Theory and phenomenology of hidden U(1)s from string compactifications

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Corfu Summer Institute
Workshop on Cosmology and Strings, Sept. 6-13, 2009, Corfu, GR
Mainly based on:


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1. Introduction

- Embeddings of the standard model in string theory typically contain several hidden sector U(1) gauge factors, e.g. ⇒ e.g. lectures by [Antoniadis; Dudas; Lüst]

- in orbifold compactifications of heterotic string theory:

  ⇒ e.g. talks by [Ramos-Sanchez; Vaudrevange]

  e.g.

  \[ E_8 \times E_8 \rightarrow G_{SM} \times U(1)^4 \times \left[ SU(4) \times SU(2) \times U(1)^4 \right] \]

  or

  \[ E_8 \times E_8 \rightarrow G_{SM} \times U(1)^4 \times \left[ SO(8) \times SU(2) \times U(1)^3 \right] \]
1. Introduction

- Embeddings of the standard model in string theory typically contain several hidden sector U(1) gauge factors, e.g. e.g. lectures by [Antoniadis; Dudas; Lüst]

- in type II string theory with branes:

e.g. lecture by [Bachas]
• Generically mix with visible U(1), i.e. low energy effective Lagrangian

\[ \mathcal{L} \supset -\frac{1}{4g_a^2} F^{(a)}_{\mu\nu} F^{(a)}_{\mu\nu} - \frac{1}{4g_b^2} F^{(b)}_{\mu\nu} F^{(b)}_{\mu\nu} + \frac{\chi_{ab}}{2g_ag_b} F^{(a)}_{\mu\nu} F^{(b)\mu\nu} + \frac{m_{ab}^2}{g_ag_b} A^{(a)}_{\mu} A^{(b)\mu} \]

• Kinetic and mass mixing terms, \( \chi_{ab} \) and \( m_{ab}^2 \), provide a unique window to hidden sectors

• Phenomenology (very strong limits on photon mass) requires structure:

\[ \chi = \begin{pmatrix} 0 & \chi \\ \chi & 0 \end{pmatrix} ; \quad m^2 \approx \begin{pmatrix} 0 & 0 \\ 0 & m_{\gamma'}^2 \end{pmatrix} \]

\[ \Rightarrow \text{Massless photon and massive U(1) (hidden photon), with mass squared } m_{\gamma'}^2 / \sqrt{1 - \chi^2} \]
• Rich phenomenology of hidden photons:

[Bartlett, ’88; Kumar, ’06; Coriano, ’07; Ahlers, ’07; Jaeckel, ’07; Redondo, ’08; ...; Bjorken, ’09, ...]
- meV scale hidden photon results in hidden CMB; may explain $N_{\nu}^{\text{eff}} > 3$, as favored from some analyses of CMB + large scale structure if Ly-$\alpha$ data is included; can be checked in light-shining-through-wall experiments [Jaeckel, Redondo, AR ’08]

- For $(\chi, m_{\gamma'}) \sim (10^{-12}, 0.1 \text{ MeV})$ the hidden photon is a lukewarm dark matter candidate [Pospelov, Ritz, Voloshin ’07; Redondo, Postma ’08]

- EW scale hidden photino of light hidden U(1) may be cold dark matter if $\chi \sim 10^{-11}$ If $\chi \sim 10^{-23}$, TeV scale hidden photino is candidate for decaying dark matter. May explain cosmic ray positron excess observed by PAMELA [Ibarra, AR, Weniger ’09]

- Region $(\chi, m_{\gamma'}) \sim (10^{-4}, \text{ GeV})$ favored by Unified Dark Matter scenario: unified description of PAMELA excess and annual modulation signal seen by direct DM search experiment DAMA ... Hidden sector dark matter; hidden U(1) mediates Dark Force [Arkani-Hamed et al. ’08; ...]

