Phenomenology in the String Mini-Landscape

Saúl Ramos-Sánchez

DESY

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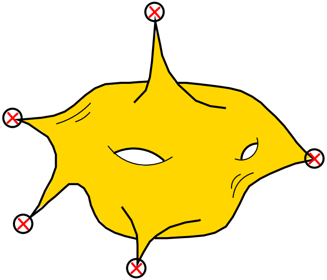
Based on collaborations with:
R. Kappl, H.P. Nilles, M. Ratz, K. Schmidt-Hoberg & P. Vaudrevange

arXiv:0812.2120

Orbifolds

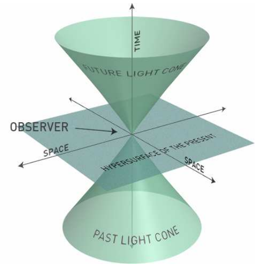


Dixon, Harvey, Vafa, Witten (1985-86)
Ibáñez, Nilles, Quevedo (1987)
Font, Ibáñez, Quevedo, Sierra (1990)
Katsuki, Kawamura, Kobayashi, Ohtsubo, Ono, Tanioka (1990)
Kobayashi, Raby, Zhang (2004)
Förste, Nilles, Vaudrevange, Wingerter (2004)
Buchmüller, Hamaguchi, Lebedev, Ratz (2004-06)
Kobayashi, Nilles,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

10 D

Heterotic

String



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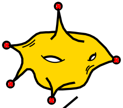

input: Orbifold

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

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

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)

- $\mathcal{G}_{4D} = \mathcal{G}_{SM} \times \mathcal{G}_{\text{hidden}}$ & global discrete symmetries
- 3 SM generations + Higgses + no exotics
- $\mathcal{N} = 1$ SUSY vacua ($also\ locally$)
  $F = 0$ & $D = 0$ cf. Rolf Kappl's talk
- gauge coupling unification
- see-saw neutrino masses Buchmüller, Hamaguchi, Lebedev, R-S, Ratz (2007)
- admissible QCD axion Choi, Nilles, R-S, Vaudrevange (2009)

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Observation

small $\mu = \frac{\partial^2 \mathcal{W}}{\partial H_u \partial H_d} \ll 1$

This Talk: why? → Further applications

Hierarchies from R-Symmetries

$\mathrm{U}(1)_R$ Symmetries

- 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

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

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

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

$\mathrm{U}(1)_R$ Symmetries

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

Consequences:

- $D\mathscr{W} = 0$ in sugra $\rightarrow$ $\langle V \rangle = 0$: Minkowski vacuum ☺
- does not matter whether exact or approximate $\mathrm{U}(1)_R$ ☺
- complementary to Nelson+Seiberg's theorem:

$\mathscr{W}$ has $\mathrm{U}(1)_R$ $\Rightarrow$
- SUSY vacuum with $\langle \mathscr{W} \rangle = 0$
- no SUSY vacuum

Nelson, Seiberg (1994)

Approximate $\mathrm{U}(1)_R$

If $\mathrm{U}(1)_R$ is approximate, i.e. explicitly broken at order N:

1. $\langle \mathscr{W} \rangle \sim \langle \phi \rangle^{\geq N}$
2. $\mathscr{W}_{eff} = \langle \mathscr{W} \rangle + \mathscr{W}_{np}$
3. $m_{3/2} \sim \langle \mathscr{W} \rangle$
4. Goldstone mode η gets mass $m_\eta \sim m_{3/2}/\langle \phi \rangle^2$

Note that, provided $\langle \phi \rangle \sim 0.1 \times M_{str}$:

- $N \sim \mathcal{O}(10) \quad \Rightarrow \quad$ hierarchical $m_{3/2}$ ☺
- η slightly heavier than gravitino ☺
- $\mathscr{W}_{eff}$ mimics KKLT ☺

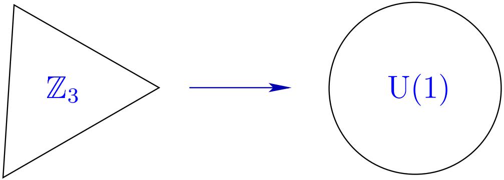
Kachru, Kallosh, Linde, Trivedi (2003)

$$\mathscr{W}_{eff} = \langle \mathscr{W} \rangle + \mathscr{W}_{np} = W_0 + Ae^{-aS}$$

Back to Orbifolds

In string orbifolds...

No stringy global U(1) symmetry, but...



Such approximate symmetries include $\mathrm{U}(1)_R$ ☺

In orbifold SUSY vacua, $D = 0 \;\rightarrow\; \langle\phi\rangle \sim 0.1 \times M_{str}$

- $H_u H_d \supset \mathbf{1}$ (gauge & string symmetries)

  $\Rightarrow$ suppressed $\mu \sim \langle \mathscr{W} \rangle$

To be specific, focus on the benchmark model 1A of the mini-landscape

$\mathrm{U}(1)_R$ in benchmark model 1A

- $\mathcal{G}_{4D} = \mathrm{SU}(3)_C \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \times [\mathrm{SU}(4) \times \mathrm{U}(1)^9]$
- Spectrum = 3 MSSM families + H_u, H_d

Ingredients:

- 23 SM singlets s_i attain VEVs $(\rightarrow\ \mathrm{U}(1)^9 \, get\ broken)$
- $\mathrm{U}(1)_R$ broken explicitly at order 9
- SUSY vacua with $D = 0$ and $\partial_i \mathscr{W} = 0$ at order 9 cf. Rolf Kappl's talk

$\Downarrow$

Consequences:

- All s_i acquire masses
- suppressed superpotential $\langle \mathscr{W} \rangle \sim \langle s_i \rangle^9$
- suppressed μ

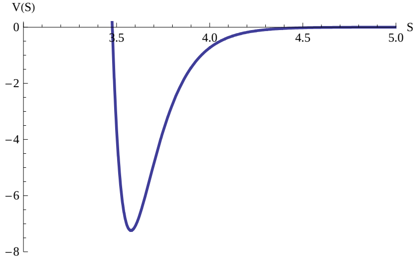
Ingredients:

- suppressed superpotential $W_0 = \langle \mathscr{W} \rangle \sim \langle s_i \rangle^9$
- pure Yang-Mills $\mathrm{SU}(4)$ in hidden sector

$\longrightarrow$ gaugino condensation

$$\Downarrow$$

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



To take home

- Approximate $\mathrm{U}(1)_R$ lead to supersymmetric vacua with suppressed $\mathscr{W}$
- suppressed $\mathscr{W}$ $\Rightarrow$ suppressed $m_{3/2}$
- suppressed $\mathscr{W}$ $\Rightarrow$ suppressed μ
- suppressed $\mathscr{W}$ $\Rightarrow$ dilaton stabilization à la KKLT
- naturally realized in the heterotic mini-landscape

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still to figure out:

- uplifting of $V(S)$
- stabilization of other moduli (in progress...)

Parameswaran, R-S, Velasco, Zavala (2009)

⋮