{(0,3)}$ Twisted sector
  - 4 Fixed Tori



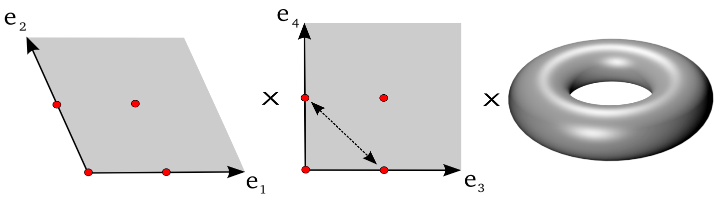
$\mathbb{Z}_2 \times \mathbb{Z}_4$ Geometry

Orbifold identification under twist $\theta(k_1, k_2)$

$$\theta(k_1, k_2) = \mathrm{Diag}(e^{2\pi i\,(k_1 v_2^i + k_2 w^i)})$$

Twisted Sectors

- $T_{(1,0)}$ Twisted Sector
  - $\boxed{12} = 8 + 4$ Fixed Tori
  - $\mathbb{Z}_4$ identification: Gauge enhancement at special fixed tori
  - Broken degeneracy without Wilson lines



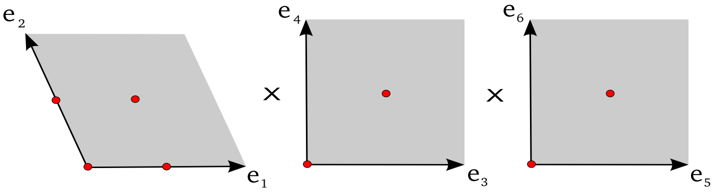
$\mathbb{Z}_2 \times \mathbb{Z}_4$ Geometry

Orbifold identification under twist $\theta(k_1, k_2)$

$$\theta(k_1, k_2) = \mathrm{Diag}(e^{2\pi i\,(k_1 v_2^i + k_2 w^i)})$$

Twisted Sectors

- $T_{(1,1)}/T_{(1,3)}$ Twisted Sector
  - $\boxed{16}$ Fixed Points
  - Fixed points, high flexibility in breaking the degeneracy via Wilson lines



The Gauge Embedding

Modular invariance of the one-loop partition function
$\hookrightarrow$ Embedding of space group twist as translation in gauge lattice $\Lambda_{E_8 \times E_8}$

Construction of inequivalent Embeddings

Quotiening the automorphism group out of $\Lambda_{E_8 \times E_8}$, we classified all

$$144 \quad (61 \text{ in } \mathbb{Z}_{6-\mathrm{II}})$$

inequivalent models and their brother model

The Gauge Embedding

Modular invariance of the one-loop partition function
$\hookrightarrow$ Embedding of space group twist as translation in gauge lattice $\Lambda_{E_8 \times E_8}$

Construction of inequivalent Embeddings

Quotiening the automorphism group out of $\Lambda_{E_8 \times E_8}$, we classified all

$$144 \quad (61 \text{ in } \mathbb{Z}_{6-\text{II}})$$

inequivalent models and their brother model

Gauge Spectrum

- 35 embeddings with SO(10) gauge factors (13 in $\mathbb{Z}_{6-\text{II}}$)
- 26 embeddings with E_6 gauge factors (16 in $\mathbb{Z}_{6-\text{II}}$)
- 25 embeddings with $SU(5)$ gauge factors (4 in $\mathbb{Z}_{6-\text{II}}$)
  $\hookrightarrow$ Seems more fertile for Model building

Phenomenological Input and Constraints

Goal: Want to judge the fertility of this geometry and find preferred field localizations

Focus on SO(10) breaking via Wilson lines to SM

1. Renormalizable Top-Yukawa from $\mathbf{16} \cdot \mathbf{16} \cdot \mathbf{10}$
2. Achieve doublet-triplet splitting via Wilson lines
3. Break the fixed point degeneracy via Wilson lines
   $\hookrightarrow$ Get three families as complete as possible

Which models are compatible with those constraints?