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Light Shining through a Wall (LSW):

Any Light Particle Search (ALPS) at DESY:
2. Hidden U(1)s in LARGE volume string compactifications

- First studies of kinetic mixing in string compactifications:
  - Heterotic string: [Dienes, Kolda, March-Russell '97; Lukas, Stelle '99; Blumenhagen, Honecker, Weigand '05]

- Type II strings with D-branes: [Lüst, Stieberger '03; Abel, Schofield '03; Berg, Haack, Körs '04]

- First studies of mass mixing in type I/II strings with D-branes:
  [Antoniadis, Kiritsis, Rizos '02; Ghilencea, Ibanez, Irges, Quevedo '02; ...; Buican, Malyshev, Morrison, Verlinde, Wijnholt '06]
LARGE volumes and hyperweak interactions

- Based on IIB strings with D3 and D7 branes
  - Visible sector on stack of space-time filling D-branes wrapping collapsed cycles
  - Gravity propagates in bulk of volume $V/l_s^6 \equiv \mathcal{V}$

$$M_P^2 = \frac{4\pi}{g_s^2} \mathcal{V} M_s^2$$

$M_s = 10^{16}$ GeV, for $\mathcal{V} \sim 100$
$M_s = 10^{10}$ GeV, for $\mathcal{V} \sim 10^{14}$
$M_s = 10^3$ GeV, for $\mathcal{V} \sim 10^{28}$

[...; Conlon, Maharana, Quevedo ‘08;...]
LARGE volumes and hyperweak interactions

- Visible sector on stack of space-time filling D-branes wrapping collapsed cycles

- Hidden U(1)s: located on space-time filling D-branes not intersecting with visible branes
  1. D7 wraps LARGE cycle

[...;Conlon,Maharana,Quevedo ’08;...]
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[...; Conlon, Maharana, Quevedo '08; ...]
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[...;Conlon,Maharana,Quevedo ‘08;...]

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D(3 + q)-brane:

\[ g^2_{(q)} = \frac{2\pi g_s}{|Z|} \approx \frac{2\pi g_s}{\mathcal{V}_q} \]

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  3. anti D3
  1. $\Rightarrow$ hyperweak interactions

$$g^2_{(4)} \approx \frac{2\pi g_s}{(V)^{2/3}} = 2\pi g_s \left(\frac{4\pi M_s^2}{g_s^2 M_P^2}\right)^{2/3}$$

[Burgess, Conlon, Hung, Kom, Maharana, Quevedo '08]

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3. Kinetic mixing between visible U(1) and hidden U(1)

- Before SUSY, kinetic mixing appears as holomorphic quantity in SUGRA:

\[ \mathcal{L} \supset \int d^2\theta \left\{ \frac{1}{4(g_a^h)^2} W_a W_a + \frac{1}{4(g_b^h)^2} W_b W_b - \frac{1}{2} \chi_{ab}^h W_a W_b \right\} \]

\( g_a^h, g_b^h \) and \( \chi_{ab}^h \) must run only at one loop

- Physical and holomorph coupling related by generalisation of [Kaplunovsky, Louis '94,95]

\[
\begin{align*}
g_a^{-2} &= \text{Re} \left[ (g_a^h)^{-2} \right] - \sum_r \frac{Q_a^2(r)}{8\pi^2} \log \det Z^{(r)} - \sum_r \frac{n_r Q_a^2(r)}{16\pi^2} \frac{K}{M_P^2} \\
\frac{\chi_{ab}}{g_a g_b} &= \text{Re}(\chi_{ab}^h) + \frac{1}{8\pi^2} \text{tr} \left( Q_a Q_b \log Z \right) + \frac{1}{16\pi^2} \sum_r n_r Q_a Q_b(r) \frac{K}{M_P^2}
\end{align*}
\]
• In analogy to structure of holomorphic gauge kinetic function

\[ \chi_{ab}^h = \chi_{ab}^{1\text{-loop}}(z^k, y_i) + \chi_{ab}^{\text{non-perturbative}}(z^k, e^{-T_j}, y_i) \]

complex structure moduli \( z^k \), Kähler moduli \( T_j \), open string moduli \( y_i \)

- \( T_j \) have shift symmetries \( \Rightarrow \) may only appear as exponentials
- \( T_j \) depend on \( g_s^{-1} \) \( \Rightarrow \) cannot enter at 1-loop

