Walking through a stable Mini-Landscape

Towards realistic constructions with all moduli stabilized

Saúl Ramos-Sánchez

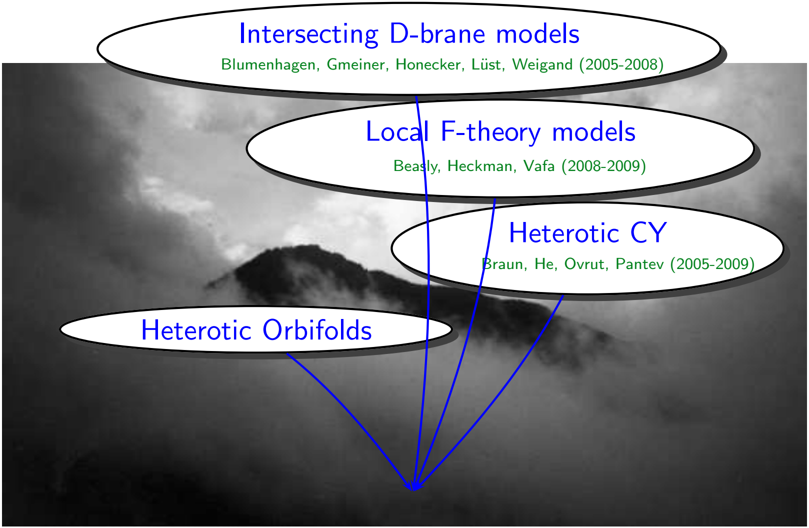
DESY

Sep. 6, 2009

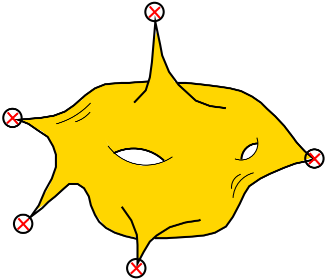
Based on collaborations with:
R. Kappl, O. Lebedev, H.P. Nilles, S. Parameswaran, S. Raby, M. Ratz,
K. Schmidt-Hoberg, A. Wingerter, P. Vaudrevange, L. Velasco & I. Zavala

arXiv:0806.3905, arXiv:0812.2120 & *work in progress*


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

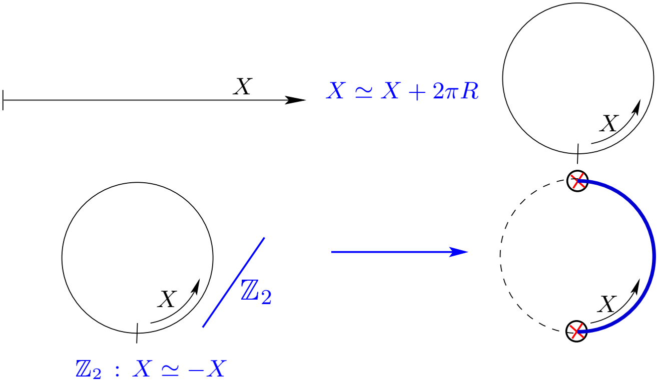
Orbifolds



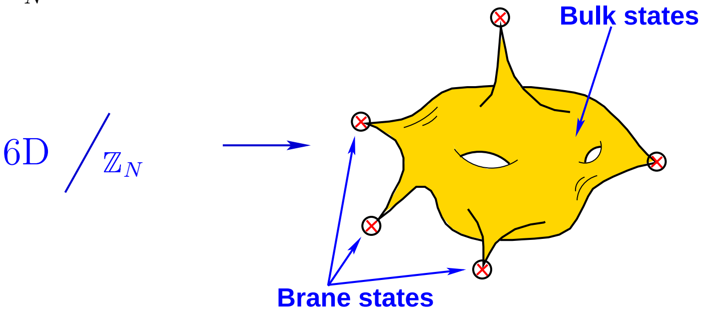
Dixon, Harvey, Vafa, Witten (1985-86)
Ibáñez, Nilles, Quevedo (1987)
Font, Ibáñez, Quevedo, Sierra (1990)
Katsuki, Kawamura, Kobayashi, Ohtsubo, Ono, Tanioka (1990)
Kobayashi, Raby, Zhang (2004)
Förste, Nilles, Vaudrevange, Wingerter (2004)
Buchmüller, Hamaguchi, Lebedev, Ratz (2004-06)
Kobayashi, Nilles,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

