Small Kinetic Mixing in String Theory

Ruben Kuespert

with A. Hebecker & J. Jaeckel to appear (soon)

String Phenomenology 2023

Outline

1. Motivation: Kinetic Mixing in Field Theory
2. Kinetic Mixing in String Theory
3. D3-D3-Brane Scenario: no KM
4. D3-D3-Brane Scenario: KM through Fluxes

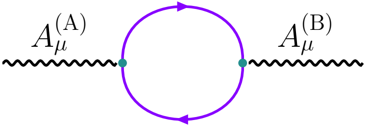
Outline

What is Kinetic Mixing (KM)?

- KM in field theory refers to specific mixing term of different $U(1)$ gauge theories (say $U(1)_A$ and $U(1)_B$) [Okun, 1982, Holdom, 1986]

$$\mathcal{L} \supset -\frac{\chi_{AB}}{2} F^{\mu\nu}_{(A)} F^{(B)}_{\mu\nu}$$

- χ_{AB} can be generated by a heavy particle running in a loop

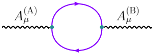


- KM is intensively researched $\Rightarrow$ creates portal from SM to DS
- KM has to satisfy strong bounds: $\chi_{AB} < 10^{-17} - 10^{-5}$ [FIPs Report 2022]

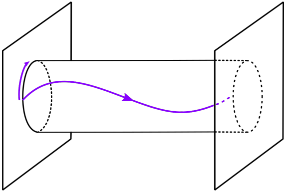
Outline

1. Motivation: Kinetic Mixing in Field Theory
2. Kinetic Mixing in String Theory
3. D3-D3-Brane Scenario: no KM
4. D3-D3-Brane Scenario: KM through Fluxes

Kinetic Mixing in String Theory

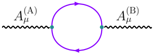
- Stringy analog of 

is an open string running in a loop

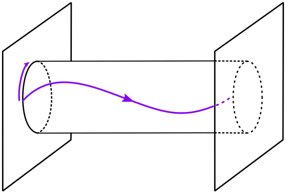


[Dienes, March-Russell, 1996]
[Abel, Schofield, 2003]

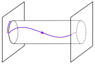
Kinetic Mixing in String Theory

- Stringy analog of 

is an open string running in a loop



[Dienes, March-Russell, 1996]
[Abel, Schofield, 2003]

- We focus on IIB, can reinterpret  as tree level exchange of closed string modes between D-branes
- $\curvearrowright$ 10d EFT analysis, possible to consider e.g. CY_3 geometries

[Abel, Goodsell, Jaeckel, Khoze, Ringwald 2008]
[Goodsell, Jaeckel, Redondo, Ringwald, 2009]
[Cicoli, Goodsell, Jaeckel, Ringwald, 2011]

Outline

1. Motivation: Kinetic Mixing in Field Theory
2. Kinetic Mixing in String Theory
3. D3-D3-Brane Scenario: no KM
4. D3-D3-Brane Scenario: KM through Fluxes

D3-D3-Brane Scenario

- Consider specific toy model of two D3-branes, A & B, separated in 6d

⇒ string loop diagram vanishes on tori [Abel, Schofield, 2003]

Does this generalize to CY_3?

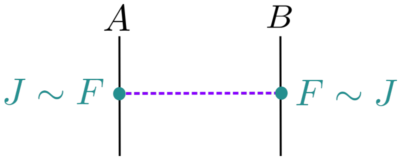
D3-D3-Brane Scenario

- Consider specific toy model of two D3-branes, A & B, separated in 6d

  $\Rightarrow$ string loop diagram vanishes on tori [Abel, Schofield, 2003]

  Does this generalize to CY_3?

- $\curvearrowright$ Invoke 10d EFT approach: compute diagrams of the type



$\Rightarrow$ Analysis approves cancellation, but neglected C_0 and quadratic self-couplings of exchanged fields [Abel, Goodsell, Jaeckel, Khoze, Ringwald 2008]

Our Extended EFT Analysis

- What are the source and self-coupling terms?

$$S_{D3} \supset T_3 \int_{D3} -\frac{g_s^{-1}}{2}\underline{(F_2 - B_2) \wedge \star_4 (F_2 - B_2)}$$

$$+ C_4 + \underline{\tfrac{1}{2} B_2 \wedge C_2} + \underline{C_2 \wedge (F_2 - B_2)} + \frac{C_0}{2}\underline{(F_2 - B_2) \wedge (F_2 - B_2)}$$

[Bergshoeff, Hull, Ortin, 1995]
[Bergshoeff, Boonstra, Ortin, 1996]
[Green, Hull, Townsend, 1998]
[Ortin, 2004]

