Hidden photons in heterotic orbifolds

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Bethe Forum

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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

Heterotic Orbifolds

- Starting point: heterotic string E

$$\begin{array}{ccccc} \mathbb{M}^4 & \times & \mathbb{R}^6 & \times & T^{16} \\ \multicolumn{3}{c}{SO(9,1)_{Lorentz}} & \times & E_8 \times E_{8\,gauge} \end{array}$$

- Input
  - Geometry: T^6, $D \to S$ (e.g. $D = \mathbb{Z}_N \to S = T^6 \rtimes \mathbb{Z}_N$)
  - Embedding: $\mathcal{O}_6 = \mathbb{R}^6/S \quad \hookrightarrow \quad \mathcal{O}_{16}$

(shift vector V and Wilson lines W_α subject to modular invariance (CFT) conditions)

- Output

$$\begin{array}{ccccc} \mathbb{M}^4 & \times & \mathcal{O}_6 & \times & \mathcal{O}_{16} \\ SO(3,1)_{Lorentz} & \bigotimes & \mathcal{G}^{(R)}_{n,\text{``}flavor\text{''}} & \times & \mathcal{G}_{4D} \subset E_8 \times E_{8\,gauge} \end{array}$$

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

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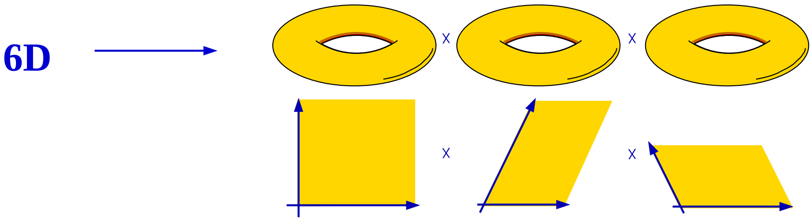
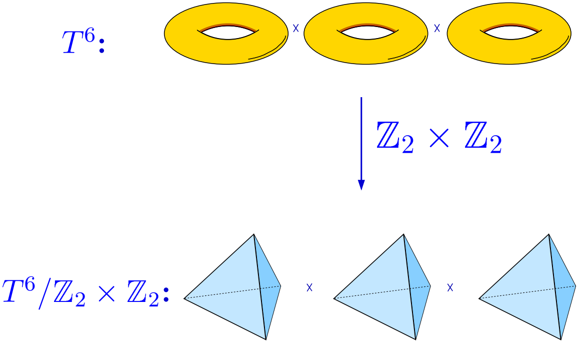
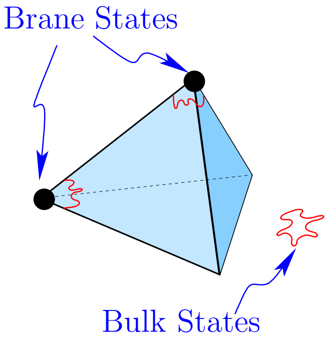
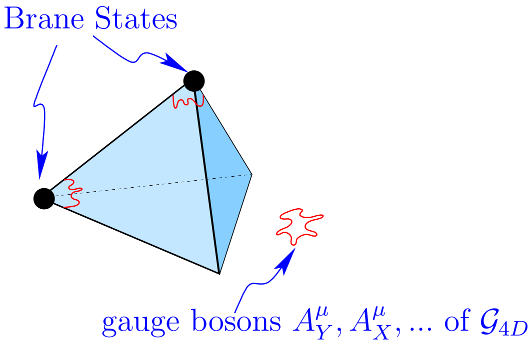
6D Orbifold



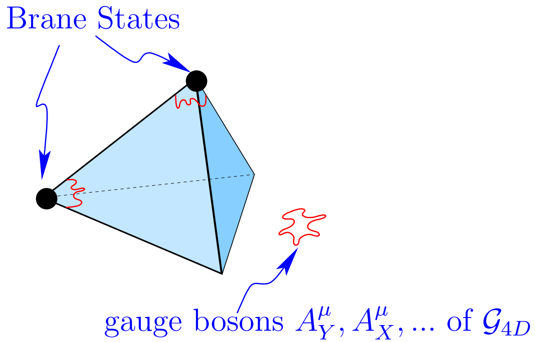
6D $\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold




