Heterotic Orbifold Phenomenology

Status and Prospects

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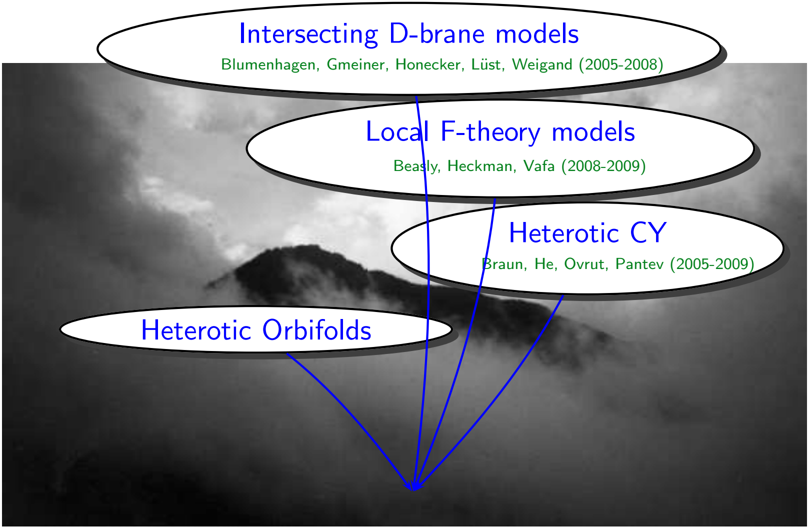
DESY

Oct. 7, 2009

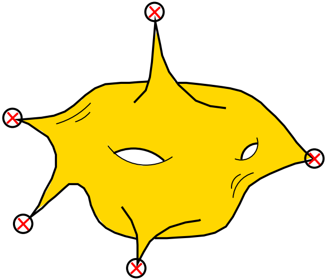
Based on collaborations with:
W. Buchmüller, R. Kappl, O. Lebedev, H.P. Nilles, S. Raby, M. Ratz, K. Schmidt-Hoberg, A. Wingerter & P. Vaudrevange

arXiv:0806.3905, arXiv:0812.2120, arXiv:0909.3948


www.DesktopCollector.com

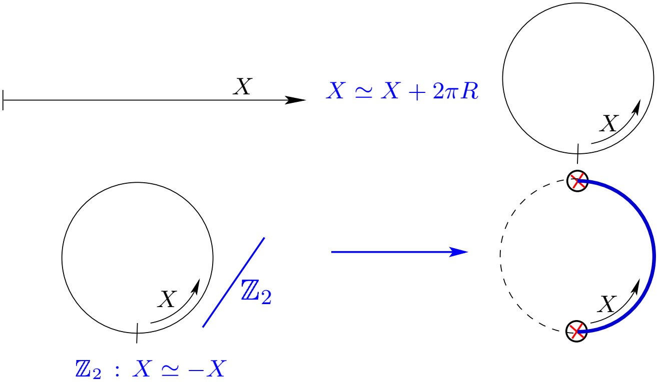

Intersecting D-brane models
Blumenhagen, Gmeiner, Honecker, Lüst, Weigand (2005-2008)
Local F-theory models
Beasly, Heckman, Vafa (2008-2009)
Heterotic CY
Braun, He, Ovrut, Pantev (2005-2009)
Heterotic Orbifolds

Orbifolds



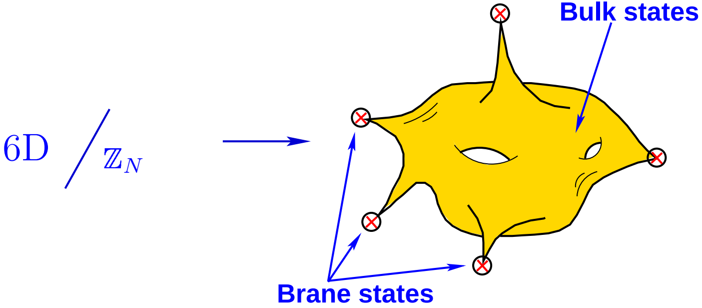
Dixon, Harvey, Vafa, Witten (1985-86)
Ibáñez, Nilles, Quevedo (1987)
Font, Ibáñez, Quevedo, Sierra (1990)
Katsuki, Kawamura, Kobayashi, Ohtsubo, Ono, Tanioka (1990)
Kobayashi, Raby, Zhang (2004)
Förste, Nilles, Vaudrevange, Wingerter (2004)
Buchmüller, Hamaguchi, Lebedev, Ratz (2004-06)
Kobayashi, Nilles, Plöger, Raby, Ratz (2006)
Faraggi, Förste, Timirgaziu (2006)
Förste, Kobayashi, Ohki, Takahashi (2006)
Kim, Kyae (2006-07)
Choi, Kim (2006-08)
...