Our Extended EFT Analysis

- What are the source and self-coupling terms?

$$S_{D3} \supset T_3 \int_{D3} C_4 + \frac{1}{2} J_{(1)} \wedge J_{(2)} - \frac{1}{2} C_2^i \wedge \star_4 \hat{m}_{ij} C_2^j + C_2^i \wedge \star_4 J_i \ ,$$

$$J_{(1)} = - \star_4 F_2 \ , \quad J_{(1)} = g_s^{-1} F_2 + C_0 \star_4 F_2 \ , \quad \hat{m}_{ij} = \begin{pmatrix} 0 & -\frac{1}{2}\star_4 \\ -\frac{1}{2}\star_4 & g_s^{-1} + C_0 \star_4 \end{pmatrix}$$

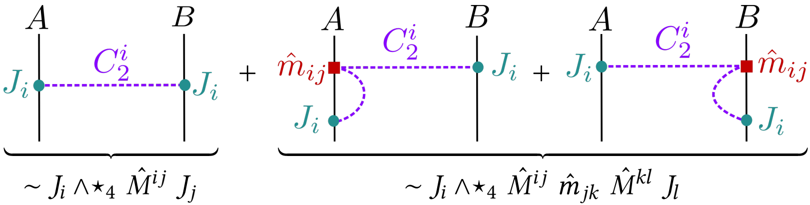
- Need to focus on $C_2^i = \begin{pmatrix} C_2 \\ B_2 \end{pmatrix}$ with kinetic term

$$S_{IIB} \supset -\frac{1}{2\kappa_{10}^2} \int_{\mathcal{M}^{10}} \frac{\hat{M}_{ij}}{2} F_3^i \wedge \star_{10} F_3^j \ , \quad \hat{M}_{ij} = g_s \begin{pmatrix} 1 & -C_0 \\ -C_0 & g_s^{-2} + C_0^2 \end{pmatrix}$$

- Appropriate basis for $SL(2, \mathbb{R})$

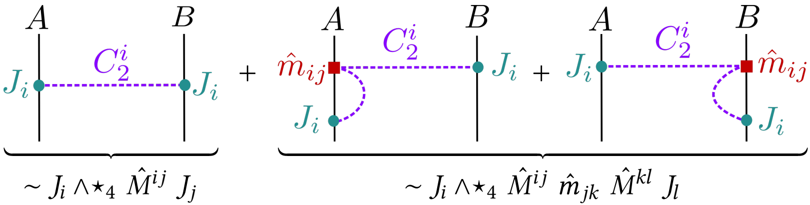
Our Extended EFT Analysis - II

- We integrate out C_2^i by treating $\hat{m}_{ij}$ as perturbation



Our Extended EFT Analysis - II

- We integrate out C_2^i by treating $\hat{m}_{ij}$ as perturbation



- $\hat{M}^{ij}$, $\hat{m}_{ij}$ and J_i have crucial relations

$$\hat{M}^{ij} J_j = \star_4 \epsilon^{ij} J_j \ , \qquad \hat{m}_{ij} \star_4 \epsilon^{jk} J_k = J_i$$

- This implies that every diagram $\sim \epsilon^{ij} J_i \wedge J_j$

$$\underline{\epsilon^{ij} J_i \wedge J_j = 0}$$

$\Rightarrow$ $SL(2, \mathbb{R})$ structure responsible for cancellation

Outline

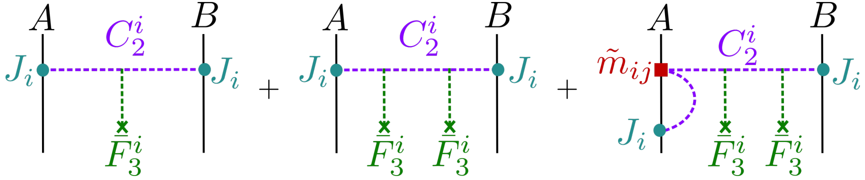
Kinetic Mixing through Fluxes

- Break $SL(2,\mathbb{R})$ with 3-form flux $\bar{F}_3^i$
- Effect of fluxes can best be seen in eom

$$J_i\ \delta(D3) = \left[\hat{M}_{ij}\ \mathrm{d}^\dagger \mathrm{d} C_2^j + \tilde{m}_{ij}\ C_2^j\ \delta(D3)\right] + \epsilon_{ij} \star_{10} \left(\bar{F}_3^j \wedge \mathrm{d}C_4\right)$$

$$0 = \mathrm{d}^\dagger \mathrm{d} C_4 + \epsilon_{ij} \star_{10} \left(\bar{F}_3^i \wedge F_3^j\right)$$

