Phenomenology of hidden photons from heterotic orbifolds

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In collaboration with M. Goodsell & A. Ringwald: arXiv:1110.6901
and with H.P. Nilles, P. Vaudrevange, & A. Wingerter: arXiv:1110.5229

Some of today's challenges

- dark matter ☹
- SM hierarchy problem (even with SUSY, μ problem) ☹
- why only 3 fundamental forces ? ☹
- anomalous muon $g_\mu - 2$ ☹
- baryon asymmetry ☹

$\Rightarrow$ new $\mathrm{U}(1)s$

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Appear **naturally** in

- GUTs ☺
- Large extra dimensions ☺
- Brane-worlds ☺
- string compactifications ☺

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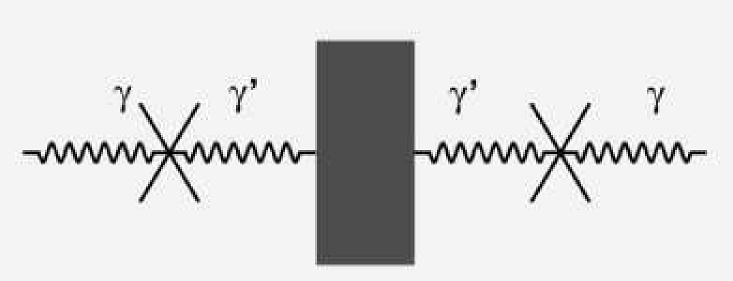
Hidden photons

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



extra: suppressed couplings to SM matter

still “alive”

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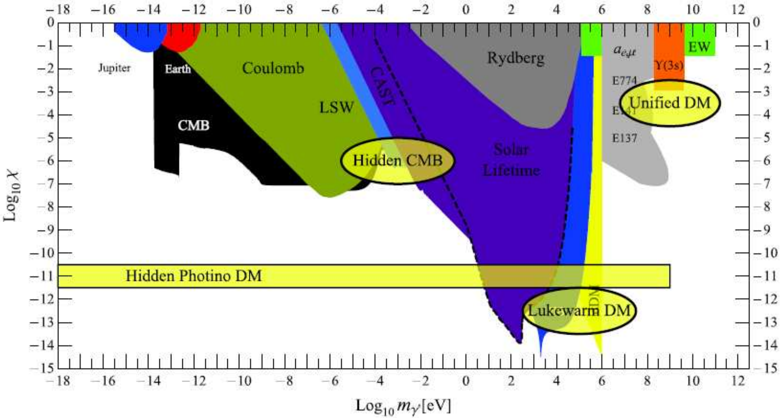

Goodsell, Jaeckel, Redondo, Ringwald (2009)

Heterotic strings

Heterotic strings

5 consistent superstring theories

- type I
- type IIA
- type IIB
- Heterotic $\mathrm{E}_8\times\mathrm{E}_8$
- Heterotic $\mathrm{SO}(32)$

- properties:
  - gauge bosons ☺
  - quantum gravity ☺
  - 10D ☹
  - $\mathcal{N}=1$ SUGRA
  - no D-branes

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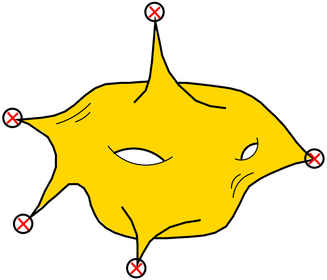
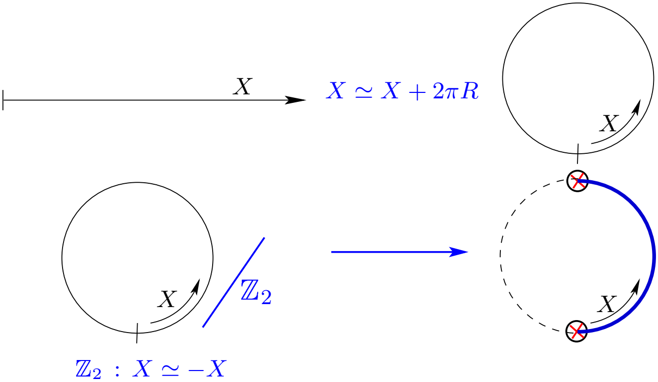
Orbifolds