Brane States
Bulk States


Brane States
gauge bosons $A_Y^\mu, A_X^\mu, \ldots$ of $\mathcal{G}_{4D}$

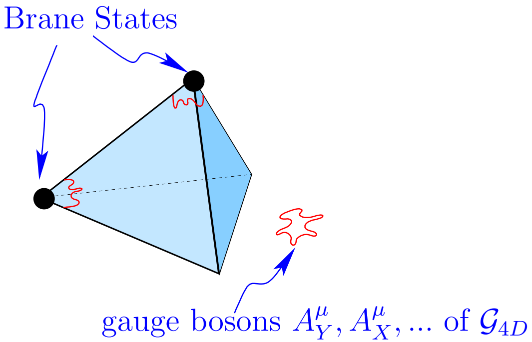
Heterotic Orbifolds: strings and states



(several) $\mathrm{U}(1)$ charge operators: $Q_a = {t_a}^I H_I$

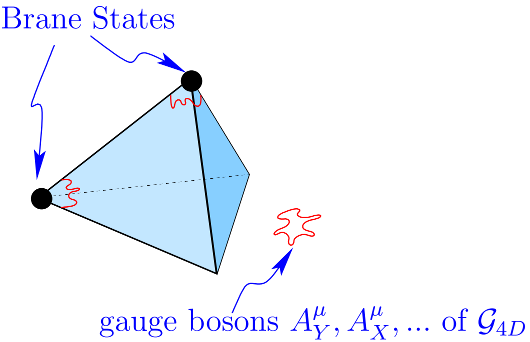
H_I : Cartan generators of $\mathrm{E}_8\times\mathrm{E}_8$ t_a : $\mathrm{U}(1)$ "generators"

Heterotic Orbifolds: strings and states



$$\mathrm{E}_8 \times \mathrm{E}_8 \xrightarrow{V, W_\alpha} \mathcal{G}_{4D} \qquad t_a \cdot V = t_a \cdot W_\alpha = 0 \mod 1$$

Heterotic Orbifolds: strings and states



Modular symmetries: $\mathsf{SL}(2,\mathbb{Z})^{3+n} \xrightarrow{W_\alpha} discrete\ \mathcal{G}_{mod}$

Love, Todd (1996)

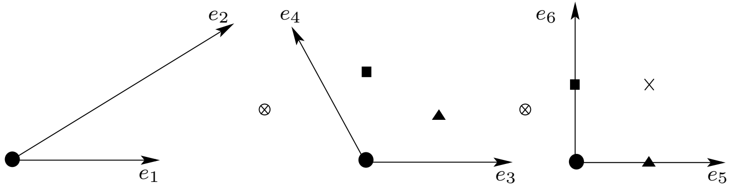
Hidden Photons in Heterotic Orbifolds

Our program:

- look for models with $\mathcal{G}_{4D} = \mathcal{G}_{SM} \times \mathcal{G}'$
- 3 SM families + Higgses
- vectorlike exotics
- identify promising vacua where
  - exotics get large masses, and
  - $\mathcal{G}' \to \mathcal{G}_{hidden}$
- does any $\mathrm{U}(1)_{hidden} \subset \mathcal{G}_{hidden}$ survive?
- study phenomenology of hidden sector: kinetic mixing
- (assume moduli stabilization and decoupling of exotics @ M_d)

Heterotic Orbifolds: $\mathbb{Z}_6$–II Geometry

- Lattice $G_2 \times SU(3) \times SO(4)$; $\mathbb{Z}_6$–II: $\left(e^{2\pi i \frac{1}{6}},\, e^{2\pi i \frac{1}{3}},\, -1\right)$



