Kinetic mixing of hidden U(1)s with the visible U(1) in string compactifications

Andreas Ringwald

Theory Seminar
27 April 2009, Bonn, D

- Mainly based on:

  – S. A. Abel, J. Jaeckel, V. V. Khoze, AR,
  "Illuminating the hidden sector of string theory by shining light through a magnetic field,"
  Phys. Lett. B **666** (2008) 66 [arXiv:hep-ph/0608248]

  – S. A. Abel, M. D. Goodsell, J. Jaeckel, V. V. Khoze, AR,
  "Kinetic Mixing of the Photon with Hidden U(1)s in String Phenomenology,"
  JHEP **0807** (2008) 124 [arXiv:0803.1449 [hep-ph]]

Table of Content:

1. Introduction

- Embeddings of the standard model in string theory typically contain several hidden sector U(1) gauge factors, e.g.
  - in orbifold compactifications of heterotic string theory:

[. . . ;Bonn group;Hamburg group;. . .]

e.g.

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

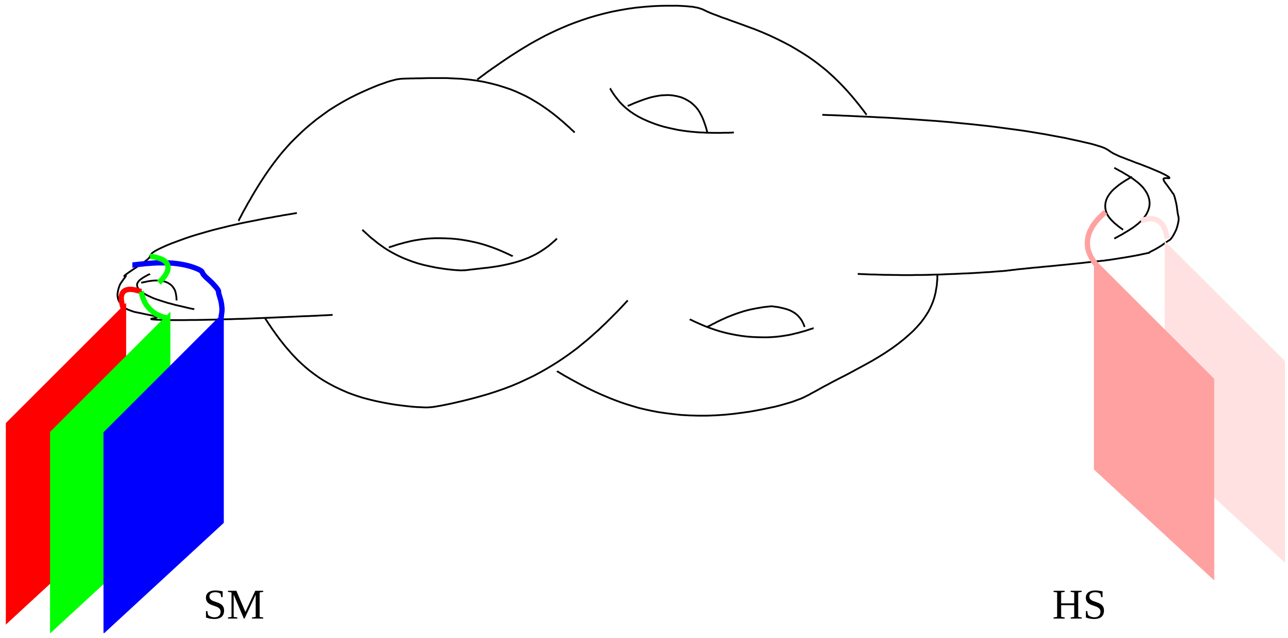
or

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

1. Introduction

- Embeddings of the standard model in string theory typically contain several hidden sector U(1) gauge factors, e.g.
  - in type II string theory with branes:

[. . . ;Berlin ⟶ Munich group;. . .]