Phenomenological Input and Constraints

Goal: Want to judge the fertility of this geometry and find preferred field localizations

Focus on SO(10) breaking via Wilson lines to SM

1. Renormalizable Top-Yukawa from $\mathbf{16} \cdot \mathbf{16} \cdot \mathbf{10}$
   String selection rules constrain field locations
2. Achieve doublet-triplet splitting via Wilson lines
3. Break the fixed point degeneracy via Wilson lines
   $\hookrightarrow$ Get three families as complete as possible

Which models are compatible with those constraints?

Phenomenological Input and Constraints

Goal: Want to judge the fertility of this geometry and find preferred field localizations

Focus on SO(10) breaking via Wilson lines to SM

1. Renormalizable Top-Yukawa from $\mathbf{16} \cdot \mathbf{16} \cdot \mathbf{10}$
   String selection rules constrain field locations
2. Achieve doublet-triplet splitting via Wilson lines
   Constraints Higgs location to be Wilson line affected
3. Break the fixed point degeneracy via Wilson lines
   $\hookrightarrow$ Get three families as complete as possible

Which models are compatible with those constraints?

Phenomenological Input and Constraints

Goal: Want to judge the fertility of this geometry and find preferred field localizations

Focus on SO(10) breaking via Wilson lines to SM

1. Renormalizable Top-Yukawa from $\mathbf{16} \cdot \mathbf{16} \cdot \mathbf{10}$
   String selection rules constrain field locations
2. Achieve doublet-triplet splitting via Wilson lines
   Constraints Higgs location to be Wilson line affected
3. Break the fixed point degeneracy via Wilson lines
   $\hookrightarrow$ Get three families as complete as possible
   Fixes Wilson configuration and family locations

Which models are compatible with those constraints?

Example Model

Given by shifts

$$V_2 = (1, -\tfrac{1}{2}, 0, 0, 0, -\tfrac{1}{2}, 0, 0)(\tfrac{5}{4}, -\tfrac{1}{4}, \tfrac{3}{4}, \tfrac{3}{4}, \tfrac{3}{4}, \tfrac{3}{4}, -\tfrac{1}{4}, \tfrac{1}{4})$$
$$V_4 = (\tfrac{1}{2}, 0, 0, 0, 0, 0, 0, 0)(\tfrac{5}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{1}{2}, -\tfrac{1}{2})$$

Leading to $SO(10) \times SU(2) \times SU(2) \times SU(8) \times U(1)^2$ with spectrum

U	1 $(\mathbf{16}, \mathbf{2}, \mathbf{1}, \mathbf{1})_{0,-1}$
	1 $(\mathbf{16}, \mathbf{1}, \mathbf{2}, \mathbf{1})_{0,1}$
	1 $(\mathbf{10}, \mathbf{2}, \mathbf{2}, \mathbf{1})_{0,0}$
	1 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-12,0}$
	1 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{12,0}$
	1 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{28})_{6,0}$
	1 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \overline{\mathbf{28}})_{6,0}$

$T(0,1)$	4 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{8})_{6,1}$
	4 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \overline{\mathbf{8}})_{0,1}$
$T(0,2)$	10 $(\mathbf{1}, \mathbf{2}, \mathbf{2}, \mathbf{1})_{6,0}$
	10 $(\mathbf{10}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-6,0}$
	6 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-6,-2}$
	6 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-6,2}$

$T(0,3)$	4 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \overline{\mathbf{8}})_{6,-1}$
	4 $(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{8})_{0,-1}$
$T(1,0)$	4 $(\mathbf{1}, \mathbf{1}, \mathbf{2}, \mathbf{8})_{-3,0}$
$T(1,1)$	Empty
$T(1,2)$	4 $(\mathbf{1}, \mathbf{2}, \mathbf{1}, \overline{\mathbf{8}})_{-3,0}$
$T(1,3)$	16 $(\mathbf{16}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{3,0}$
	16 $(\mathbf{1}, \mathbf{2}, \mathbf{1}, \mathbf{1})_{3,1}$
	16 $(\mathbf{1}, \mathbf{1}, \mathbf{2}, \mathbf{1})_{3,-1}$