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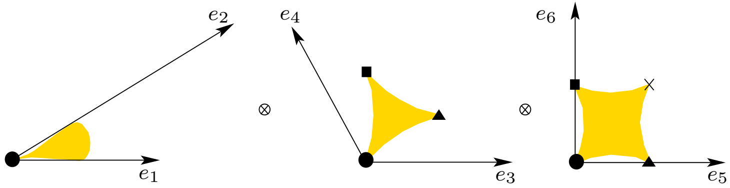

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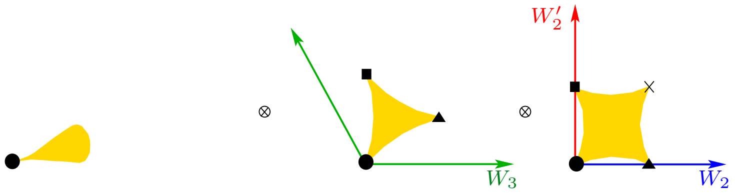


3 possible Wilson lines (WL): W_3 order 3, W_2 & W_2' order 2

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

$\mathbb{Z}_6$–II Minilandscape

267 MSSM candidates:

- supergravity multiplet
- $\mathcal{G}_{4D} = \mathcal{G}_{SM} \times \mathcal{G}_{hid}$
- 3 SM families + Higgses
- vectorlike exotics
- Y *correctly* normalized
- heavy top

} demanded

- TeV gravitino mass
- seesaw
- R-parity, flavor symmetries
- vacua with(out) $\mathrm{U}(1)_X$

} for free !! ☺

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

Hidden Photons

in heterotic orbifolds

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

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

$$\textit{hidden}\ \mathrm{U}(1) \quad \rightarrow \quad b_{ab} = 0$$

1-loop threshold corrections ⇒ computable in heterotic orbifolds

Dixon, Kaplunovsky, Louis (1990)

Kinetic mixing

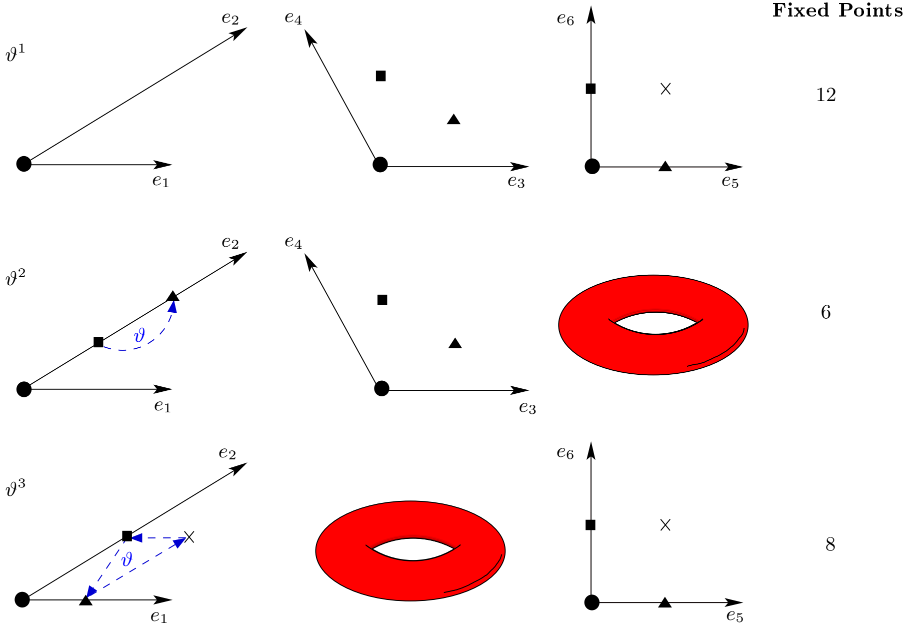
In heterotic orbifolds: Goodsell, SR-S, Ringwald (2011)