- Generically mix with visible U(1), i.e. low energy effective Lagrangian

$$\mathcal{L} \supset -\frac{1}{4}F^{(a)}_{\mu\nu}F^{\mu\nu}_{(a)} - \frac{1}{4}F^{(b)}_{\mu\nu}F^{\mu\nu}_{(b)} - \frac{\chi_{ab}}{2}F^{(a)}_{\mu\nu}F^{(b)\mu\nu} + \frac{M^2_{ab}}{2}A^{(a)}_{\mu}A^{(b)\mu} + j^{\mu}_{(a)}A^{(a)}_{\mu}$$

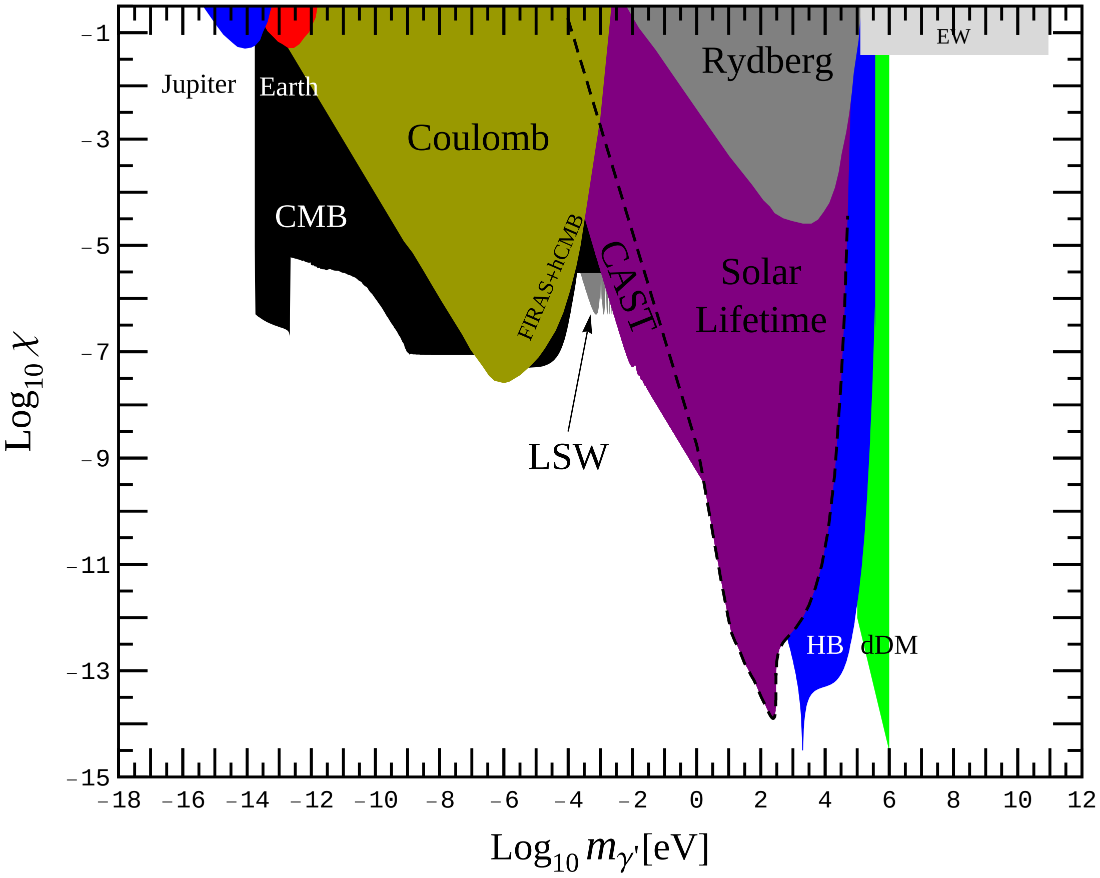
- Kinetic and mass mixing terms, χ_{ab} and M^2_{ab}, provide a unique window to hidden sectors

- Phenomenology strongly dependent on mass scale. For illustration, consider two parameter case:

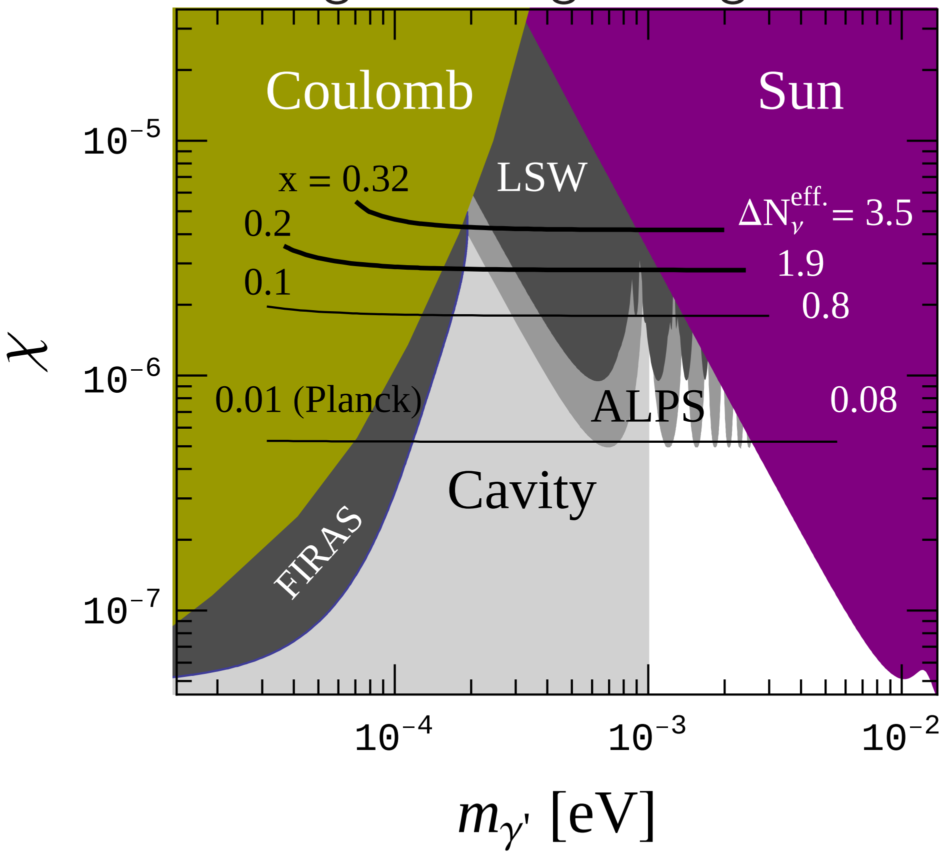
$$\chi = \begin{pmatrix} 0 & \chi \\ \chi & 0 \end{pmatrix}; \qquad M^2 = \begin{pmatrix} 0 & 0 \\ 0 & m^2_{\gamma'} \end{pmatrix}$$

$\Rightarrow$ Massless photon and massive hidden photon, with mass squared $m^2_{\gamma'}/\sqrt{1-\chi^2}$. Latter couples to both visible and hidden sector currents

- Searches for hidden photons: [Bartlett,..'88; Kumar,..'06; Ahlers,..'07; Jaeckel,..'07; Redondo,..'08]

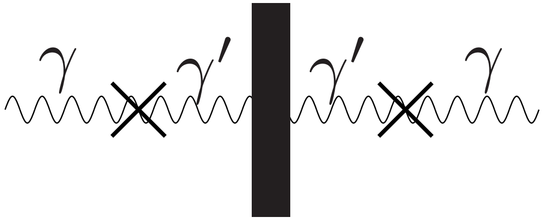


- meV scale hidden photon results in hidden CMB; may explain $N_\nu^{\rm eff} > 3$, as favored from analyses of CMB + large scale structure if Ly-α data is included; can be checked in light-shining-through-wall experiments



[Jaeckel,Redondo,AR '08]

Light Shining through a Wall (LSW):