- Need to simultaneously integrate out appropriate modes of C_2^i and C_4

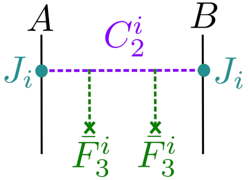


Kinetic Mixing through fluxes - II

- Can eliminate $\hat{m}_{ij}$ from all diagrams

  $\Rightarrow$ pure perturbation theory in $\bar{F}_3^i$ flux

- The leading order contribution to KM comes from



- Parametric estimate of χ_{AB} (flux quanta $=1$):

$$\chi_{AB} \sim \frac{g_s^{-1}}{\mathcal{V}^{4/3}}$$

Summary & Outlook

- Only single D3 branes $\curvearrowright$ consider better pheno scenarios
- We completed the 10d EFT analysis for D3-D3
  $\Rightarrow$ still find KM cancellation due to $SL(2,\mathbb{R})$
- Obtain KM by breaking $SL(2,\mathbb{R})$ with 3-form fluxes
- Parametric estimate of $\chi_{AB} \sim \frac{g_s^{-1}}{\mathcal{V}^{4/3}}$

Summary & Outlook

- Only single D3 branes $\curvearrowright$ consider better pheno scenarios
- We completed the 10d EFT analysis for D3-D3
  $\Rightarrow$ still find KM cancellation due to $SL(2,\mathbb{R})$
- Obtain KM by breaking $SL(2,\mathbb{R})$ with 3-form fluxes
- Parametric estimate of $\chi_{AB} \sim \frac{g_s^{-1}}{\mathcal{V}^{4/3}}$

Thank you!

“Extra Term” in D3-Brane Action

[Bergshoeff, Hull, Ortin, 1995]
[Bergshoeff, Boonstra, Ortin, 1996]

$$S_{\text{IIB}} \supset \int_{\mathcal{M}} -\frac{1}{4}\tilde{F}_5 \wedge \star \tilde{F}_5 \ ,$$

$$\tilde{F}_5 = \mathrm{d}C_4 - \frac{1}{2}C_2 \wedge \mathrm{d}B_2 + \frac{1}{2}B_2 \wedge \mathrm{d}C_2$$

[Green, Hull, Townsend, 1998]

$$S_{CS} \supset \int_{D3} \hat{C}_4 \ ,$$

$$\tilde{F}_5 = \mathrm{d}\hat{C}_4 - C_2 \wedge \mathrm{d}B_2$$

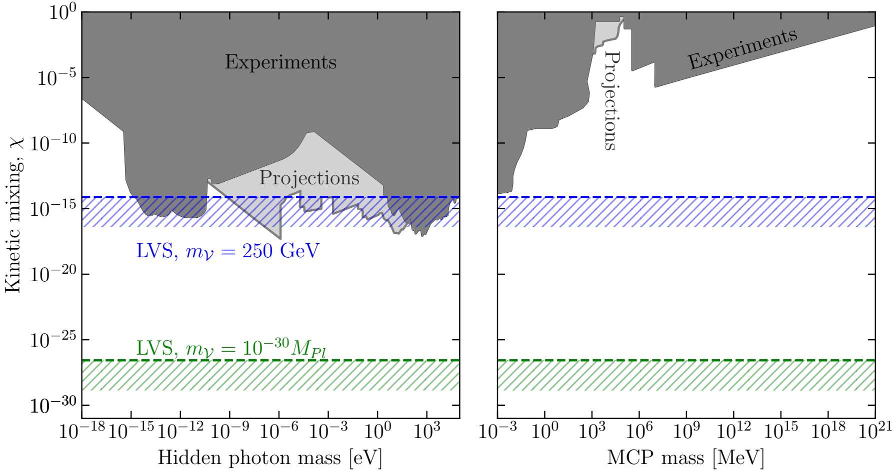
[Ortin, 2004]

Relation: $\hat{C}_4 = C_4 + \frac{1}{2}B_2 \wedge C_2$

$SL(2,\mathbb{R})$ transformation: $\hat{C}_4' = \hat{C}_4 + \frac{1}{2}\left(C_2 \ , \ B_2\right) \wedge \begin{pmatrix} ac & cb \\ cb & bd \end{pmatrix} \begin{pmatrix} C_2 \\ B_2 \end{pmatrix}$

$C_4' = C_4$

Transfer LVS volume constraints to KM



adapted from plots in [Caputo et al., 2021] [Fabbrichesi et al., 2020]