1D $\mathbb{Z}_2$ Orbifold in 5D

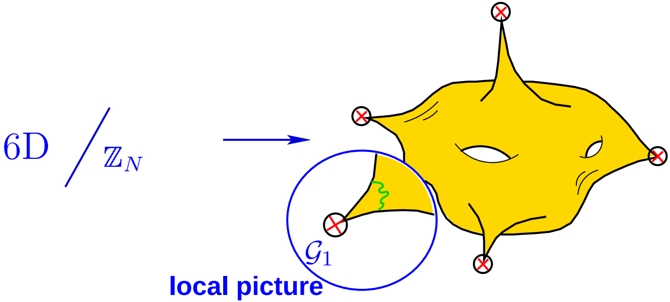


Orbifolds

6D $\mathbb{Z}_N$ Orbifold in 10D



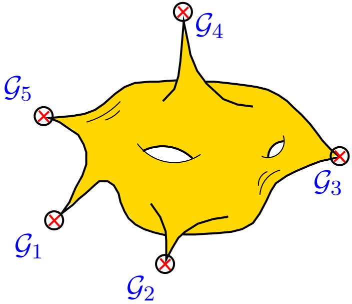
6D $\mathbb{Z}_N$ Orbifold in 10D



Orbifolds

6D $\mathbb{Z}_N$ Orbifold in 10D

$$6\mathrm{D} \Big/ \mathbb{Z}_N \quad \longrightarrow$$



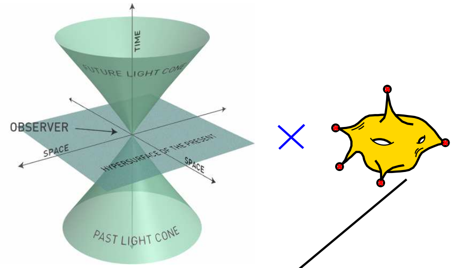
$$\mathrm{E}_8 \times \mathrm{E}_8 \;\longrightarrow\; \mathcal{G}_{4D} = \mathcal{G}_1 \cap \mathcal{G}_2 \cap \ldots \quad \subset \mathrm{E}_8 \times \mathrm{E}_8$$

Orbifolds

10 D

Heterotic

String



input: Orbifold

Geometry

Embedding

($\mathbb{Z}_N$, Lattice(s), Twist, Shifts, Wilson lines, discrete torsion)

output: 4D effective theory

Gauge symmetry $\mathcal{G}_{4D}$

Matter spectrum

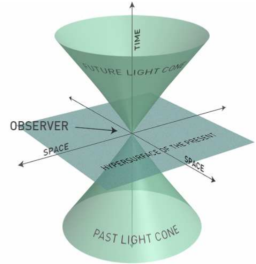
Interactions

$(K, W, f_a, \ldots)$

10 D

Heterotic

String



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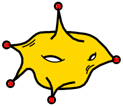


In this talk...

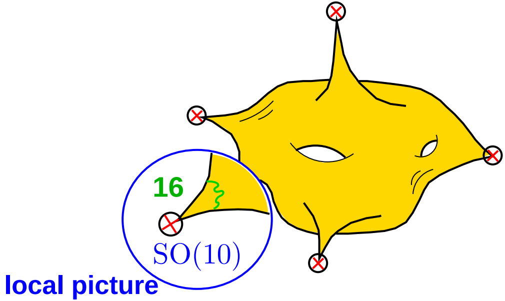
- how to get stringy MSSM candidates ?
- how realistic are they ?

Minilandscape

Orbifolds: Local GUTs

- Local GUTs

Kobayashi, Raby, Zhang (2004)
Förste, Nilles, Vaudrevange, Wingerter (2004)
Buchmüller, Hamaguchi, Lebedev, Ratz (2004)