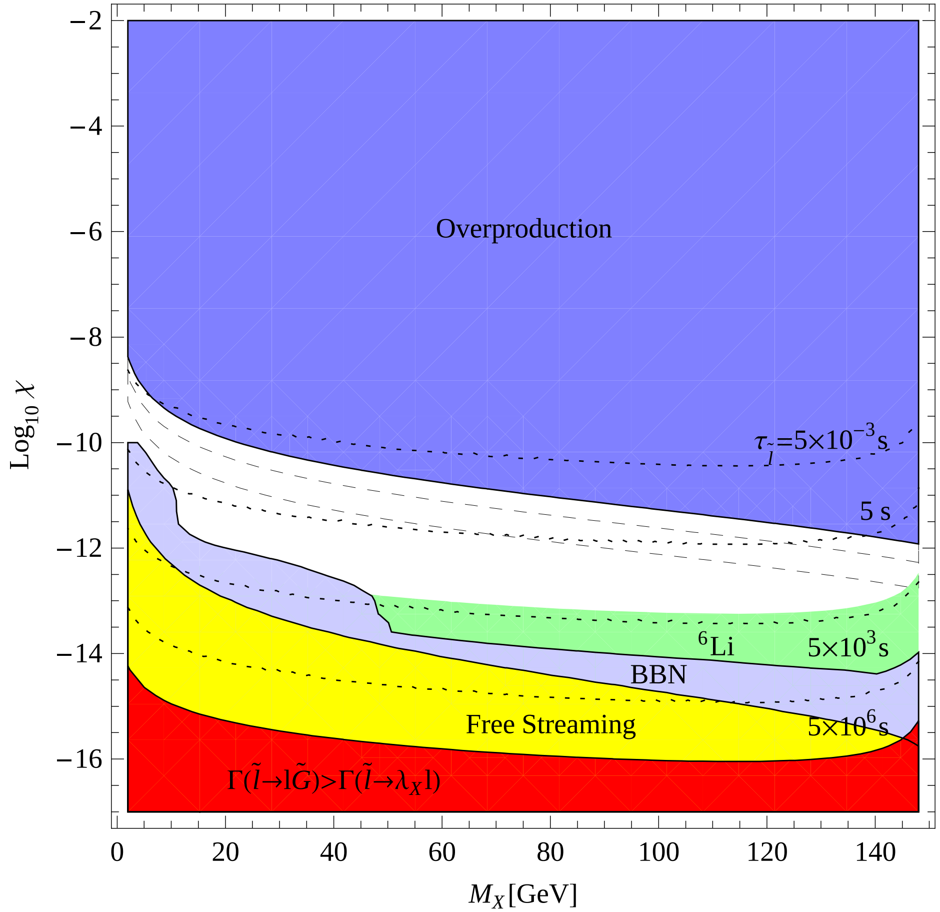


Any **L**ight **P**article **S**earch **(ALPS)** at DESY:

- meV scale hidden photon may be used for hidden laser communications through the Earth

[Jaeckel,Redondo,AR ‘09]

- EW scale hidden photino of unbroken hidden U(1) may be cold dark matter if $\chi \sim 10^{-11}$



[Ibarra,AR,Weniger '09]

- Various models involving hidden U(1)s with kinetic mixing have been proposed which aim at explanation of cosmic ray positron excess observed by PAMELA, exploiting annihilating or decaying dark matter, e.g.

  [Arkani-Hamed *et al.*;Nath;Chen,Takahashi,Yanagida;Ibarra,AR,Tran,Weniger '09]

  Kinetic mixing parameters needed range between

$$10^{-23} < \chi < 10^{-3},$$

  while the required hidden photon/photino masses range between zero and a TeV

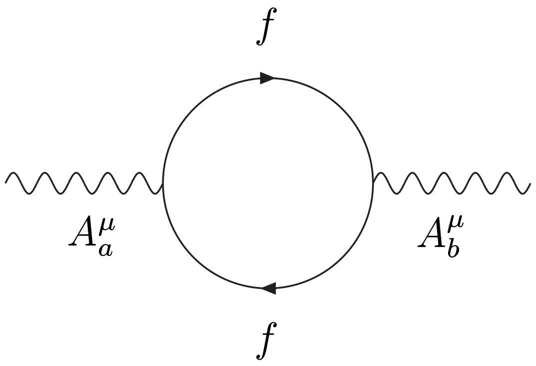
2. U(1) mixing in compactifications of type II string theory

- First studies of kinetic mixing in string compactifications:
  - Heterotic string: [Dienes,Kolda,March-Russell '97]
  - Type II strings with D-branes: [Lüst,Stieberger '03; Abel,Schofield '03; Berg,Haack,Körs '04]

- First studies of mass mixing in type II strings with D-branes:

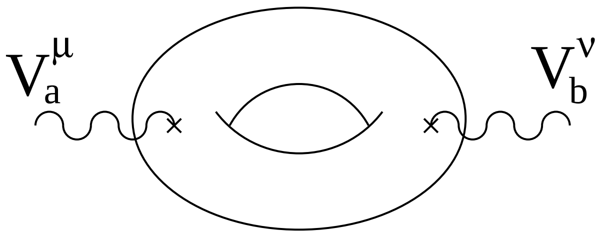
[Antoniadis,Kiritsis,Rizos '02; Ghilencea,Ibanez,Irges,Quevedo '02]

- Generalities:
  - Integrating out heavy particles generically tends to generate $\chi \neq 0$:



$$\Rightarrow \Delta\chi = \frac{g_a g_b}{16\pi^2} \log(m^2/\mu^2)$$

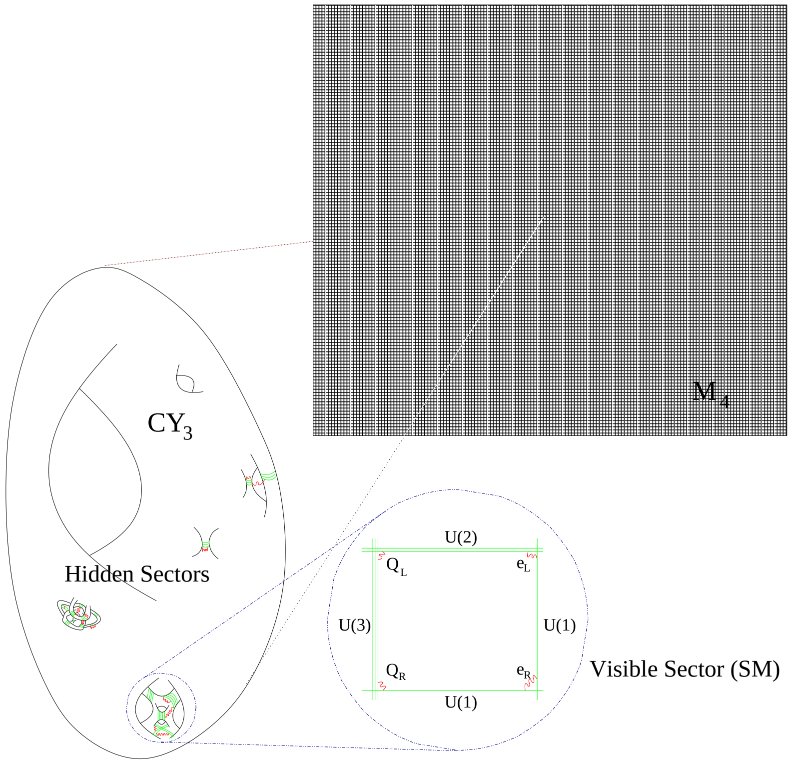
  - In compactifications of heterotic string: [Dienes,Kolda,March-Russell '97]



$$\chi \simeq \frac{g_a g_b}{16\pi^2} C \frac{\Delta m}{M_P} \gtrsim 10^{-17}$$

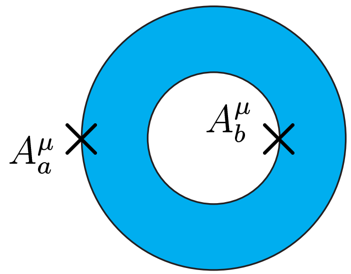
- In type II compactifications with branes:
  - D-branes in the bulk that have no intersection with branes responsible for visible sector, are ubiquitous ⇒ hidden U(1)s

adapted from [Conlon,Abdussalam,Quevedo,Suruliz '06]

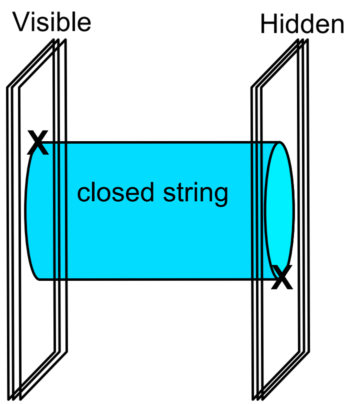


- In type II compactifications with branes:

  – annulus diagram (open string exchange)



⇔ cylinder diagram (closed string exchange)



- Amplitude in closed string channel (orbi/orientifolded torus background):

$$\langle V_i^a V_j^b \rangle = 4(\alpha')^2 \mathrm{tr}_i(\lambda_i^a)\mathrm{tr}_j(\lambda_j^b)\varepsilon_\mu\varepsilon_\nu(g^{\mu\nu}k^2 - k^\mu k^\nu)\int_0^\infty dl \int_0^1 dx$$

$$\underbrace{e^{k^\mu k^\nu G_{\mu\nu}} \sum_\nu \left[\frac{\theta_4''(x)}{\theta_4(x)} - \frac{\theta_\nu''(0)}{\theta_\nu(0)}\right] \frac{1}{(8\pi^2\alpha')^2}\frac{\theta_\nu(0)}{\eta^3(\mathrm{i}l)} Z_\nu^{ij}(\mathrm{i}l)}_{\propto\, e^{-\frac{1}{2}\pi\alpha' k^2 l}\left[1+\sum_{p_6} e^{-\frac{1}{2}\pi\alpha' p_6^2 l - \mathrm{i}p_6\cdot z_{ij}}\right],\ \text{for large } l/l_s \text{ (small } k^2)}$$