Example Model

Given by shifts

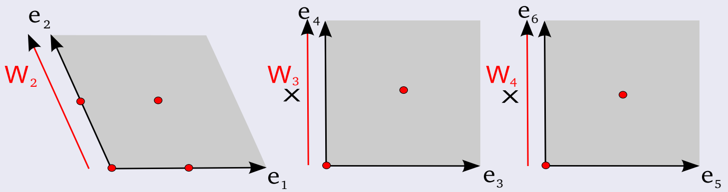
$$V_2 = (1, -\tfrac{1}{2}, 0, 0, 0, -\tfrac{1}{2}, 0, 0)(\tfrac{5}{4}, -\tfrac{1}{4}, \tfrac{3}{4}, \tfrac{3}{4}, \tfrac{3}{4}, \tfrac{3}{4}, -\tfrac{1}{4}, \tfrac{1}{4})$$
$$V_4 = (\tfrac{1}{2}, 0, 0, 0, 0, 0, 0, 0)(\tfrac{5}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{1}{2}, -\tfrac{1}{2})$$

and Wilson lines

$$W_2 = (-\tfrac{1}{2}, \tfrac{1}{2}, -\tfrac{3}{2}, -\tfrac{1}{2}, 0, -1, -1, 2)(-\tfrac{3}{4}, -\tfrac{7}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{7}{4}, \tfrac{3}{4}, \tfrac{3}{4})$$
$$W_3 = (-1, \tfrac{3}{2}, -\tfrac{1}{2}, \tfrac{1}{2}, 0, \tfrac{1}{2}, 0, 2)(-\tfrac{1}{2}, 1, -2, 0, \tfrac{3}{2}, -1, -\tfrac{3}{2}, -\tfrac{3}{2})$$
$$W_4 = (-\tfrac{5}{4}, \tfrac{5}{4}, \tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{3}{4}, -\tfrac{1}{4}, \tfrac{5}{4}, \tfrac{9}{4})(0, 1, 1, 2, -1, -\tfrac{1}{2}, 2, \tfrac{3}{2})$$

Wilson line breaking

$$SO(10) \times SU(2) \times SU(2) \times SU(8) \times U(1)^2 \rightarrow SU(3)_C \times SU(2)_L \times U(1)_Y \times SU(3) \times SU(2) \times U(1)^9$$



Example Model

Given by shifts

$$V_2 = (1, -\tfrac{1}{2}, 0, 0, 0, -\tfrac{1}{2}, 0, 0)(\tfrac{5}{4}, -\tfrac{1}{4}, \tfrac{3}{4}, \tfrac{3}{4}, \tfrac{3}{4}, \tfrac{3}{4}, -\tfrac{1}{4}, \tfrac{1}{4})$$
$$V_4 = (\tfrac{1}{2}, 0, 0, 0, 0, 0, 0, 0)(\tfrac{5}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{1}{2}, -\tfrac{1}{2})$$

and Wilson lines

$$W_2 = (-\tfrac{1}{2}, \tfrac{1}{2}, -\tfrac{3}{2}, -\tfrac{1}{2}, 0, -1, -1, 2)(-\tfrac{3}{4}, -\tfrac{7}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{7}{4}, \tfrac{3}{4}, \tfrac{3}{4})$$
$$W_3 = (-1, \tfrac{3}{2}, -\tfrac{1}{2}, \tfrac{1}{2}, 0, \tfrac{1}{2}, 0, 2)(-\tfrac{1}{2}, 1, -2, 0, \tfrac{3}{2}, -1, -\tfrac{3}{2}, -\tfrac{3}{2})$$
$$W_4 = (-\tfrac{5}{4}, \tfrac{5}{4}, \tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{3}{4}, -\tfrac{1}{4}, \tfrac{5}{4}, \tfrac{9}{4})(0, 1, 1, 2, -1, -\tfrac{1}{2}, 2, \tfrac{3}{2})$$