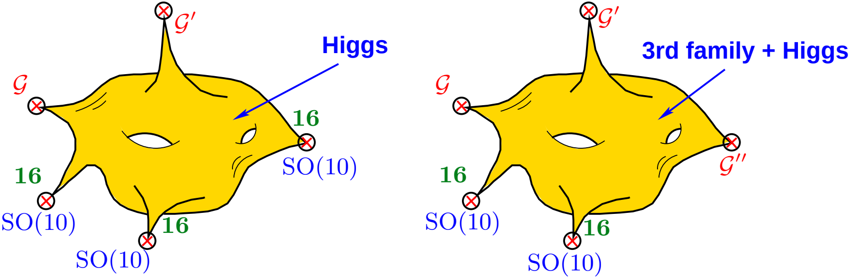


$$\mathbf{16} \;\longrightarrow\; \underset{q}{(\mathbf{3},\mathbf{2})_{1/6}} + \underset{\overline{u}}{(\overline{\mathbf{3}},\mathbf{1})_{-2/3}} + \underset{\overline{d}}{(\overline{\mathbf{3}},\mathbf{1})_{1/3}} + \underset{\ell}{(\mathbf{1},\mathbf{2})_{-1/2}} + \underset{\overline{e}}{(\mathbf{1},\mathbf{1})_{1}} + \underset{\overline{\nu}}{(\mathbf{1},\mathbf{1})_{0}}$$

Orbifolds: Local GUTs

- Helpful local GUT scenarios

Require $\mathcal{G}_{4D} = \mathcal{G}_{SM} = \mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1)_Y$

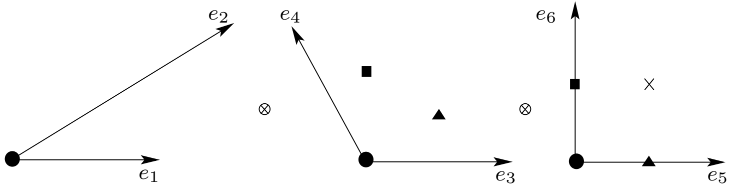


Impossible in $\mathbb{Z}_N$, $N < 6$ $\Rightarrow$ We consider $\mathbb{Z}_6$–II orbifolds

Kobayashi, Raby, Zhang (2004)
Buchmüller, Hamaguchi, Lebedev, Ratz (2004)

Orbifolds: $\mathbb{Z}_6$–II Geometry

- Lattice $\mathrm{G}_2 \times \mathrm{SU}(3) \times \mathrm{SO}(4)$; $\mathbb{Z}_6$–II: $\left(e^{2\pi \frac{1}{6}},\, e^{2\pi \frac{1}{3}},\, e^{2\pi \frac{1}{2}}\right)$



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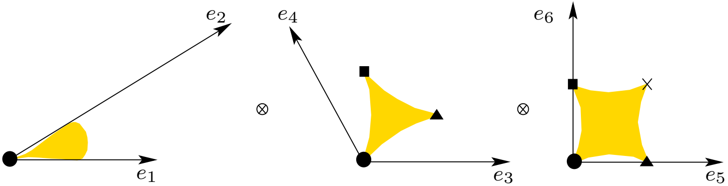

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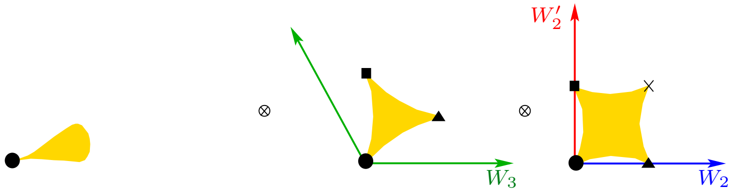

Three Wilson lines possible: W_3 order 3, W_2 & W_2' order 2

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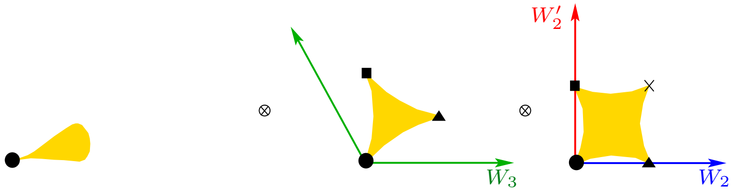
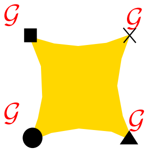


Three Wilson lines possible: W_3 order 3, W_2 & W_2' order 2

- Local GUTs with Wilson lines



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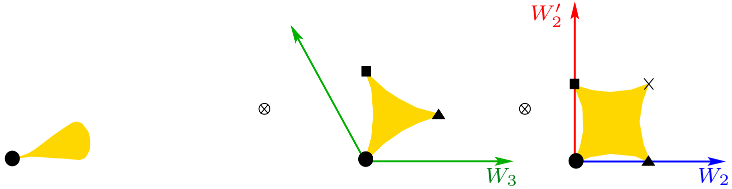

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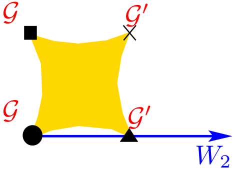