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

$\mathcal{N}=2$ beta-function coefficient

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

$\mathcal{N} = 2$ theories in $\mathbb{Z}_6$–II orbifolds



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$\mathcal{N}=2$ beta-function coefficient

if the $\mathcal{N}=1$ $\mathrm{U}(1)$ generators are

$$t_a = \textstyle\sum_{i=1}^r m_a^{b',i}\hat\alpha_i^{b'} + \sum_{b'=r+1}^{16} n_a^{b'} t_{b'}\,, \qquad m_a^{b',i}, n_a^{b'} \in \mathbb{R}$$

and $\left(b^{\mathcal{N}=2}_{\mathrm{U}(1)}\right)_{a'b'} = \frac{1}{2}\left(-2\,\mathrm{tr}_{V,\mathcal{N}=2}(Q_{a'}Q_{b'}) + \mathrm{tr}_{H,\mathcal{N}=2}(Q_{a'}Q_{b'})\right)$

$$\Rightarrow \quad b^i_{ab} = \left(m_a^{b'} C^{b'} m_b^{b'}\right) b_{b'}^{\mathcal{N}=2} + 2\left(n_a\, b^{\mathcal{N}=2}_{\mathrm{U}(1)}\, n_b\right)$$

In heterotic orbifolds: Goodsell, SR-S, Ringwald (2011)

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

$\mathcal{N}=2$ beta-function coefficient

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

$|G|$: order of the $\mathcal{N}=1$ twist
$|G^i|$: order of the $\mathcal{N}=2$ twist in the i-th plane
p_i, q_i: coefs. of the modular-transformations in the i-th plane

Kinetic mixing in the Minilandscape

In $\mathbb{Z}_6$–II heterotic orbifolds:

Goodsell, SR-S, Ringwald (2011)

Most of the $\mathrm{U}(1)$s acquire masses close to M_S

4% of the models have $b_{ab} = 0$ and

$$10^{-4} \lesssim \Delta_{YX} \lesssim 10^{-2}$$

assuming moduli T_2, T_3, U_3 stabilized ~ 1

Contrary to previous results

Dienes, Kolda, March-Russell (1997)

An explicit MSSM candidate: matter spectrum

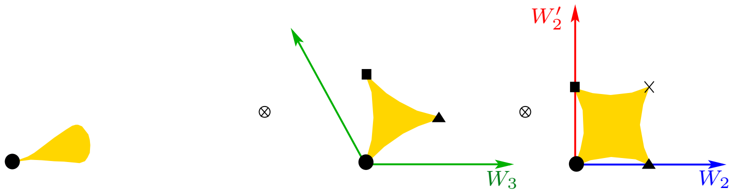
$\mathbb{Z}_6$–II Gauge embedding

$$V = \tfrac{1}{6}(-2,-3,1,0,0,0,0,0)(0,0,0,0,0,0,0,0)$$

$$\begin{aligned}\mathcal{W}_2 &= \tfrac{1}{4}(0,2,6,-10,-2,0,0,0)(5,-1,-5,-5,-5,-5,-5,5)\\ \mathcal{W}_3 &= \tfrac{1}{6}(-1,3,7,-5,1,1,1,1)(5,1,-5,-5,-5,-3,-3,3)\end{aligned}$$

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

$$\mathcal{G}_{mod} = SL(2,\mathbb{Z}) \times \Gamma_1(3)_{T_2} \times \Gamma_1(2)_{T_3} \times \Gamma^1(2)_{U_3}$$