Break the degeneracy

Lower the degeneracy by factor of 8

Two local **16**-plets unaffected

→ Two light families

$T(0,3)$	$4\ (\mathbf{1},\mathbf{1},\mathbf{1},\bar{\mathbf{8}})_{6,-1}$ $4\ (\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{8})_{0,-1}$
$T(1,0)$	$4\ (\mathbf{1},\mathbf{1},\mathbf{2},\mathbf{8})_{-3,0}$
$T(1,1)$	Empty
$T(1,2)$	$4\ (\mathbf{1},\mathbf{2},\mathbf{1},\bar{\mathbf{8}})_{-3,0}$
$T(1,3)$	$16(\mathbf{16},\mathbf{1},\mathbf{1},\mathbf{1})_{3,0}$ $16\ (\mathbf{1},\mathbf{2},\mathbf{1},\mathbf{1})_{3,1}$ $16\ (\mathbf{1},\mathbf{1},\mathbf{2},\mathbf{1})_{3,-1}$

Example Model

Given by shifts

$$V_2 = (1, -\tfrac{1}{2}, 0, 0, 0, -\tfrac{1}{2}, 0, 0)(\tfrac{5}{4}, -\tfrac{1}{4}, \tfrac{3}{4}, \tfrac{3}{4}, \tfrac{3}{4}, \tfrac{3}{4}, -\tfrac{1}{4}, \tfrac{1}{4})$$
$$V_4 = (\tfrac{1}{2}, 0, 0, 0, 0, 0, 0, 0)(\tfrac{5}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{1}{2}, -\tfrac{1}{2})$$

and Wilson lines

$$W_2 = (-\tfrac{1}{2}, \tfrac{1}{2}, -\tfrac{3}{2}, -\tfrac{1}{2}, 0, -1, -1, 2)(-\tfrac{3}{4}, -\tfrac{7}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{7}{4}, \tfrac{3}{4}, \tfrac{3}{4})$$
$$W_3 = (-1, \tfrac{3}{2}, -\tfrac{1}{2}, \tfrac{1}{2}, 0, \tfrac{1}{2}, 0, 2)(-\tfrac{1}{2}, 1, -2, 0, \tfrac{3}{2}, -1, -\tfrac{3}{2}, -\tfrac{3}{2})$$
$$W_4 = (-\tfrac{5}{4}, \tfrac{5}{4}, \tfrac{1}{4}, -\tfrac{1}{4}, \tfrac{3}{4}, -\tfrac{1}{4}, \tfrac{5}{4}, \tfrac{9}{4})(0, 1, 1, 2, -1, -\tfrac{1}{2}, 2, \tfrac{3}{2})$$

Project out unwanted tripletts

U	
	$1\ (\mathbf{16}, \mathbf{2}, \mathbf{1}, \mathbf{1})_{0,-1}$
	$1\ (\mathbf{16}, \mathbf{1}, \mathbf{2}, \mathbf{1})_{0,1}$
	$1\ (\mathbf{10}, \mathbf{2}, \mathbf{2}, \mathbf{1})_{0,0}$
	$1\ (\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-12,0}$
	$1\ (\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{12,0}$
	$1\ (\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{28})_{6,0}$
	$1\ (\mathbf{1}, \mathbf{1}, \mathbf{1}, \overline{\mathbf{28}})_{6,0}$

$$(\mathbf{16}, \mathbf{2}, \mathbf{1}, \mathbf{1})_{0,-1} \rightarrow (\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-1,\dots} + \underbrace{(\overline{\mathbf{3}}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{1/3,\dots}}_{\overline{u}}$$

$$(\mathbf{16}, \mathbf{1}, \mathbf{2}, \mathbf{1})_{0,1} \rightarrow \underbrace{(\mathbf{3}, \mathbf{2}, \mathbf{1}, \mathbf{1})_{-1/6,\dots}}_{Q}$$

$$(\mathbf{10}, \mathbf{2}, \mathbf{2}, \mathbf{1})_{0,0} \rightarrow \underbrace{(\mathbf{1}, \mathbf{2}, \mathbf{1}, \mathbf{1})_{-1/2,\dots}}_{H_u} + \underbrace{(\mathbf{1}, \mathbf{2}, \mathbf{1}, \mathbf{1})_{1/2,\dots}}_{H_d}$$