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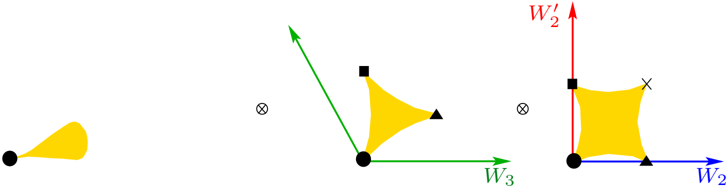

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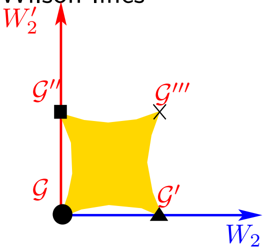
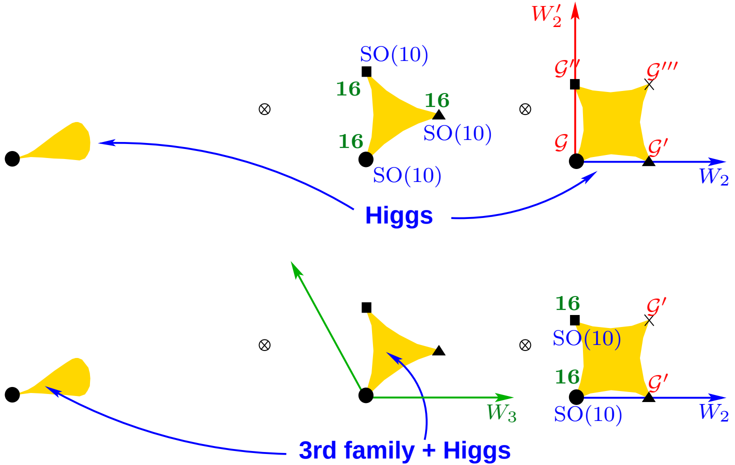
- Local GUTs with Wilson lines



Orbifolds: $\mathbb{Z}_6$–II Geometry

- 2 promising scenarios with 2 WL



Minilandscape

- Take shifts with local $\mathrm{SO}(10)$ GUTs

$$
\begin{aligned}
V^{\mathrm{SO}(10),1} &= \quad \left(\tfrac{1}{3},\, \tfrac{1}{2},\, \tfrac{1}{2},\, 0,\, 0,\, 0,\, 0,\, 0\right) \quad \left(\tfrac{1}{3},\, 0,\, 0,\, 0,\, 0,\, 0,\, 0,\, 0\right) \\
V^{\mathrm{SO}(10),2} &= \quad \left(\tfrac{1}{3},\, \tfrac{1}{3},\, \tfrac{1}{3},\, 0,\, 0,\, 0,\, 0,\, 0\right) \quad \left(\tfrac{1}{6},\, \tfrac{1}{6},\, 0,\, 0,\, 0,\, 0,\, 0,\, 0\right)
\end{aligned}
$$

- Build all models with these shifts $+$ 2 Wilson lines
- Select models with $\mathcal{G}_{SM}$ in 4D
- Select models with 3 families
- Discard models with anomalous Hypercharge
- Give VEVs to SM-singlets, such that $F = 0$ & $D = 0$
- Compute the mass matrices of additional states (exotics)
- Discard models with massless exotics

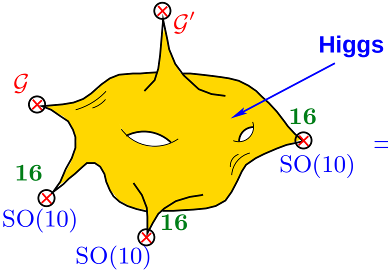
$$\Downarrow$$

Remaining models are MSSM candidates

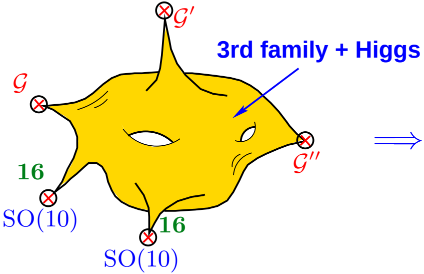
Minilandscape

Minilandscape: Search Results

total of models = 30,000 ⇒



⟹



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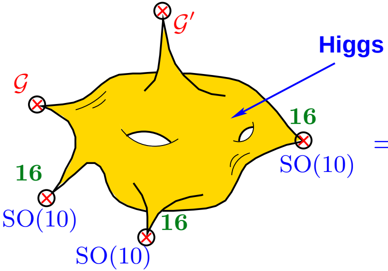
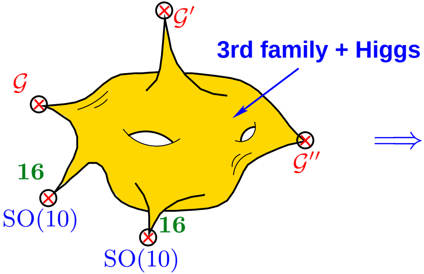
Minilandscape: Search Results