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
3 + 2	$(\mathbf{1},\mathbf{1};\mathbf{1})_{1,0}$	$\bar{e}_i$	2	$(\mathbf{1},\mathbf{1};\mathbf{1})_{-1,0}$	e_i
3 + 7	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1})_{1/3,0}$	$\bar{d}_i$	7	$(\mathbf{3},\mathbf{1};\mathbf{1})_{-1/3,0}$	d_i
3	$(\mathbf{1},\mathbf{2};\mathbf{1})_{-1/2,0}$	ℓ_i			
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	$(\mathbf{1},\mathbf{1};\mathbf{1})_{0,*}$	$\xi_i^{\pm}$
7	$(\mathbf{1},\mathbf{1};\mathbf{8})_{0,*}$	h_i	7	$(\mathbf{1},\mathbf{1};\overline{\mathbf{8}})_{0,*}$	$\bar{h}_i$
Exotics					
8	$(\mathbf{3},\mathbf{1};\mathbf{1})_{1/6,*}$	w_i	8	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1})_{-1/6,*}$	$\bar{w}_i$
8	$(\mathbf{1},\mathbf{1};\mathbf{1})_{1/2,\pm\sqrt{2}/3}$	$s_i^{+\pm}$	8	$(\mathbf{1},\mathbf{1};\mathbf{1})_{-1/2,\pm\sqrt{2}/3}$	$s_i^{-\pm}$
4	$(\mathbf{1},\mathbf{2};\mathbf{1})_{0,\sqrt{2}/3}$	m_i^+	4	$(\mathbf{1},\mathbf{2};\mathbf{1})_{0,-\sqrt{2}/3}$	m_i^-

Goodsell, SR-S, Ringwald (2011)

An explicit MSSM candidate: matter spectrum

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4	$(\mathbf{1},\mathbf{2};\mathbf{1}$ ...			... $\sqrt{2}/3$	m_i^-

$\mathrm{SU}(8)$ strong int. $\Lambda \sim 10^{11}$ GeV

Goodsell, SR-S, Ringwald (2011)

An explicit MSSM candidate: matter spectrum

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$X,\ \bar{X}$

Goodsell, SR-S, Ringwald (2011)

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8	$(\mathbf{3}$				$\bar{w}_i$
8				$/3$	$s_i^{-\pm}$
4	$($				m_i^{-}

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

$\Downarrow$

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

$$M\, X\, \overline{X} \equiv \langle n \rangle^s X\, \overline{X}$$

…ousell, SR-S, Ringwald (2011)

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

$\Downarrow$

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

$M\, X\, \overline{X} \equiv \langle n\rangle^s X\, \overline{X}$

...ousell, SR-S, Ringwald (2011)

Kinetic mixing in a realistic model

$\mathbb{Z}_2$ $\mathcal{N}=2$ theory: $\mathrm{SU}(4)\times\mathrm{SU}(3)\times\mathrm{U}(1)^3\times[\mathrm{SU}(8)\times\mathrm{U}(1)]$
$\mathrm{U}(1)$ generators:

$$\begin{aligned}
t_{13'} &= \tfrac{1}{\sqrt{30}}(-1,5,-1,0,0,1,1,1)(0,0,0,0,0,0,0,0)\,,\\
t_{14'} &= \tfrac{1}{\sqrt{20}}(-1,0,4,0,0,1,1,1)(0,0,0,0,0,0,0,0)\,,\\
t_{15'} &= \tfrac{1}{\sqrt{2}}(0,0,0,1,1,0,0,0)(0,0,0,0,0,0,0,0)\,,\\
t_{16'} &= \tfrac{1}{\sqrt{32}}(0,0,0,0,0,0,0,0)(1,-1,-1,-1,-1,3,3,-3)\,.
\end{aligned}$$

Matter spectrum:

#	Irrep	U(1) charges	#	Irrep	U(1) charges
2	$(\mathbf{1},\mathbf{3},\mathbf{1})$	$(-\frac{1}{\sqrt{30}},\ \frac{2}{\sqrt{5}},\ -\frac{1}{\sqrt{2}},\ 0)$	8	$(\mathbf{1},\mathbf{3},\mathbf{1})$	$(\sqrt{\frac{2}{15}},\ \frac{1}{\sqrt{5}},\ \frac{1}{\sqrt{2}},\ 0)$
2	$(\mathbf{6},\mathbf{1},\mathbf{1})$	$(-\sqrt{\frac{3}{10}},\ \frac{1}{\sqrt{5}},\ \frac{1}{\sqrt{2}},\ 0)$	8	$(\mathbf{1},\mathbf{1},\mathbf{8})$	$(0,\ 0,\ \frac{1}{\sqrt{2}},\ -\frac{1}{\sqrt{8}})$
8	$(\mathbf{4},\mathbf{1},\mathbf{1})$	$(\sqrt{\frac{3}{10}},\ \frac{3}{\sqrt{20}},\ 0,\ 0)$			