Example Model

Yukawa Couplings

U	
	$1\ (\mathbf{16},\mathbf{2},\mathbf{1},\mathbf{1})_{0,-1}$
	$1\ (\mathbf{16},\mathbf{1},\mathbf{2},\mathbf{1})_{0,1}$
	$1\ (\mathbf{10},\mathbf{2},\mathbf{2},\mathbf{1})_{0,0}$
	$1\ (\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-12,0}$
	$1\ (\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{12,0}$
	$1\ (\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{28})_{6,0}$
	$1\ (\mathbf{1},\mathbf{1},\mathbf{1},\overline{\mathbf{28}})_{6,0}$

Trilinear Top-Yukawa:

$\hookrightarrow (\mathbf{10},\mathbf{2},\mathbf{2},\mathbf{1}) \cdot (\mathbf{16},\mathbf{1},\mathbf{2},\mathbf{1}) \cdot (\mathbf{16},\mathbf{2},\mathbf{1},\mathbf{1}) \xrightarrow{W_2, W_3, W_4} H_u Q \overline{U}$

Vector-like Higgs pair protected by R-Symmetry:

$\hookrightarrow (\mathbf{10},\mathbf{2},\mathbf{2},\mathbf{1}) \cdot (\mathbf{10},\mathbf{2},\mathbf{2},\mathbf{1}) \xrightarrow{W_2, W_3, W_4} H_u H_d$

Example Model

Yukawa Couplings

U	
	$1\ (\mathbf{16},\mathbf{2},\mathbf{1},\mathbf{1})_{0,-1}$
	$1\ (\mathbf{16},\mathbf{1},\mathbf{2},\mathbf{1})_{0,1}$
	$1\ (\mathbf{10},\mathbf{2},\mathbf{2},\mathbf{1})_{0,0}$
	$1\ (\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-12,0}$
	$1\ (\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{12,0}$
	$1\ (\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{28})_{6,0}$
	$1\ (\mathbf{1},\mathbf{1},\mathbf{1},\overline{\mathbf{28}})_{6,0}$

Trilinear Top-Yukawa:

$\hookrightarrow (\mathbf{10},\mathbf{2},\mathbf{2},\mathbf{1}) \cdot (\mathbf{16},\mathbf{1},\mathbf{2},\mathbf{1}) \cdot (\mathbf{16},\mathbf{2},\mathbf{1},\mathbf{1}) \xrightarrow{W_2,W_3,W_4} H_u Q \overline{U}$

Vector-like Higgs pair protected by R-Symmetry:

$\hookrightarrow (\mathbf{10},\mathbf{2},\mathbf{2},\mathbf{1}) \cdot (\mathbf{10},\mathbf{2},\mathbf{2},\mathbf{1}) \xrightarrow{W_2,W_3,W_4} H_u H_d$

Specific Model Details

- Net MSSM spectrum
- Non-Anomalous Hypercharge
- One unique pair of Higgs doublets
- All MSSM Exotics are vector-like
- Hidden Sector must be completely broken
- VEV configuration breaks all symmetries, preventing μ-term

The General Story

The Higgs System

1. Untwisted Higgs seems favored due to high flexibility to couple trilinearly
2. Same solution for μ-problem as in the $\mathbb{Z}_{6-\mathrm{II}}$ orbifold due to $\mathbb{Z}_2$ twist

The General Story

The Higgs System

1. Untwisted Higgs seems favored due to high flexibility to couple trilinearly
2. Same solution for μ-problem as in the $\mathbb{Z}_{6-\text{II}}$ orbifold due to $\mathbb{Z}_2$ twist

The Three Families

1. Models with three all local **16**-plets, NOT incompatible with heavy top
2. Models with 2 local **16**-plets favored
3. A Heavy Top Quarks suggests its location in bulk as well.

The General Story

The Higgs System

1. Untwisted Higgs seems favored due to high flexibility to couple trilinearly
2. Same solution for μ-problem as in the $\mathbb{Z}_{6-\text{II}}$ orbifold due to $\mathbb{Z}_2$ twist

The Three Families

1. Models with three all local **16**-plets, NOT incompatible with heavy top
2. Models with 2 local **16**-plets favored
3. A Heavy Top Quarks suggests its location in bulk as well.