total of models = 30,000 $\Rightarrow$



$\Longrightarrow$

- **all** models have **chiral exotics**



$\Longrightarrow$

Minilandscape: Search Results

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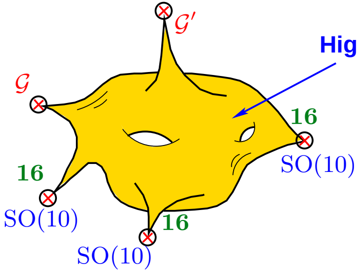

⟹

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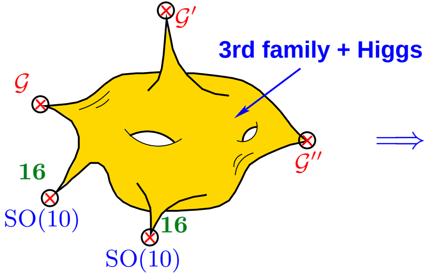

⟹

$\sim$ 100 models:

- $\mathcal{G}_{4D} = \mathcal{G}_{SM} \times \mathcal{G}_{\text{hidden}}$
- 3 SM generations + Higgses
- $\sin^2 \vartheta_w = 3/8$ @ M_{GUT}
- $\mathcal{N} = 1$ SUSY preserved
- no exotics

Are other orbifold-landscape

regions equally good?

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regions equally good?

No

Completing the Minilandscape

Extend the search, including all models with:

- 3 Wilson lines
- other local GUTs
- no local GUTs

Total of models $\sim 10^7$

Completing the Minilandscape

Extend the search, including all models with:

- 3 Wilson lines
- other local GUTs
- no local GUTs

Total of models $\sim 10^7$

local GUT	"family"	2 WL	3 WL
E_6	$\mathbf{27}$	14	53
$\mathrm{SO}(10)$	$\mathbf{16}$	87	7
$\mathrm{SU}(6)$	$\mathbf{15}+\bar{\mathbf{6}}$	2	4
$\mathrm{SU}(5)$	$\mathbf{10}$	51	10
rest		39	0
total		193	74

Bottom line: Most models arise from local GUTs. ☺

scale of ~~SUSY~~

An Observation on ~~SUSY~~

Key observation: in promising models

$$\mathcal{G}_{4D} \quad = \quad \mathcal{G}_{SM} \times \mathcal{G}_{\rm hid}$$

$\&$ $\mathcal{G}_{\rm hid}$ 'pure' Yang-Mills

$\Longrightarrow$ hidden sector gaugino condensation
$\langle \lambda\lambda \rangle \equiv \Lambda$

$\Downarrow$

nonperturbatively

Nilles (1982)
Ferrara, Girardello, Nilles (1983)

$W \approx M^3_{\rm GUT} e^{-aS}$ induced

$\Rightarrow$ ~~SUSY~~

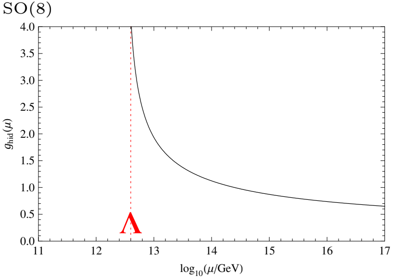
$\&$ $m_{3/2} \approx \frac{\Lambda^3}{M^2_{\rm Pl}}$

provided dilaton S stabilization $(\mathrm{Re}\langle S \rangle \sim 2 + \ldots)$

Naïve estimate of Λ

$$g^2_{\text{hid}}(\mu) \approx \left(2 - \beta_{\text{hid}} \ln(M^2_{\text{GUT}}/\mu^2)\right)^{-1}$$

$$g^2_{\text{hid}} \to \infty \Rightarrow \Lambda \approx M_{\text{GUT}}\; e^{-\frac{1}{\beta_{\text{hid}}}}$$



Lebedev, Nilles, Raby, S.R-S, Ratz, Vaudrevange, Wingerter (2006)
Lebedev, Nilles, S.R-S, Ratz, Vaudrevange (2008)