Kinetic mixing in a realistic model

β function coefficients

$$b^{\mathcal{N}=2}_{\mathrm{SU}(4)} = b^{\mathcal{N}=2}_{\mathrm{SU}(3)} = 4, \qquad b^{\mathcal{N}=2}_{\mathrm{SU}(8)} = -8$$

$$b^{\mathcal{N}=2}_{\mathrm{U}(1)} = \begin{pmatrix} \frac{83}{10} & \frac{12}{5}\sqrt{6} & \frac{3}{2}\sqrt{\frac{3}{5}} & 0 \\ \frac{12}{5}\sqrt{6} & \frac{66}{5} & 6\sqrt{\frac{2}{5}} & 0 \\ \frac{3}{2}\sqrt{\frac{3}{5}} & 6\sqrt{\frac{2}{5}} & \frac{53}{2} & -8 \\ 0 & 0 & -8 & 4 \end{pmatrix} .$$

Overlap of the hypercharge and $\mathrm{U}(1)_X$

$$n_Y = (\tfrac{1}{\sqrt{30}}, \tfrac{1}{\sqrt{20}}, -\tfrac{1}{\sqrt{2}}, 0), \qquad m_Y^{\mathrm{SU}(4)} = (\tfrac{1}{12}, \tfrac{1}{6}, \tfrac{1}{4}),$$

$$m_Y^{\mathrm{SU}(3)} = (-\tfrac{1}{6}, -\tfrac{1}{3}), \qquad m_Y^{\mathrm{SU}(8)} = 0$$

$$n_X = (0, 0, 0, 1), \qquad m_X^{b'} = 0 \text{ for all } b'$$

$$\Longrightarrow \quad b^2_{YX} = 8\sqrt{2}$$

Kinetic mixing in a realistic model

$\mathbb{Z}_3\ \mathcal{N}=2$ theory: $\mathrm{SU}(4)\times\mathrm{SU}(2)_a\times\mathrm{SU}(2)_b\times\mathrm{U}(1)^3\times[\mathrm{SU}(8)\times\mathrm{U}(1)]$

$\mathrm{U}(1)$ generators

$$
\begin{aligned}
t_{13'} &= \frac{1}{4\sqrt{11}}(11,-5,5,1,1,1,1,1)(0,0,0,0,0,0,0,0)\,,\\
t_{14'} &= \frac{1}{\sqrt{66}}(0,6,5,1,1,1,1,1)(0,0,0,0,0,0,0,0)\,,\\
t_{15'} &= \frac{1}{\sqrt{32}}(0,0,0,0,0,0,0,0)(1,-1,-1,-1,-1,3,3,-3)\,.\\
t_{16'} &= \frac{1}{\sqrt{6}}(0,0,-1,1,1,1,1,1)(0,0,0,0,0,0,0,0)\,,
\end{aligned}
$$

Matter spectrum:

#	Irrep	$\mathrm{U}(1)$ charges	#	Irrep	$\mathrm{U}(1)$ charges
1	$(\mathbf{6},\mathbf{1},\mathbf{1},\mathbf{1})$	$(\frac{3}{\sqrt{11}},\ \frac{1}{\sqrt{66}},\ 0,\ \frac{1}{\sqrt{6}})$	3	$(\mathbf{1},\mathbf{1},\mathbf{1},\overline{\mathbf{8}})$	$(0,\ 0,\ -\frac{1}{6\sqrt{2}},\ \sqrt{\frac{2}{3}})$
1	$(\mathbf{1},\mathbf{2},\mathbf{2},\mathbf{1})$	$(\frac{1}{\sqrt{11}},\ \sqrt{\frac{8}{33}},\ 0,\ \sqrt{\frac{2}{3}})$	3	$(\mathbf{1},\mathbf{1},\mathbf{1},\overline{\mathbf{8}})$	$(\frac{2}{\sqrt{11}},\ -\sqrt{\frac{3}{22}},\ -\frac{1}{6\sqrt{2}},\ -\frac{1}{\sqrt{6}})$
3	$(\mathbf{6},\mathbf{1},\mathbf{1},\mathbf{1})$	$(\frac{1}{3\sqrt{11}},\ -\frac{7}{3\sqrt{66}},\ 0,\ \frac{5}{3\sqrt{6}})$	6	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})$	$(-\frac{8}{3\sqrt{11}},\ -\frac{5}{3}\sqrt{\frac{2}{33}},\ 0,\ \frac{1}{3}\sqrt{\frac{2}{3}})$
3	$(\mathbf{4},\mathbf{2},\mathbf{1},\mathbf{1})$	$(-\frac{7}{6\sqrt{11}},\ \frac{4}{3}\sqrt{\frac{2}{33}},\ 0,\ \frac{1}{3}\sqrt{\frac{2}{3}})$	3	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})$	$(-\frac{8}{3\sqrt{11}},\ \frac{23}{3\sqrt{66}},\ 0,\ -\frac{1}{3\sqrt{6}})$
3	$(\mathbf{4},\mathbf{1},\mathbf{2},\mathbf{1})$	$(-\frac{1}{6\sqrt{11}},\ -\frac{13}{3\sqrt{66}},\ 0,\ -\frac{1}{3\sqrt{6}})$	3	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})$	$(-\frac{2}{3\sqrt{11}},\ -\frac{19}{3\sqrt{66}},\ 0,\ -\frac{7}{3\sqrt{6}})$
3	$(\mathbf{1},\mathbf{2},\mathbf{2},\mathbf{1})$	$(-\frac{5}{3\sqrt{11}},\ \frac{1}{3}\sqrt{\frac{2}{33}},\ 0,\ -\frac{2}{3}\sqrt{\frac{2}{3}})$	3	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})$	$(-\frac{4}{3\sqrt{11}},\ -\frac{5}{3\sqrt{66}},\ -\frac{2\sqrt{2}}{3},\ -\frac{5}{3\sqrt{6}})$
3	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{8})$	$(\frac{2}{3\sqrt{11}},\ -\frac{7}{3}\sqrt{\frac{2}{33}},\ \frac{1}{6\sqrt{2}},\ \frac{2}{3}\sqrt{\frac{2}{3}})$	3	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})$	$(-\frac{2}{\sqrt{11}},\ \sqrt{\frac{3}{22}},\ \frac{2\sqrt{2}}{3},\ -\frac{1}{\sqrt{6}})$
3	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{8})$	$(\frac{2}{3\sqrt{11}},\ \frac{19}{3\sqrt{66}},\ \frac{1}{6\sqrt{2}},\ \frac{1}{3\sqrt{6}})$			

Kinetic mixing in a realistic model

β function coefficients

$$b^{\mathcal{N}=2}_{\mathrm{SU}(4)} = 12, \qquad b^{\mathcal{N}=2}_{\mathrm{SU}(2)_a} = b^{\mathcal{N}=2}_{\mathrm{SU}(2)_b} = 16, \qquad b^{\mathcal{N}=2}_{\mathrm{SU}(8)} = -4$$

$$b^{\mathcal{N}=2}_{\mathrm{U}(1)} = \begin{pmatrix} \frac{490}{33} & -\frac{131}{33}\sqrt{\frac{2}{3}} & -\frac{4}{3}\sqrt{\frac{2}{11}} & \frac{13}{3}\sqrt{\frac{2}{33}} \\ -\frac{131}{33}\sqrt{\frac{2}{3}} & \frac{2171}{99} & \frac{28}{3\sqrt{33}} & -\frac{25}{9\sqrt{11}} \\ -\frac{4}{3}\sqrt{\frac{2}{11}} & \frac{28}{3\sqrt{33}} & \frac{10}{3} & \frac{4}{3\sqrt{3}} \\ \frac{13}{3}\sqrt{\frac{2}{33}} & -\frac{25}{9\sqrt{11}} & \frac{4}{3\sqrt{3}} & \frac{227}{9} \end{pmatrix}.$$