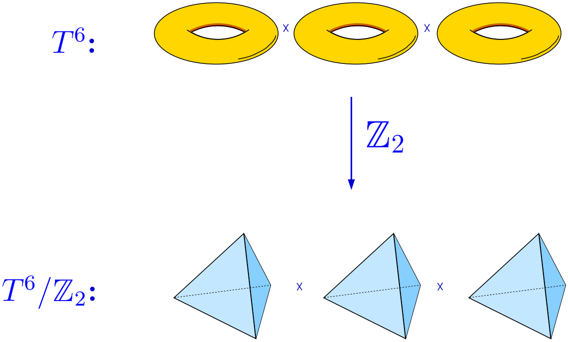


Dixon, Harvey, Vafa, Witten ('85-'86)
Ibáñez, Nilles, Quevedo ('87)
Font, Ibáñez, Quevedo, Sierra (1990)
Katsuki, Kawamura, Kobayashi, Ohtsubo, Ono, Tanioka ('90)
Kobayashi, Raby, Zhang ('04)
Förste, Nilles, Vaudrevange, Wingerter ('04)
Buchmüller, Hamaguchi, Lebedev, Ratz ('04-'06)
Kobayashi, Nilles, Plöger, Raby, Ratz ('06)
Faraggi, Förste, Timirgaziu ('06)
Förste, Kobayashi, Ohki, Takahashi ('06)
Kim, Kyae ('06-'07)
Choi, Kim ('06-'08)
...

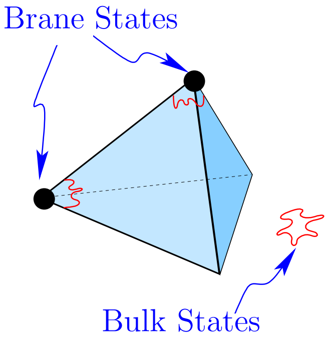
1D $\mathbb{Z}_2$ Orbifold in 5D

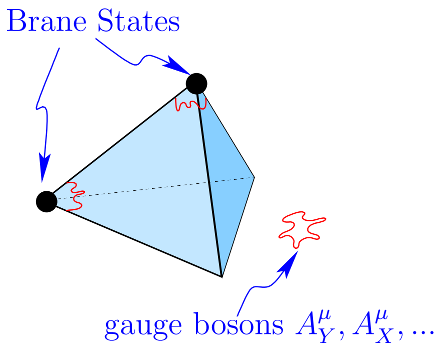


6D $\mathbb{Z}_2$ orbifold in 10D



Heterotic Orbifolds: strings and states




Brane States
gauge bosons $A_Y^\mu, A_X^\mu, \ldots$

Input and Output

- Starting point: heterotic string

$$\begin{array}{ccccc} \mathbb{M}^4 & \times & \mathbb{R}^6 & \times & T^{16} \\ & \mathrm{SO}(9,1)_{Lorentz} & & \times & \mathrm{E}_8 \times \mathrm{E}_{8\,gauge} \end{array}$$

- Input
  - Geometry: T^6, $\mathbb{Z}_N$
  - Embedding: $\mathcal{O}_6 = \mathbb{R}^6/T^6 \rtimes \mathbb{Z}_N \quad \hookrightarrow \quad \mathcal{O}_{16}$

(subject to modular invariance (CFT) conditions)

- Output

$$\begin{array}{ccccc} \mathbb{M}^4 & \times & \mathcal{O}_6 & \times & \mathcal{O}_{16} \\ & \mathrm{SO}(3,1) \times \bigotimes \mathbb{Z}^R_{n_i\,Lorentz} & & \times & \mathcal{G}_{4D} \subset \mathrm{E}_8 \times \mathrm{E}_{8\,gauge} \end{array}$$

$+$ 4D matter (quarks, leptons, exotics)

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Orbifolder (arXiv:1110.5229 Nilles, SR-S, Vaudrevange, Wingerter)

"Program" example:

```
create orbifold(myZ6II) with point group(6,1)
cd myZ6II
set heterotic string type(E8xE8)
print available space groups
use space group(3)
set shift V = (1/3 1/2 1/2 0^5 1/3 0^7)
cd ~
create random orbifold from(myZ6II) load when done print info if(SM)
                                     use(1,1,1,1,0,0,0,1) #models(1)
wait(1)
cd Model_SM1
cd vev-config
analyze config
```

$\mathbb{Z}_6$–II Minilandscape

~ 300 MSSM candidates:

- supergravity multiplet
- $\mathcal{G}_{4D} = \mathcal{G}_{SM} \times \mathcal{G}_{hid}$
- 3 SM families + Higgses
- vectorlike exotics
- gauge unification
- heavy top
- TeV gravitino mass
- seesaw
- R-parity
- flavor symmetries

Lebedev, Nilles, Raby, Ramos-Sanchez, Vaudrevange, Wingerter (2006-2008)

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} demanded (applies to the items from $\mathcal{G}_{4D}$ through heavy top)

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(supergravity multiplet through heavy top:) demanded