• Generically,

\[ \chi_{ab}^h \simeq \chi_{ab}^{1\text{-loop}}(z^k, y_i) \simeq \frac{1}{16\pi^2} \times O(1) \]

\[ \Rightarrow \text{Therefore,} \]

\[ \chi_{ab} \simeq \frac{g_ag_b}{16\pi^2} \times O(1) \]
4. Mass of hidden U(1)

- **Stückelberg masses**: [Buican, Malyshev, Morrison, Verlinde, Wijnholt ’06; Conlon, Maharana, Quevedo ’08; ...]

\[
m_{\text{St}ab}^2 = \frac{g_ag_b}{4\pi} M_s^2 \left[ G_{cd} \tilde{\Pi}^{cD_1} \tilde{\Pi}^{dD_2} r_{aD_1} r_{bD_2} + G^\alpha\beta \Pi^{D_1 A}_\alpha \Pi^{D_2 B}_\beta (p_{aD_1 A} - r_{aD_1 b_{D_1 A}}) (p_{bD_2 B} - r_{bD_2 b_{D_2 B}}) \right]
\]

- \(O(1)\) factors: overlaps \(\tilde{\Pi}^{cD_1}, \Pi^{D_1 A}_\alpha\); D7 brane charges \(r_{aD_1}\); fluxes \(p_{aD_1 A}\) and \(b_{D_1 A}\)

- Size determined by metric \(G_{cd}\) and \(G^{\alpha\beta}\) on space of harmonic forms
  - For anomalous U(1)s, dual cycles vanishing \(\Rightarrow G \sim 1\)
  - For bulk cycles, corresponding to non-anomalous U(1)s,
    \[
    G_{cd} \sim \mathcal{V}^{1/3}, \quad G^{\alpha\beta} \sim \mathcal{V}^{-1/3}
    \]
- Theory and phenomenology of hidden U(1)s . . . – 21

• **Masses from hidden Higgs mechanism:**
  - Expect generically $m_{\gamma'} \sim m_{H_h} \sim m_{\text{hid soft}}$
  - In gauge mediation, for example,

  $$m_{\text{vis soft}} \sim \frac{g_{\text{vis}}^2 M_{\text{SUSY}}^2}{16\pi^2 M_{\text{mess}}}$$

  * If hidden sector couples directly to sequestered SUSY sector,

  $$m_{\text{hid soft}} \sim \frac{g_h^2 M_{\text{SUSY}}^2}{16\pi^2 M_{\text{mess}}} \sim \frac{g_h}{g_{\text{vis}}} m_{\text{vis soft}}$$

  * If hidden sector couples only indirectly via kinetic mixing to it,

    $$(m_{\text{hid soft}}^2 = Q_h g_h \chi \langle D_Y \rangle = Q_h g_h g_Y \chi \frac{1}{8} v^2 \cos 2\beta \ll (m_{\text{vis soft}}^2)$$

[Dienes,Kolda,March-Russell '96;...;Suematsu '06;...;Morrissey,Poland,Zurek '09;...]

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5. Discussion and outlook

- Extra U(1) gauge bosons kinetically mixing with the electromagnetic (or hypercharge) U(1) may provide us with a unique window into hidden sector physics.

- Moreover, they could play a role in a number of observed phenomena possibly connected to dark matter.

- LARGE volume scenarios allow for a variety of different extra, hidden U(1) gauge bosons ⇒ a variety of possibilities, some of which overlapping with the phenomenologically interesting regions.
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• LARGE volume scenarios allow for a variety of different extra, hidden U(1) gauge bosons ⇒ a variety of possibilities, some of which overlapping with the phenomenologically interesting regions

• Near future astrophysical observations and laboratory experiments can test a variety of possible scenarios and an impressive range of string scales
5. Discussion and outlook

![Diagram showing various regions and labels including hidden Higgs, Collapsed cycle, MW cavity, LSW, Helioscope, Fixed Target, Super B, X-ray SAT, Stuckelberg H1, Stuckelberg H2, LHC, and regions denoted by $<10^7$, $<10^5$, $W_0<10^3$. The diagram is labeled with log-log axes for $m_Y$ and $m_{\chi}$ with ranges from $10^{-16}$ to $10^{-5}$ for $m_Y$ and from $10^{-5}$ to $10^9$ for $m_{\chi}$.]

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