Orbifolds

5D $\mathbb{Z}_2$ Orbifold

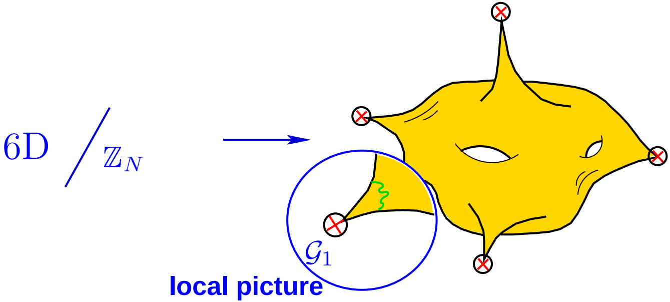


10D $\mathbb{Z}_N$ Orbifold



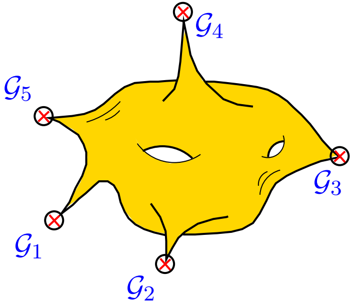
Orbifolds

10D $\mathbb{Z}_N$ Orbifold



10D $\mathbb{Z}_N$ Orbifold

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

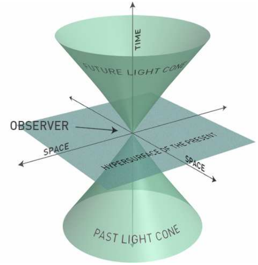


$$\mathrm{E}_8 \times \mathrm{E}_8 \longrightarrow \mathcal{G}_{4D} = \mathcal{G}_1 \cap \mathcal{G}_2 \cap \ldots \quad \subset \mathrm{E}_8 \times \mathrm{E}_8$$

10 D

Heterotic

String



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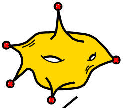


input: Orbifold

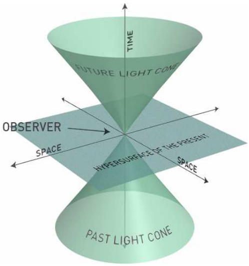
Geometry
Embedding
($\mathbb{Z}_N$, Lattice(s), Twist, Shifts, Wilson lines, discrete torsion)

output: 4D effective theory

Gauge symmetry $\mathcal{G}_{4D}$
Matter spectrum
Interactions
$(K, W, f_a, \ldots)$

Bulk Moduli

10 D
Heterotic
String



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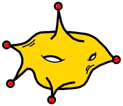


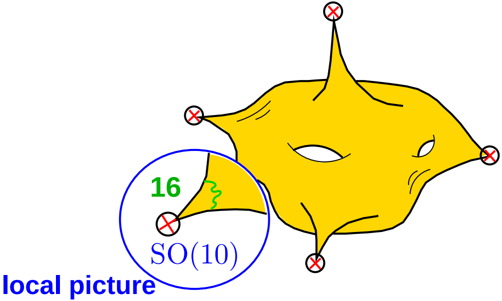
In this talk...

- how to get stringy MSSM candidates ?
- how realistic are they ?
- moduli stabilization possible ?

Mini-Landscape

- 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

Advantages of local $\mathrm{SO}(10)$ GUTs

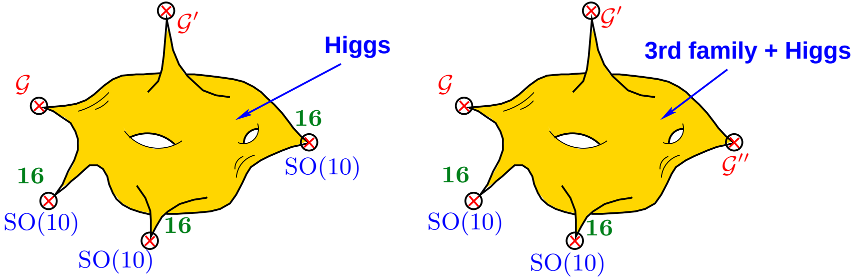
- local matter: $\mathbf{16}$, $\mathbf{1}$
- $\mathbf{16}$ furnishes a complete SM family
- in 4D
  - $\mathrm{SO}(10) \longrightarrow \mathcal{G}_{4D} = \mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1)_Y$ possible
  - complete $\mathbf{16}$ survive
  - no $\mathbf{10}$ at the branes with local GUTS implies