An Observation on $\cancel{\text{SUSY}}$

Naïve estimate of Λ

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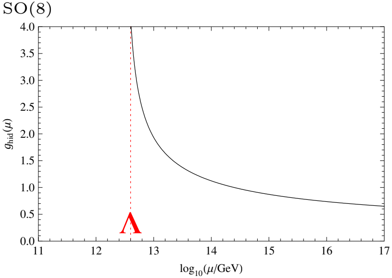
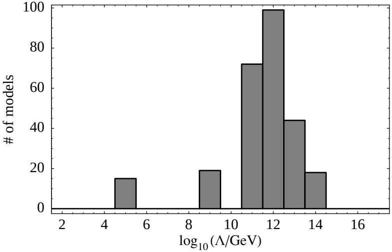


In promising models

- Mostly $\Lambda \sim 10^{11-13}$ GeV
- $\boxed{\Rightarrow\; m_{3/2} \sim \text{GeV} - \text{TeV}}$



Conclusion

low scale $\cancel{\text{SUSY}}$ favored ! ☺

Lebedev, Nilles, Raby, S.R-S, Ratz, Vaudrevange, Wingerter (2006)
Lebedev, Nilles, S.R-S, Ratz, Vaudrevange (2008)

Hierarchies & μ–term Problem

Hierarchies & μ-term: Ingredients

- Perturbative superpotential

$$\mathscr{W} \;=\; \sum c_{n_1\cdots n_M}\phi_1^{n_1}\cdots\phi_M^{n_M}$$

- $\mathcal{N}=1$ vacuum

$$-F_i^\dagger \;=\; \frac{\partial\mathscr{W}}{\partial\phi_i} \;=\; 0 \quad \text{at } \phi_j = \langle\phi_j\rangle\ \forall\ i,j$$

- $\mathrm{U}(1)_R$ Symmetry

$$\mathscr{W} \;\to\; \mathrm{e}^{2\mathrm{i}\,\alpha}\,\mathscr{W} \qquad\qquad \phi_j \;\to\; \phi_j' \;=\; \mathrm{e}^{\mathrm{i}\,r_j\,\alpha}\,\phi_j$$

$$\mathscr{W}(\phi_i) \;\to\; \mathscr{W}(\phi_i') \;=\; \mathscr{W}(\phi_i) + \sum_j \underbrace{\frac{\partial\mathscr{W}}{\partial\phi_j}}_{=0}\,\Delta\phi_j$$

$$\Rightarrow \mathscr{W} \;=\; 0$$

Hierarchies & μ-term

$\mathrm{U}(1)_R \quad \& \quad F = 0$ $\Rightarrow$ vacuum with $\langle \mathscr{W} \rangle = 0$

$D = \xi + \langle \phi_i \rangle^2 q_i = 0$ $\Rightarrow$ $\langle \phi \rangle \sim 0.1 \times M_{str}$

Consequences:

- $D\mathscr{W} = 0$ in sugra $\quad \rightarrow \quad \langle V \rangle = 0$: Minkowski vacuum ☺

Hierarchies & μ-term

$\mathrm{U}(1)_R$ & $F = 0$	$\Rightarrow$	vacuum with $\langle \mathscr{W} \rangle = 0$
$D = \xi + \langle \phi_i \rangle^2 q_i = 0$	$\Rightarrow$	$\langle \phi \rangle \sim 0.1 \times M_{str}$

Consequences:

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In MSSM-like orbifolds: $\mu \propto \langle \mathscr{W} \rangle$ ☺

approximate $\mathrm{U}(1)_R$ present ☺

- $\mathrm{U}(1)_R$ is approximate, i.e. explicitly broken at order N:
  1. $\mu \sim \langle \mathscr{W} \rangle \sim \langle \phi \rangle^{\geq N}$ $\rightarrow$ suppressed! ☺
  2. $\mathscr{W}_{eff} = \langle \mathscr{W} \rangle + \mathscr{W}_{np}$ $\rightarrow$ KKLT ☺

Kappl, Nilles, R-S, Ratz, Vaudrevange (2008)

Minilandscape: Search Results

out of a total of 10^7 $\mathbb{Z}_6$–II orbifold models:

~ 300 models: Lebedev, Nilles, Raby, R-S., Ratz, Vaudrevange, Wingerter (2006-2008)

- $\mathcal{G}_{4D} = \mathcal{G}_{SM} \times \mathcal{G}_{\text{hidden}}$
- 3 SM generations + Higgses + no exotics
- $\mathcal{N}=1$ susy vacua ($F=0 \quad \& \quad D=0$)
- gauge coupling unification
- local GUTs $\Rightarrow$ natural doublet-triplet splitting
- nontrivial (lepton & quark) mass textures
- see-saw neutrino masses — Buchmüller, Hamaguchi, Lebedev, R-S, Ratz (2007)
- low-energy SUSY breaking
- natural μ–term suppression
- admissible QCD axion — Choi, Nilles, R-S, Vaudrevange (2009)
- candidate symmetries for proton stability
- origin of family symmetries — Förste, Nilles, R-S, Vaudrevange (2009)