Properties of Untwisted Sector crucial ingredient

Untwisted sectors with these features are frequent: $\sim 75\%$ of all embeddings

Conclusion

We investigated the MSSM matter properties found in the $\mathbb{Z}_{6-\text{II}}$ and extended them to $\mathbb{Z}_2 \times \mathbb{Z}_4$

What we did

- Considered the factorisable $\mathbb{Z}_2 \times \mathbb{Z}_4$ geometry
- Constructed all gauge twist embeddings
- Setting a Strategy to find and then explored promising models

Our findings

The $\mathbb{Z}_2 \times \mathbb{Z}_4$ is an extension of the $\mathbb{Z}_{6-\text{II}}$ Mini-Landscape with similar lessons:

- Higgs and Top Quark are favorably untwisted fields
- $\mathbb{Z}_2$ twist does two things at a time:
  - **Induces** a vector-like Higgs pair
  - **Forbids** μ-term by its R-Symmetry
- Light families originating from localized **16**-plets

Conclusion

We investigated the MSSM matter properties found in the $\mathbb{Z}_{6-\text{II}}$ and extended them to $\mathbb{Z}_2 \times \mathbb{Z}_4$

What we did

- Considered the factorisable $\mathbb{Z}_2 \times \mathbb{Z}_4$ geometry
- Constructed all gauge twist embeddings
- Setting a Strategy to find and then explored promising models

Thank you!

Our findings

The $\mathbb{Z}_2 \times \mathbb{Z}_4$ is an extension of the $\mathbb{Z}_{6-\text{II}}$ Mini-Landscape with similar lessons:

- Higgs and Top Quark are favorably untwisted fields
- $\mathbb{Z}_2$ twist does two things at a time:
  - **Induces** a vector-like Higgs pair
  - **Forbids** μ-term by its R-Symmetry
- Light families originating from localized **16**-plets

Example Model: Full Spectrum

$$SU(3)_C \times SU(2)_L \times U(1)_Y \underbrace{\times SU(3) \times SU(2) \times U(1)^9}_{Hidden}$$

#	Rep.	label	#	Rep.	label
3	$(\overline{\mathbf{3}},\mathbf{1},\mathbf{1},\mathbf{1})_{\frac{2}{3}}$	$\overline{u}$	69	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_0$	n
3	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-1}$	$\overline{e}$	32	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-\frac{1}{2}}$	r
3	$(\mathbf{3},\mathbf{2},\mathbf{1},\mathbf{1})_{-\frac{1}{6}}$	q	4	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{-\frac{1}{2}}$	b
4	$(\mathbf{1},\mathbf{2},\mathbf{1},\mathbf{1})_{\frac{1}{2}}$	l	30	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{\frac{1}{2}}$	$\overline{r}$
1	$(\mathbf{1},\mathbf{2},\mathbf{1},\mathbf{1})_{-\frac{1}{2}}$	$\overline{l}$	4	$(\mathbf{1},\mathbf{1},\overline{\mathbf{3}},\mathbf{1})_0$	s
9	$(\overline{\mathbf{3}},\mathbf{1},\mathbf{1},\mathbf{1})_{-\frac{1}{3}}$	$\overline{d}$	10	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_0$	$\tilde{v}$
6	$(\mathbf{3},\mathbf{1},\mathbf{1},\mathbf{1})_{\frac{1}{3}}$	d	8	$(\mathbf{1},\mathbf{1},\mathbf{3},\mathbf{1})_0$	$\overline{s}$
6	$(\mathbf{3},\mathbf{1},\mathbf{1},\mathbf{1})_{-\frac{1}{6}}$	f	2	$(\mathbf{1},\mathbf{1},\overline{\mathbf{3}},\mathbf{1})_{\frac{1}{2}}$	χ
8	$(\mathbf{1},\mathbf{2},\mathbf{1},\mathbf{1})_0$	v	5	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{\frac{1}{2}}$	$\overline{b}$
1	$(\mathbf{3},\mathbf{1},\mathbf{1},\mathbf{2})_{-\frac{1}{6}}$	m	2	$(\mathbf{1},\mathbf{1},\overline{\mathbf{3}},\mathbf{1})_{-\frac{1}{2}}$	$\tilde{\chi}$
8	$(\overline{\mathbf{3}},\mathbf{1},\mathbf{1},\mathbf{1})_{\frac{1}{6}}$	$\overline{f}$			