$$\cancel{(\overline{\mathbf{3}},\mathbf{1})_{1/3} + (\mathbf{3},\mathbf{1})_{-1/3}} + (\mathbf{1},\overline{\mathbf{2}})_{1/2} + (\mathbf{1},\mathbf{2})_{-1/2}$$

doublet-triplet splitting achievable

- Helpful local GUT scenarios

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

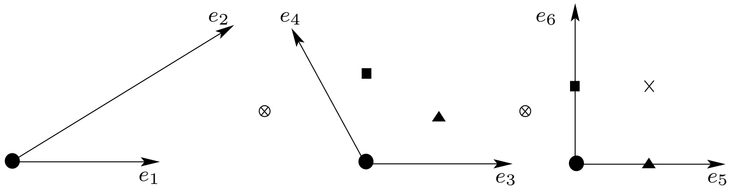


Impossible in $\mathbb{Z}_N$, $N < 6$ $\Rightarrow$ We consider $\mathbb{Z}_6$–II orbifolds

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

Orbifolds: $\mathbb{Z}_6$–II Geometry

- Lattice $G_2 \times SU(3) \times SO(4)$; $\mathbb{Z}_6$–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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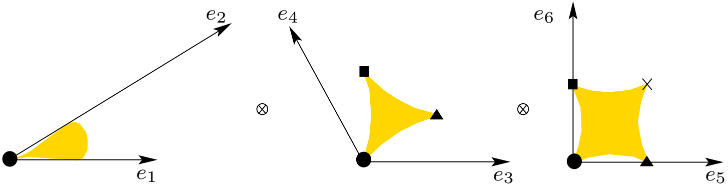

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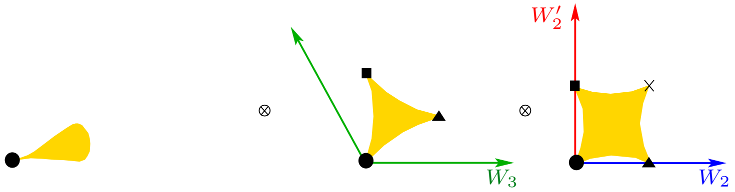

Three Wilson lines possible: W_3 order 3, W_2 & W_2' order 2

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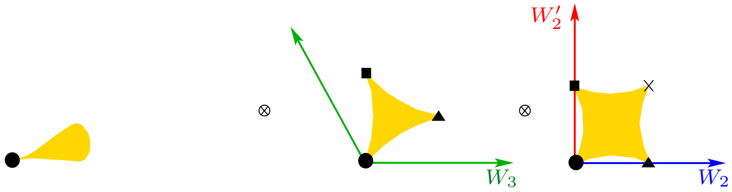
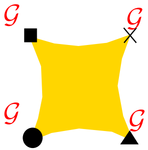


Three Wilson lines possible: W_3 order 3, W_2 & W_2' order 2

- Local GUTs with Wilson lines



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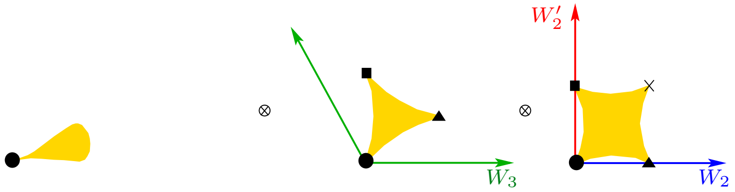

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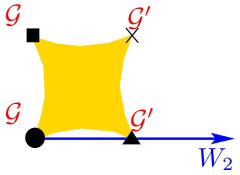

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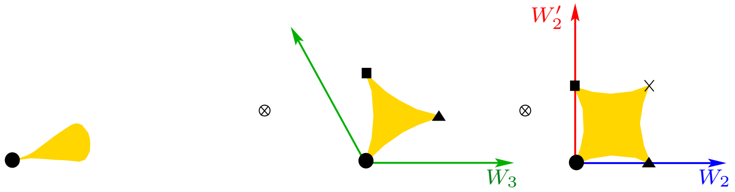