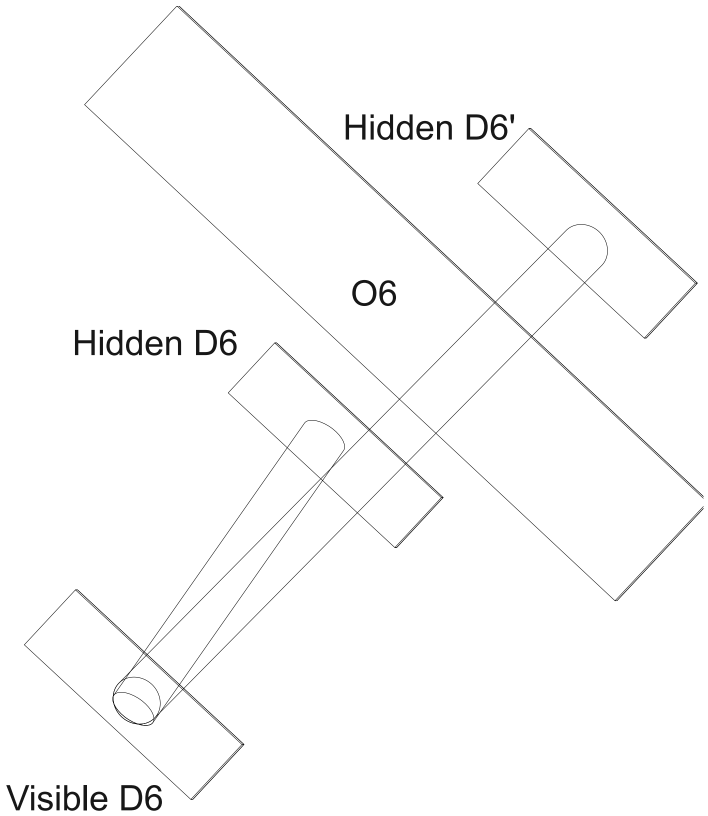
- Compare with:

$$\langle V^a V^b \rangle = \frac{M_{ab}^2}{g_a g_b} A_\mu^a A_b^\mu + \frac{\chi_{ab}}{g_a g_b} k^2 A_\mu^a A_b^\mu \,.$$

  - M_{ab}^2 from $1/k^2$ pole $\leftrightarrow$ massless closed string modes $\leftrightarrow$ independent of separations z_{ij}
  - χ_{ab} from non-pole contributions $\leftrightarrow$ massless and massive closed string modes $\leftrightarrow$ dependent on z_{ij}. Large z_{ij} $\leftrightarrow$ small χ_{ab}.

$\Rightarrow$ U(1)s can mix kinetically, while being massless or light.

- Example:



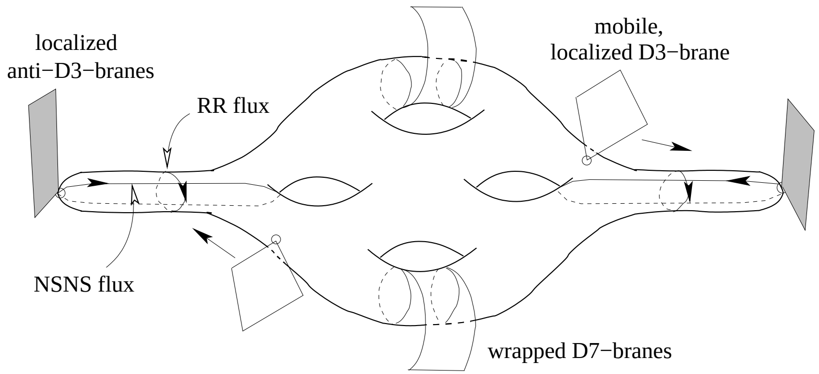
- For explicit calculation exploiting D6 branes in $\mathbb{R}^{3,1} \times \mathbb{T}^2 \times (\mathbb{T}^2 \times \mathbb{T}^2)/\mathbb{Z}_2$, see e.g. [Abel,Goodsell,Jaeckel,Khoze,AR '08]

stack	N	gauge group	$(n^1, m^1) \times (n^2, m^2) \times (n^3, m^3)$
A_1	6	$\mathrm{SU}(3), Q_{A_1}$	$(1,0) \times (1,1) \times (1,-1)$
A_2	2	Q_{A_2}	$(1,0) \times (1,1) \times (1,-1)$
B_1	4	$\mathrm{SU}(2)$	$(1,0) \times (0,1) \times (0,-1)$
C_1	2	Q_{C_1}	$(1,0) \times (1,0) \times (1,0)$
D	4	Q_h	$(1,0) \times (1,-1) \times (1,1)$
C_2	2	Q_{C_2}	$(1,0) \times (1,0) \times (1,0)$

$$\chi_{ij} = \frac{g_a g_b}{4\pi^2} \underbrace{I_{AB} \left[\log \left| \frac{\theta_1\left(\frac{\mathrm{i} z_{ij} L_1}{2\pi^2 \alpha'}, \frac{\mathrm{i} T_1^2}{\alpha'}\right)}{\eta\left(\frac{\mathrm{i} T_1^2}{\alpha'}\right)} \right|^2 - \frac{z_{ij}^2}{2\pi^3 \alpha'} \frac{(L_1)^2}{T_2^1} \right]}_{\text{generically } \mathcal{O}(1)}$$

- U(1) mixing in non-toroidal compactifications of type II string theory:
  - LARGE volume models [Balasubramanian,Berglund,Conlon,Quevedo '05;...]
  - KKLT models [Kachru,Kallosh,Linde,Trivedi '03;...]