(TeV gravitino mass through flavor symmetries:) for free !! ☺

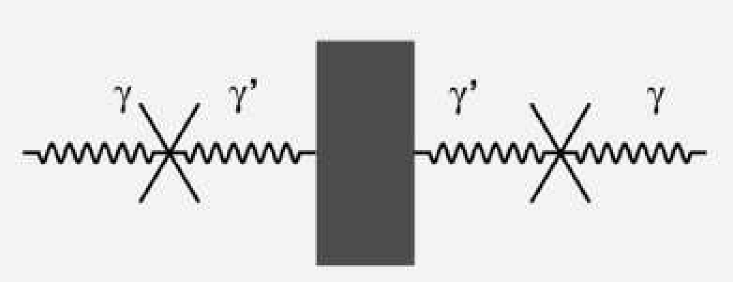
Lebedev, Nilles, Raby, Ramos-Sanchez, Vaudrevange, Wingerter (2006-2008)

Hidden Photons

in heterotic orbifolds

Hidden photons

$$\mathcal{L} \supset -\frac{1}{4}F_a^{\mu\nu}F_{\mu\nu,a} - \frac{1}{4}F_b^{\mu\nu}F_{\mu\nu,b} - \frac{1}{2}\chi_{ab}F_a^{\mu\nu}F_{\mu\nu,b} + \frac{1}{2}m_b^2 A_b^\mu A_{\mu,b}$$



Kinetic mixing

In SUSY theories

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

with

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

In heterotic orbifolds, string threshold:

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

$$b^i_{ab} = \frac{1}{2} \left(-2\, \text{tr}^i_{V,\mathcal{N}=2}(Q_a Q_b) + \text{tr}^i_{H,\mathcal{N}=2}(Q_a Q_b) \right)$$

Goodsell, SR-S, Ringwald (2011)

An explicit MSSM candidate: matter spectrum

3 (net) generations					
3 + 1	$(\mathbf{3},\mathbf{2};\mathbf{1})_{1/6,0}$	q_i	1	$(\overline{\mathbf{3}},\mathbf{2};\mathbf{1})_{-1/6,0}$	$\bar{q}_i$
3 + 2	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1})_{-2/3,0}$	$\bar{u}_i$	2	$(\mathbf{3},\mathbf{1};\mathbf{1})_{2/3,0}$	u_i
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Higgses					
1 + 9	$(\mathbf{1},\mathbf{2};\mathbf{1})_{-1/2,0}$	h_d	1 + 9	$(\mathbf{1},\mathbf{2};\mathbf{1})_{1/2,0}$	h_u
SM Singlets					
45	$(\mathbf{1},\mathbf{1};\mathbf{1})_{0,0}$	n_i	8	$(\mathbf{1},\mathbf{1};\mathbf{1})_{0,*}$	$\xi_i^{\pm}$
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$\mathrm{SU}(8)$ strong int. $\Lambda \sim 10^{11}$ GeV

Goodsell, SR-S, Ringwald (2011)

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$X,\ \bar{X}$

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$\langle n\rangle \sim \mathcal{O}(M_{\rm Pl})+$ string couplings

$\Downarrow$

$$\mathcal{G}_{4D} \longrightarrow \mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \times [\mathrm{SU}(8) \times \mathrm{U}(1)_X]$$

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usell, SR-S, Ringwald (2011)

Kinetic mixing in a realistic model

In our model $b_{ab} = b_{YX} = 0$ and

$$\frac{\chi_{XY}}{g_X g_Y} = \Delta_{YX} = \frac{1}{16\pi^2}\frac{8\sqrt{2}}{3}\log\left(|\eta(3\,T_2)|^4 \mathrm{Im}(T_2)\right) \neq 0$$

Contrary to previous findings

Dienes, Kolda, March-Russell ('96)

Dark force scenario

If $\langle n_i \rangle \sim \mathcal{O}(0{,}1)$, then

$$W = \frac{10^{-5}}{M_S}(\xi^+\xi^-)(h\bar{h}) + 10^{-8}\, M_S\,(h\bar{h})$$

Through $\mathrm{SU}(8)$ strong interactions, SUSY breaking with $m_{3/2} \sim 1$ TeV and

$$W_{np} = 7\left(\frac{\Lambda^{23}}{\langle h\bar{h}\rangle}\right)^{1/7}$$

Since $\langle h\bar{h}\rangle = \Lambda^2(10^{-8}z)^{-7/8}$, dark matter mass

$$W \supset 10^2 M_S z^{-23/8}\xi^+\xi^-$$

yielding $m_\xi \sim 10$ GeV for $z \sim 10^7$.

Good Dark Matter ☺

To take home...

- Many interesting stringy MSSM candidates ✓
- Extra $\mathrm{U}(1)$s solve some problems and are natural in these models ✓
- Possible to obtain nice dark matter ✓