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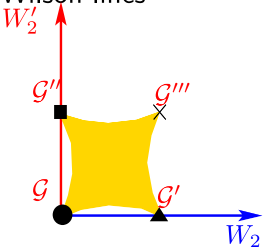
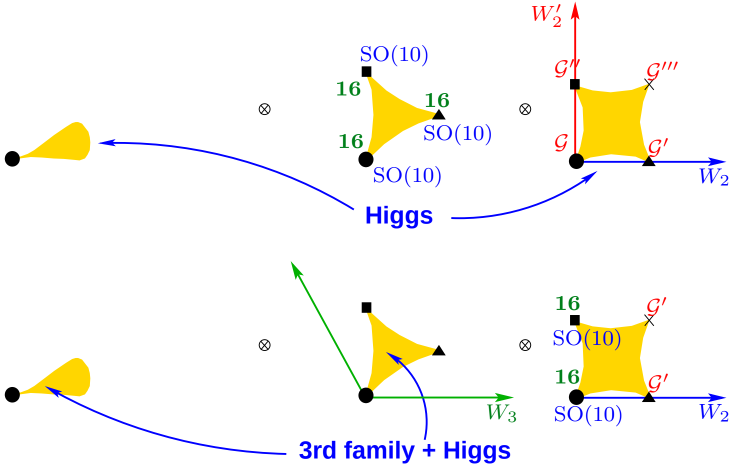


- 2 promising scenarios with 2 WL



Minilandscape

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
- low-energy SUSY breaking — Buchmüller, Hamaguchi, Lebedev, R-S, Ratz (2007)
- natural μ–term suppression
- admissible QCD axion — Choi, Nilles, R-S, Vaudrevange (2009)
- candidate symmetries for proton stability — cf. Stefan Förste's talk
- origin of family symmetries

Minilandscape: Search Results

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- local GUTs ⇒ natural doublet-triplet splitting
- non
- a
- candidate sym cf. Stefan Förste's talk
- origin of family symmetries

Nice, but...

What about moduli stabilization?

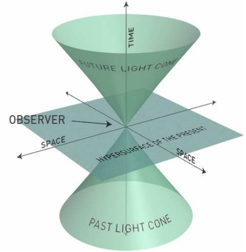
Moduli

&

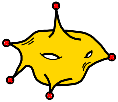
Matter

Bulk Moduli

10 D Heterotic String



$\times$



10D Heterotic String $\longrightarrow$ $\mathbb{M}^4$ $\times$ $\frac{T^2 \times T^2 \times T^2}{\mathbb{Z}_N}$

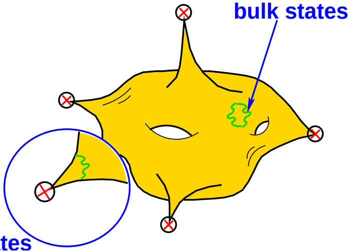
g_{MN}, B_{MN}, Φ $\longrightarrow$ $g_{\mu\nu},\ a$ g_{ij}, B_{ij}, S

$M, N = 0, \ldots, 9$ $\mu, \nu = 0, \ldots, 3$ $i, j = 4, \ldots, 9$

4D Graviton Moduli

$\mathbb{Z}_N$ invariant moduli:
- Kähler $h^{1,1}$: $T_i = f_{1,1}(g_{ij},\ B_{ij})$
- complex struc. $h^{2,1}$: $U_m = f_{2,1}(g_{ij})$
- dilaton : S

Brane Matter & Moduli



$$E_8 \times E_8 \longrightarrow \mathcal{G}_{4D} = \mathcal{G}_{SM} \times \mathcal{G}_{\text{hidden}}$$

brane states : $\{N_\alpha, \quad A_\alpha, \quad Q_\alpha\}$

singlets — SM matter — hidden matter

$\langle A_\alpha \rangle = 0 \Rightarrow \mathcal{G}_{SM}$ unbroken; $\langle Q_\alpha \rangle = 0 \Rightarrow \mathcal{G}_{\text{hidden}}$ unbroken

N_α → blow-up modes cf. Patrick Vaudrevange's talk

N_α → "moduli" (no flat potential)

