$Z'$ in heterotic orbifolds

Saúl Ramos-Sánchez
UNAM

String Phenomenology 2014

July 9, 2014

In collaborations with R. Alapisco: arXiv:1407.xxxx
In semi-realistic stringy constructions, one finds

\[ G_{SM} \times G_{hidden} \times U(1)^n \]

Kobayashi et al, Buchmüller et al, Nilles et al, Braun et al, Donagi et al...
Ibáñez et al, Honecker et al,...
Faraggi et al, Dienes et al; Schellekens et al,...

Two options:

\[ \rightarrow \text{very heavy } Z' \ (M_{Z'} \sim M_{str}) \]

\[ \rightarrow \text{“light” } Z' \]
In semi-realistic stringy constructions, one finds

\[ G_{SM} \times G_{hidden} \times U(1)^n \]

Kobayashi et al, Buchmüller et al, Nilles et al, Braun et al, Donagi et al...
Ibáñez et al, Honecker et al, ...
Faraggi et al, Dienes et al; Schellekens et al, ...

Two options:

\[ \rightarrow \text{very heavy } Z' \quad (M_{Z'} \sim M_{str}) \]
\[ \rightarrow \text{“light” } Z' \]
\[ \rightarrow \text{some extra “light” (SM-vectorlike) matter} \]
In semi-realistic stringy constructions, one finds

\[ G_{SM} \times G_{hidden} \times U(1)^n \]

Kobayashi et al, Buchmüller et al, Nilles et al, Braun et al, Donagi et al...
Ibáñez et al, Honecker et al, ...
Faraggi et al, Dienes et al; Schellekens et al, ...

Two options:

\[ \rightarrow \] very heavy \( Z' \) (\( M_{Z'} \sim M_{str} \))
\[ \rightarrow \] “light” \( Z' \)

\( \rightarrow \) some extra “light” (SM-vectorlike) matter
\( \text{pheno: dark matter? observable exotics? new interactions?} \)
Pros and cons of $Z'$s

Additional $U(1)$s can be good for
- hierarchy problems
- flavor structure
- anomalous $g_\mu - 2$
- origin of dark matter
- ...
Pros and cons of $Z'$

Additional $U(1)$s can be good for

- hierarchy problems
- flavor structure
- anomalous $g_\mu - 2$
- origin of dark matter

... 

Only one problem:

![Graph showing CMS data for $R_{0.8\text{ TeV}}$](image)

CMS: 1212.6175
Pros and cons of $Z$’s

Additional $U(1)$s can be good for

- hierarchy problems
- flavor structure
- anomalous $g_\mu - 2$
- origin of dark matter
- ...

Only one problem:

Can we call it advantage?

We can look for them at LHC right now!
Z’ in stringy models

Very few aspects have been explored about stringy Z’s

- proton stability
- $R$-parity violation
- Light neutrinos
- $E_6$ unification compatibility
- ...

Faraggi et al; Antoniadis et al
Z’ in stringy models

Very few aspects have been explored about stringy $Z'$s

- proton stability
- $R$-parity violation
- Light neutrinos
- $E_6$ unification compatibility
- ...

In this talk...

- kinetic mixing & dark matter
- gauge coupling magnitude & unification

Faraggi et al; Antoniadis et al
Light hidden $Z'$ mixing with the hypercharge

Kinetic Mixing

& Dark Matter

Goodsell, SR-S, Ringwald
Hidden photons

\[ \mathcal{L} \supset -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{2} \chi F^{\mu\nu} B_{\mu\nu} + \frac{1}{2} m_{\gamma'}^2 B_{\mu} B^\mu \]

further: suppressed couplings to SM matter
Our scope

Compactify the heterotic string on $\mathbb{Z}_6$–II orbifolds

- Minilandscape $\rightarrow \mathcal{O}(300)$ candidatos a MSSM
  
  Lebedev, Nilles, Raby, S.R-S., Ratz, Wingertor, Vaudrevange (’06–’08)

- 4D EFT is known

  Dixon, Friedan, Martinec, Shenker (’87), Kaplunovsky, Louis (’91), Mayr, Stieberger (’93),…

![Diagram of heterotic string compactification](image-url)
In SUSY theories

\[ \mathcal{L}_{\text{canonical}} \supset \int d^2 \theta \left\{ \frac{1}{4} W_a W_a + \frac{1}{4} W_b W_b - \frac{1}{2} \chi_{ab} W_a W_b \right\} \]

\[
\chi_{ab} \frac{g_a g_b}{16 \pi^2} = \frac{b_{ab}}{\mu^2} \log \frac{M_S^2}{\mu^2} + \Delta_{ab}
\]
In SUSY theories

\[ \mathcal{L}_{\text{canonical}} \supset \int d^2 \theta \left\{ \frac{1}{4} W_a W_a + \frac{1}{4} W_b W_b - \frac{1}{2} \chi_{ab} W_a W_b \right\} \]

con

\[ \frac{\chi_{ab}}{g_a g_b} = \frac{b_{ab}}{16 \pi^2} \log \frac{M_S^2}{\mu^2} + \Delta_{ab} \]