⇒ Stacks of D6 branes or D3 and D7 branes with gauge fluxes, realising the standard model, to be considered as a mere local construction supported in some small region of a larger manifold, e.g.



⇒ Larger variety of possible brane separations ⇔ kinetic mixing

- Supergravity calculation of U(1) mixing in type II compactifications:

  * M_{ab}^2 [Ghilencea,Ibanez,Irges,Quevedo '02]
  * χ_{ab} [Abel,Goodsell,Jaeckel,Khoze,AR '08]

  – reproduces results from toroidal compactifications
  – can be applied to scenarios where global properties less understood

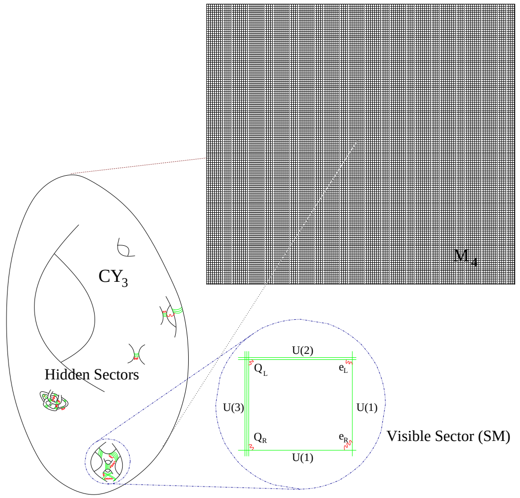
- U(1) mixing apparent in action of brane and supergravity fields: C_{p-1} and B_2 fields mediate mixing,

$$
\begin{aligned}
S_{\rm DBI} &= \mu_p \int d^{p+1}x e^{-\Phi}\sqrt{-\det g + 2\pi\alpha' F + B} \\
S_{\rm WZ} &= \mu_p \int_{Dp} \sum_q C_q \wedge tr\exp(2\pi\alpha' F + B) \wedge \sqrt{\frac{\hat{A}(4\pi^2\alpha' R_T)}{\hat{A}(4\pi^2\alpha' R_N)}}, \\
S_{\rm R} &= -\frac{1}{4\kappa_{10}^2}\int d^{10}x(-\det G)^{1/2}\left(|F_1|^2 + |\tilde{F}_3|^2 + \frac{1}{2}|\tilde{F}_5|^2\right), \\
S_{\rm NS} &= -\frac{1}{4\kappa_{10}^2}\int d^{10}x(-\det G)^{1/2} e^{-2\Phi}|H_3|^2,
\end{aligned}
$$

A_μ is a gauge field, C_q are the R-R forms and B_2 is the NS-NS 2-form and the field-strengths are defined as

$$F = dA; F_{q+1} = dC_q; H_3 = dB_2; \tilde{F}_3 = F_3 - C_0 \wedge H_3; \tilde{F}_5 = F_5 - \frac{1}{2}C_2 \wedge H_3 + \frac{1}{2}B_2 \wedge F_3; *_{10}\tilde{F}_5 = \tilde{F}_5$$

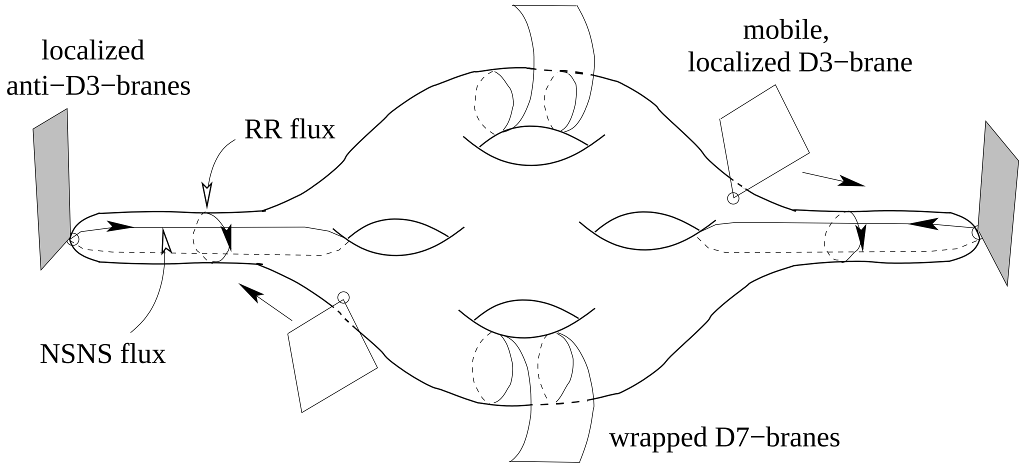
– Kinetic mixing with generic hidden U(1) in LARGE volume model:



– e.g. D3-brane supporting visible U(1) and hidden D3-brane located at generic position in Calabi-Yau ⇒ [Abel,Goodsell,Jaeckel,Khoze,R: JHEP '08]

$$\chi_{ab} \simeq \frac{g_a g_b}{16\pi^2} \left(V_6 M_s^6\right)^{-2/3} \sim 10^{-14}, \quad \text{for} \quad V_6 M_s^6 \sim 10^{14} \; (M_s \sim 10^{10}\,\mathrm{GeV})$$

- Kinetic mixing through in KKLT like model:

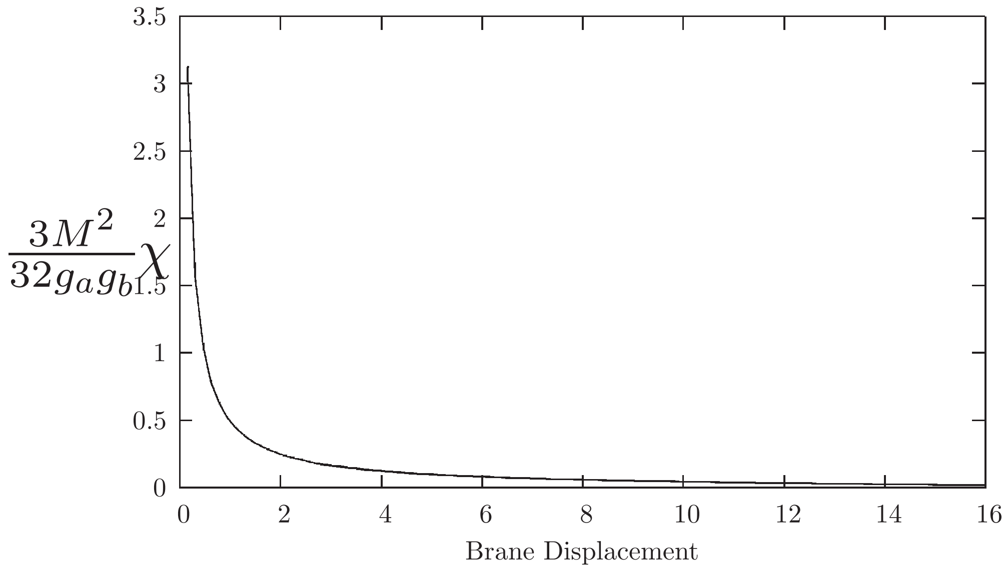


- Visible U(1) brane placed at tip of warped throat, hidden brane separated by distance $d \Rightarrow$ [Abel,Goodsell,Jaeckel,Khoze,R: JHEP '08]

$$\chi_{ab} \sim \frac{g_a g_b}{16\pi^2} \exp\left(-md\right), \text{ where } m \sim \min\left(H_3^{(6)}, F_3^{(6)}\right) \sim \frac{n M_s}{V_3\, M_s^3}$$

- Kinetic mixing in the Klebanov-Tseytlin throat:

$$\chi_{ab} = g_a g_b \frac{32}{3M^2} \frac{1}{4y_1 + 2(y_1 - y_0)^2)} \frac{\tilde{G}_<(y_s)}{\tilde{G}'_<(y_1)}$$



$\Rightarrow$ can take any value, depending on the separation

3. Conclusions

- Kinetic mixing opens a window of opportunity for probing hidden sectors

- In type II compactifications, natural to find massless (or light) hidden U(1)s in models with branes wrapping cycles that do not intersect the branes supporting the standard model

- Size of kinetic mixing model-dependent, but often within reach of current or near future experiments

  ⇒ When building models with stable moduli, should examine for kinetic mixing. Current limits may rule models out.
  ⇒ Signal from experiment would rule out many models and may tell us much about the string vacuum