Towards the goal:

how to stabilize

$T_i,\ U_m,\ S,\ N_\alpha$

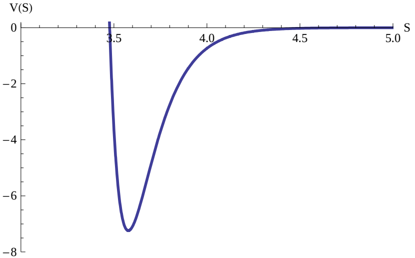
Stabilizing S: a naïve approach

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

- unbroken SUSY $\Rightarrow \langle N_\alpha \rangle \sim 0.1$
- effective suppressed superpotential $W_0 = \langle \mathscr{W} \rangle \sim \langle N_\alpha \rangle^9$
- pure Yang-Mills $\mathrm{SU}(N)$ in hidden sector, e.g. $\mathrm{SU}(4)$
  $\rightarrow$ gaugino condensation

$\Downarrow$

- $\mathscr{W}_{eff} = W_0 + Ae^{-\frac{2}{3}\pi^2 S}$ & $K = -\log(S + \bar{S})$



Moduli Stabilization Ingredients

Previous efforts

- Racetrack – multiple gaugino condensates

de Carlos, Casas, Muñoz (1992)

- Kähler stabilization (not under control)

Casas (1996)

However, either

not all moduli stabilized simultaneously ☹
unrealistic stabilization values ☹
not clear whether realizable in heterotic orbifolds

In orbifolds:

- string selections rules $\Rightarrow$ $\mathscr{W}^{pert}$
- large $\mathcal{G}_{\text{hidden}}$ $\Rightarrow$ $\mathscr{W}^{np}$ from gaugino condensation
- threshold corrections: $f_a = S + \Delta_a(T_i, U_m)$
- N_α $\Rightarrow$ De Sitter Vacua possible

Lebedev, Nilles, Ratz (2006)

Moduli Stabilization Ingredients

Focus on a $\mathbb{Z}_6$-II MSSM candidate:

- $\mathcal{G}_{4D} \;=\; \mathcal{G}_{SM} \times \mathrm{SO}(8) \times \mathrm{SU}(3)$
- 3 MSSM generations $\;+\;\; h_u,\; h_d$
- additional brane singlets $N_\alpha \quad \Rightarrow \quad N_1,\; N_2$
- In $\mathbb{Z}_6$-II with lattice $\mathrm{G}_2{\times}\mathrm{SU}(3){\times}\mathrm{SO}(4)$

  Orbifold invariance of the lattice leaves free parameters:

  R_1 size of first torus G_2
  R_3 size of second torus $\mathrm{SU}(3)$
  $R_5,\; R_6$ radii of third torus $\mathrm{SO}(4)$
  α_{56} angle between the $\mathrm{SO}(4)$ radii

$$\Downarrow$$

$$T_1,\; T_2,\; T_3,\; U_3$$

- From sugra multiplet S

Moduli Stabilization Ingredients

Advantage of orbifolds: sugra limit known! ☺

Dixon, Kaplunovsky, Louis (1990-1991)

Lüst, Muñoz (1992)

Nontrivial moduli Kähler potential and superpotential:

$$\mathscr{W}^{pert} = d\ {N_1}^2 N_2\ e^{-\alpha T_2}(1 + e^{-\beta T_1})$$

$$\mathscr{W}^{np} = A \frac{e^{-aS} + e^{-bS}}{\left(\eta(T_2)\eta(T_3)\eta(U_3)\right)^2}$$

$$\begin{aligned} K &= -\log(S+\bar{S}) - \sum_{i=1}^{3} \log(T_i + \bar{T}_i) - \log(U_3 + \bar{U}_3) \\ &\quad + \frac{|N_1|^2 + |N_2|^2}{(U_3+\bar{U}_3)^{\ell_3} \prod_{i=1}^{3}(T_i+\bar{T}_i)^{n_i}} \end{aligned}$$

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 200 MSSM candidates with successful phenomenology
- in orbifolds, sugra limit known $\longrightarrow$ ingredients for moduli stabilization available
- presence of matter fields $\longrightarrow$ De Sitter vacua achievable
- necessary to address explicitly this question in particular models

Parameswaran, R-S, Velasco-Sevilla, Zavala, *work in progress*