Stringy kinetic mixing 😊
Kinetic mixing

In SUSY theories

$$\mathcal{L}_{\text{canonical}} \supset \int d^2 \theta \left\{ \frac{1}{4} W_a W_a + \frac{1}{4} W_b W_b - \frac{1}{2} \chi_{ab} W_a W_b \right\}$$

con

$$\frac{\chi_{ab}}{g_a g_b} = \frac{b_{ab}}{16 \pi^2} \log \frac{M_S^2}{\mu^2} + \Delta_{ab}$$

Result 1: In heterotic orbifolds, stringy threshold corrections:

$$\Delta_{ab} = \sum_i \frac{b_{ab}^i |G^i|}{16 \pi^2 |G|} \left[ \log \left( |\eta(T_i)|^4 \text{Im}(T_i) \right) + \log \left( |\eta(U_i)|^4 \text{Im}(U_i) \right) \right]$$

$$b_{ab}^i = \frac{1}{2} \left( -2 \text{tr}_{V,N=2}^i (Q_a Q_b) + \text{tr}_{H,N=2}^i (Q_a Q_b) \right)$$
Kinetic mixing

In SUSY theories

\[ \mathcal{L}_{\text{canonical}} \supset \int d^2 \theta \left\{ \frac{1}{4} W_a W_a + \frac{1}{4} W_b W_b - \frac{1}{2} \chi_{ab} W_a W_b \right\} \]

\[
\frac{\chi_{ab}}{g_a g_b} = \frac{b_{ab}}{16\pi^2} \log \frac{M_S^2}{\mu^2} + \Delta_{ab}
\]

Result 2: We find for all MSSM candidates of the minilandscape\(^a\)

\[
\Delta_{XY} \neq 0, \quad 10^{-2} \lesssim \Delta_{XY} \lesssim 10^{-1}
\]

Contrary to previous findings

\(^a\) Supposing T-moduli stabilization \(\langle T \rangle \sim \mathcal{O}(1)\)

Dienes, Kolda, March-Russell ('96)

Dundee, Raby, Westphal; Parameswaran, SR-S, Zavala; Kappl, Petersen, Raby, Ratz, Schieren, Vaudrevange

Saúl Ramos-Sánchez – UNAM \quad Z’ in heterotic orbifolds
Simplest promising scenario

\[ W \supset \mu' \xi^+ \xi^- \]

lightest combination of \( \xi^+, \xi^- \) can lead to acceptable dark matter for \( m_{\gamma'} \sim \mu' \sim m_{3/2} \sim 10 \ \text{GeV} \)
Simplest promising scenario

\[ W \supset \mu' \xi^+ \xi^- \]

lightest combination of \( \xi^+, \xi^- \) can lead to acceptable dark matter for \( m_{\gamma'} \sim \mu' \sim m_{3/2} \sim 10 \text{ GeV} \)

In generic Minilandscape models with hidden photons:

- \( G_{\text{hidden}} = \text{SU}(N + 1) \times U(1)_x \), \( \text{SU}(N + 1) \) gets strong int.
- few hidden “quarks” \( h, \bar{h} \) in the fund. rep. of \( \text{SU}(N + 1) \)
- singlets with VEVs (such that \( D = F = 0 \), \( \langle s_0 \rangle \sim \mathcal{O}(0.1) \))
- few \( \xi^+, \xi^- \) charged under \( U(1)_x \)
Simplest promising scenario

\[ W \supset \mu' \xi^+ \xi^- \]

lightest combination of \( \xi^+, \xi^- \) can lead to acceptable dark matter for \( m_{\gamma'} \sim \mu' \sim m_{3/2} \sim 10 \text{ GeV} \)

In generic Minilandscape models with hidden photons:

- \( G_{\text{hidden}} = SU(N + 1) \times U(1)_x \), \( SU(N + 1) \) gets strong int.
- few hidden “quarks” \( h, \bar{h} \) in the fund. rep. of \( SU(N + 1) \)
- singlets with VEVs (such that \( D = F = 0 \)), \( \langle s_0 \rangle \sim O(0.1) \)
- few \( \xi^+, \xi^- \) charged under \( U(1)_x \)

\[
W = \frac{s^n_0}{M_S} (\xi^+ \xi^-) (h \bar{h}) + s^m_0 \ M_S \ (h \bar{h}) + N \left( \frac{\Lambda^{3N+2}}{\langle hh \rangle} \right)^{1/N}
\]
Toy scenario of ‘dark forces’: dark matter

Simplest promising scenario

$$W \ni \mu' \xi^+ \xi^-$$

lightest combination of $\xi^+, \xi^-$ can lead to acceptable dark matter for $m_{\gamma'} \sim \mu' \sim m_{3/2} \sim 10 \text{ GeV}$

In generic Minilandscape models with hidden photons:

- $G_{\text{hidden}} = \text{SU}(N+1) \times \text{U}(1)_x$, $\text{SU}(N+1)$ gets strong int.
- few hidden “quarks” $h, \bar{h}$ in the fund. rep. of $\text{SU}(N+1)$
- singlets with VEVs (such that $D = F = 0$), $\langle s_0 \rangle \sim \mathcal{O}(0.1)$
- few $\xi^+, \xi^-$ charged under $\text{U}(1)_x$

$$W = \frac{s_0^n}{M_S} (\xi^+ \xi^-) (h \bar{h}) + s_0^m M_S (h \bar{h}) + N \left( \frac{\Lambda^{3N+2}}{\langle h\bar{h} \rangle} \right)^{1/N}$$

If e.g. $N = 7, n = 5, m = 8 \rightarrow m_\xi \sim 10 \text{ GeV}$ para $z \sim 10^7$ 😊

Models of this type exist!! 😊
\[ \mathcal{L} \supset -\frac{1}{4} F^{\mu\nu} F_{\mu\nu} - \frac{1}{4} B^{\mu\nu} B_{\mu\nu} - \frac{1}{2} \chi F^{\mu\nu} B_{\mu\nu} + \frac{1}{2} m^2_{\gamma^\prime} B^\mu B_\mu \]
Z’ gauge couplings

& unification

Alapisco, SR-S
There are plenty of MSSM candidates beyond the minilandscape.

<table>
<thead>
<tr>
<th>$P$</th>
<th>lattice</th>
<th># MSSM-like models</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathbb{Z}_6$-l</td>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>$\mathbb{Z}_6$-l</td>
<td>2</td>
<td>31</td>
</tr>
<tr>
<td>$\mathbb{Z}_8$-l</td>
<td>1</td>
<td>271</td>
</tr>
<tr>
<td>$\mathbb{Z}_8$-l</td>
<td>2</td>
<td>164</td>
</tr>
<tr>
<td>$\mathbb{Z}_8$-l</td>
<td>3</td>
<td>402</td>
</tr>
<tr>
<td>$\mathbb{Z}_8$-ll</td>
<td>1</td>
<td>1264</td>
</tr>
<tr>
<td>$\mathbb{Z}_8$-ll</td>
<td>2</td>
<td>448</td>
</tr>
</tbody>
</table>

Compare to models found by Nilles+Vaudrevange (1403.1597) and by Groot-Nibbelink+Orestis (1308.5145)
Priors and goals

Facts:
- \( \sin^2 \theta_w \sim 0.23 \), \( \alpha_{em}^{-1} \sim 128 \), \( \alpha_3^{-1} \sim 8.4 \) @ \( M_Z \sim 91 \text{ GeV} \)
- in our models: \( G_{SM} \times G_{\text{hidden}} \times U(1)^n \), \( 2 \leq n \leq 8 \)
  + a bunch of (SM-vectorlike) exotics

Priors:
- there is unification at large energies
- SUSY is broken due to gaugino condensation in \( G_{\text{hidden}} \) and gravitationally mediated
Priors and goals

Facts:
- \( \sin^2 \theta_w \sim 0.23 \), \( \alpha_{em}^{-1} \sim 128 \), \( \alpha_3^{-1} \sim 8.4 \) @ \( M_Z \sim 91 \text{ GeV} \)
- in our models: \( G_{SM} \times G_{hidden} \times U(1)^n \), \( 2 \leq n \leq 8 \)
  + a bunch of (SM-vectorlike) exotics

Priors:
- there is unification at large energies
- SUSY is broken due to gaugino condensation in \( G_{hidden} \) and gravitationally mediated

Main questions

- What’s the size of \( g_s \) @ \( M_{GUT} \)?
- What’s the size of \( \alpha_{Z'} \) @ low energies?
Results

based on 1-loop RGEs

\[ \alpha_s^{-1}(M_{GUT}) = \frac{4\pi}{g_s^2(M_{GUT})} = 4\pi \langle S \rangle \in (1, 25) \]
with $\Lambda \sim M_{GUT} e^{-2\pi \alpha_s^{-1}(M_{GUT})/b}$,

$m_3/2 \sim \Lambda^3/M_{Pl}^2$

and letting $\alpha_{Z'}$ run down according to the RGEs

$$\Rightarrow \quad g_{Z'}^2 \in (1/20, 1/2)$$
Conclusions

• Broadening the search for (inequivalent) MSSM-like models, one finds many more models \( \smiley \rightarrow \) full classification still missing

• Many \( Z' \) candidates in string models, some of which may be light

• There are couplings in semi-realistic models that may lead to admissible dark matter scenarios \( \smiley \)

• Computing the running of couplings, unification still possible with additional \( U(1) \)'s \( \smiley \)

\[ \Theta \ M_{GUT}, \ 4\pi \langle S \rangle \in (1, 25) \rightarrow \text{dilaton constraint?} \ \smiley \]

\[ \Theta \sim TeV, \ g_{Z'}^2 \in (1/20, 1/2)!! \ \smiley \]

\( m_{Z'} \) very difficult to obtain without a new hierarchy \( \frownie \)
Conclusions

To be done

- Threshold corrections?

- Phenomenology and classification of $Z'$s (Lebedev, SR-S)

- Full classification of orbifold models with $Z'$ (Escalante, SR-S)

- Hierarchy associated to accidental symmetries?

- Stability and constraints due to Higgs/cosmological data?

- Proper study of proton stability in the various cases?