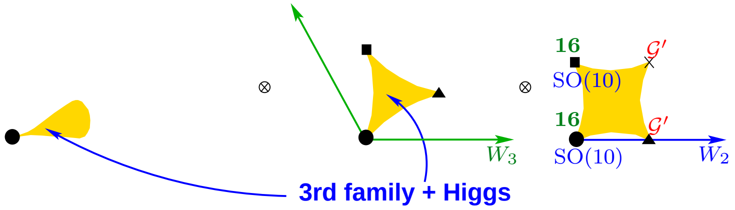
Example

Input:

- Shift $V^{\mathrm{SO}(10),1}$
- Wilson lines $W_2,\ W_3$
  $W_2 = (\frac{1}{4}, -\frac{1}{4}, -\frac{1}{4}, -\frac{1}{4}, -\frac{1}{4}, \frac{1}{4}, \frac{1}{4}, \frac{1}{4})\,(1, -1, -\frac{5}{2}, -\frac{3}{2}, -\frac{1}{2}, -\frac{5}{2}, -\frac{3}{2}, \frac{3}{2})$
  $W_3 = (-\frac{1}{2}, -\frac{1}{2}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6})\,(\frac{10}{3}, 0, -6, -\frac{7}{3}, -\frac{4}{3}, -5, -3, 3)$
- String selection rules for couplings

Output:

- $\mathcal{G}_{4D} = \mathcal{G}_{SM} \times \mathrm{U}(1)_{B\text{–}L} \times [\mathrm{SO}(8) \times \mathrm{SU}(2) \times \mathrm{U}(1)^6]$



Minilandscape: An example

3 (net) generations					
3	$(\mathbf{3},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/6,1/3)}$	q_i			
3	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-2/3,-1/3)}$	$\bar{u}_i$			
3	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1,1)}$	$\bar{e}_i$			
3+1	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/3,-1/3)}$	$\bar{d}_i$	1	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/3,1/3)}$	d_i
3+1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1/2,-1)}$	ℓ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/2,1)}$	$\bar{\ell}_i$
Higgses					
1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1/2,0)}$	h_d	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/2,0)}$	h_u
SM Singlets					
2	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,\pm 2)}$	χ_i	18	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,0)}$	s_i^0
20	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,0)}$	h_i	5	$(\mathbf{1},\mathbf{1};\mathbf{8},\mathbf{1})_{(0,0)}$	w_i
15	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,1)}$	$\bar{n}_i$	12	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,-1)}$	n_i
3	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,1)}$	$\bar{\eta}_i$	3	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,-1)}$	η_i
Exotics					
2	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{2})_{(0,0)}$	y_i	4	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(0,*)}$	m_i
2	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(1/2,1)}$	x_i^+	2	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(-1/2,-1)}$	x_i^-
3	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/3,2/3)}$	$\bar{\delta}_i$	3	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/3,-2/3)}$	δ_i
4	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/6,*)}$	$\bar{v}_i$	4	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/6,*)}$	v_i
20	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/2,*)}$	s_i^+	20	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/2,*)}$	s_i^-
2	$(\mathbf{1},\mathbf{1};\mathbf{8},\mathbf{1})_{(0,-1/2)}$	f_i	2	$(\mathbf{1},\mathbf{1};\mathbf{8},\mathbf{1})_{(0,1/2)}$	$\bar{f}_i$

Lebedev, Nilles, Raby, S.R-S., Ratz, Vaudrevange, Wingerter (2007)

		3 (net) generations			
3	$(\mathbf{3},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/6,1/3)}$	q_i			
3	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-2/3,-1/3)}$	$\bar{u}_i$			
3	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1,1)}$	$\bar{e}_i$			
3+1	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/3,-1/3)}$	$\bar{d}_i$	1	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/3,1/3)}$	d_i
3+1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1/2,-1)}$	ℓ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/2,1)}$	$\bar{\ell}_i$
		Higgses			
1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1/2,0)}$	h_d	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/2,0)}$	h_u
		SM Singlets			
2	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,\pm 2)}$	χ_i	18	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,0)}$	s_i^0
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15	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,1)}$	$\bar{n}_i$	12	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,-1)}$	n_i
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4	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/6,*)}$	$\bar{v}_i$	4	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/6,*)}$	v_i
20	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/2,*)}$	s_i^+	[illegible]	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/2,*)}$	s_i^-
2	$(\mathbf{1},\mathbf{1};\mathbf{8},\mathbf{1})_{(0,-1/2)}$	f_i	2	$(\mathbf{1},\mathbf{1};\mathbf{8},\mathbf{1})_{(0,1/2)}$	$\bar{f}_i$