Overlap of the hypercharge and $\mathrm{U}(1)_X$

$$\begin{aligned} m_Y^{\mathrm{SU}(4)} &= (\tfrac{1}{6}, \tfrac{1}{3}, \tfrac{1}{2}), & m_Y^{\mathrm{SU}(2)_b} &= -\tfrac{1}{2}\,, \\ n_Y &= 0, & m_Y^{b'} &= 0 \text{ for other } b'\,, \\ n_X &= (0, 0, 1, 0)\,, & m_X^{b'} &= 0 \text{ for all } b' \end{aligned}$$

$$\implies \quad b^3_{YX} = 0$$

Kinetic mixing in a realistic model

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

$$\frac{\chi_{XY}}{g_X g_Y} = \Delta_{YX} = \frac{1}{16\pi^2}\frac{8\sqrt{2}}{3}\log\left(|\eta(3\,T_2)|^4 \mathrm{Im}(T_2)\right) \sim 10^{-2} \neq 0$$

Kinetic mixing in a realistic model

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

$$\frac{\chi_{XY}}{g_X g_Y} = \Delta_{YX} = \frac{1}{16\pi^2}\frac{8\sqrt{2}}{3}\log\left(|\eta(3\,T_2)|^4 \mathrm{Im}(T_2)\right) \sim 10^{-2} \neq 0$$

useful for phenomenology ??

Phenomenology of

Hidden Photons

TOY Dark force scenario

If $\langle n_i \rangle \sim \mathcal{O}(0.1)$, then

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

Via $\mathrm{SU}(8)$ strong interactions, SUSY breaking with $m_{3/2} \sim 10$ GeV and $M_S = z\Lambda$

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

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

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

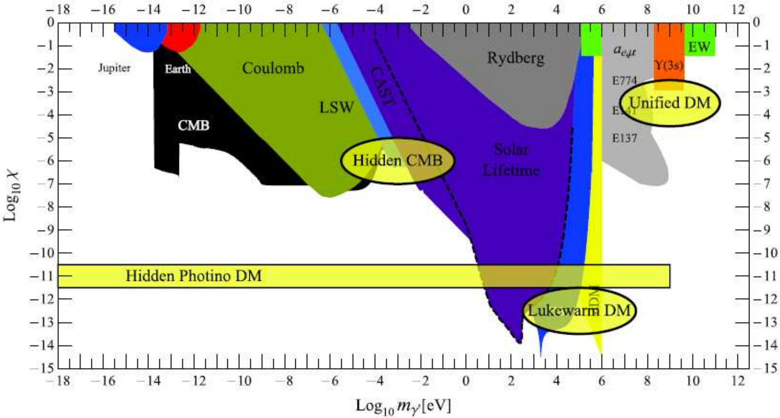
yielding $m_\xi \sim 10$ GeV for $z \sim 10^7$ ☺

Further, $m_{\gamma'} \sim 10 m_\xi \sim 100$ GeV ☺

Morrissey, Poland, Zurek (2009)

To be seen at LHC?

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



Goodsell, Jaeckel, Redondo, Ringwald (2009)

To take home...

- In semi-realistic heterotic orbifolds, vacua with $\mathrm{U}(1)_{hidden}$
- Found a method to compute kinetic mixing in heterotic orbifolds $\checkmark$
- Mixing between $\mathrm{U}(1)_{hidden}$ and Y possible:

$$10^{-4} \lesssim \Delta_{XY} \lesssim 10^{-2} \quad \checkmark$$

- Possible to obtain promising dark matter candidates – observable? $\checkmark$