$X,\ \bar{X}$

Lebedev, Nilles, Raby, S.R-S., Ratz, Vaudrevange, Wingerter (2007)

Minilandscape: An example

3 (net) generations					
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3+1	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/3,-1/3)}$	$\bar{d}_i$	1	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/3,1/3)}$	d_i
3+1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1/2,-1)}$	ℓ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/2,1)}$	$\bar{\ell}_i$
Higgses					
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3	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2}$				η_i
2	$(\mathbf{1},$				m_i
2	$($				
3	$($				
4	$(\overline{\mathbf{3}}$				
20	$(\mathbf{1},\mathbf{1},$				s_i^-
2	$(\mathbf{1},\mathbf{1};\mathbf{8},\mathbf{1})$				$\bar{f}_i$

$\langle\chi\rangle, \langle h\rangle, \langle s\rangle \sim \mathcal{O}(M_{\rm Pl})+$ string couplings

$$\Downarrow$$

$$\mathcal{G}_{4D} \longrightarrow \mathcal{G}_{SM} \times \mathbb{Z}_2^{\rm Matter} \times [\mathrm{SO}(8)]$$

&

$$M\ X\ \overline{X} \equiv \langle s\rangle^n \langle h\rangle^m \langle\chi\rangle^r X\ \overline{X}$$

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3+1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1/2,-1)}$	ℓ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/2,1)}$	$\bar{\ell}_i$
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3	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})$				η_i
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3+1	$(\bar{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/3,-1/3)}$	$\bar{d}_i$	1	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/3,1/3)}$	d_i
3+1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1/2,-1)}$	ℓ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/2,1)}$	$\bar{\ell}_i$
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		[illegible]			
2	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{2})$ [illegible]	[illegible]	[illegible]	[illegible]	m_i
2	[illegible]	[illegible]	[illegible]	[illegible]	x_i^-
3	$(\bar{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})$	[illegible]	[illegible]	[illegible]	δ_i
4	$(\bar{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/6,*)}$	[illegible]	[illegible]	[illegible]$_{(1/6,*)}$	v_i
20	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/2,*)}$	s_i^+	20	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/2,*)}$	s_i^-
2	$(\mathbf{1},\mathbf{1};\mathbf{8},\mathbf{1})_{(0,-1/2)}$	f_i	2	$(\mathbf{1},\mathbf{1};\mathbf{8},\mathbf{1})_{(0,1/2)}$	$\bar{f}_i$

Many right-handed neutrinos

$\bar{\nu}$

with $q_{B-L} = \pm 1$

Lebedev, Nilles, Raby, S.R-S., Ratz, Vaudrevange, Wingerter (2007)

Minilandscape: An example

Further appealing aspects

- unbroken hidden gauge group $\mathrm{SO}(8) \Rightarrow\ m_{3/2} \sim$ TeV
- nontrivial Yukawa matrices for quarks and fermions
- seesaw mechanism possible:

$$M_* \bar{\nu}\bar{\nu} \to |M_*| \sim M_{GUT}/\#\bar{\nu}$$
$$\Downarrow$$
$$\text{seesaw } m_\nu \sim 10^{-3\ldots-1} \text{ eV}$$

Buchmüller, Hamaguchi, Lebedev, S.R-S., Ratz (2007)

- suppressed μ–term

$$\mu = \frac{\partial^2 \mathscr{W}}{\partial h_u \partial h_d} \ll 1$$

Kappl, Nilles, S.R-S., Ratz, Schmidt-Hoberg, Vaudrevange (2008)

To take home

- too many vacua (10^{500}) in the string landscape $\longrightarrow$ search strategy needed
- local GUTs offer an optimal strategy to find realistic vacua
- in $\mathbb{Z}_6$-II heterotic orbifolds, about 300 MSSM candidates with promising features

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- too many vacua (10^{500}) in the string landscape $\longrightarrow$ search strategy needed
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Open questions:

- proton decay ? — Förste, Nilles, R-S, Vaudrevange *work in progress*
- moduli stabilization ? — Parameswaran, R-S, Velasco-Sevilla, Zavala, *work in progress*
- cosmological evolution — Papineau, Postma, R-S (2009)
- relation to F-theory ? — Buchmüller, R-S, Schmidt *work in progress*

  ⋮