Obtaining small Kinetic Mixing

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work in progress with A.Hebecker & J. Jaeckel

String Phenomenology 2022

Motivation - What is Kinetic Mixing?

- Standard story: non-diagonal kinetic term for multiple $U(1)$ gauge bosons [Okun, 1982, Holdom, 1986]

$$\mathcal{L} \supset -\frac{\chi_{ab}}{2} F^{\mu\nu}_{(a)} F^{(b)}_{\mu\nu}$$

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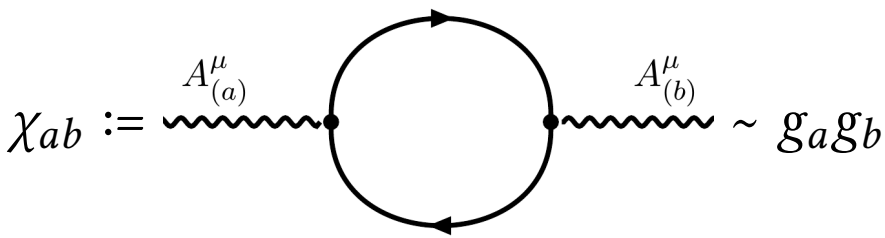
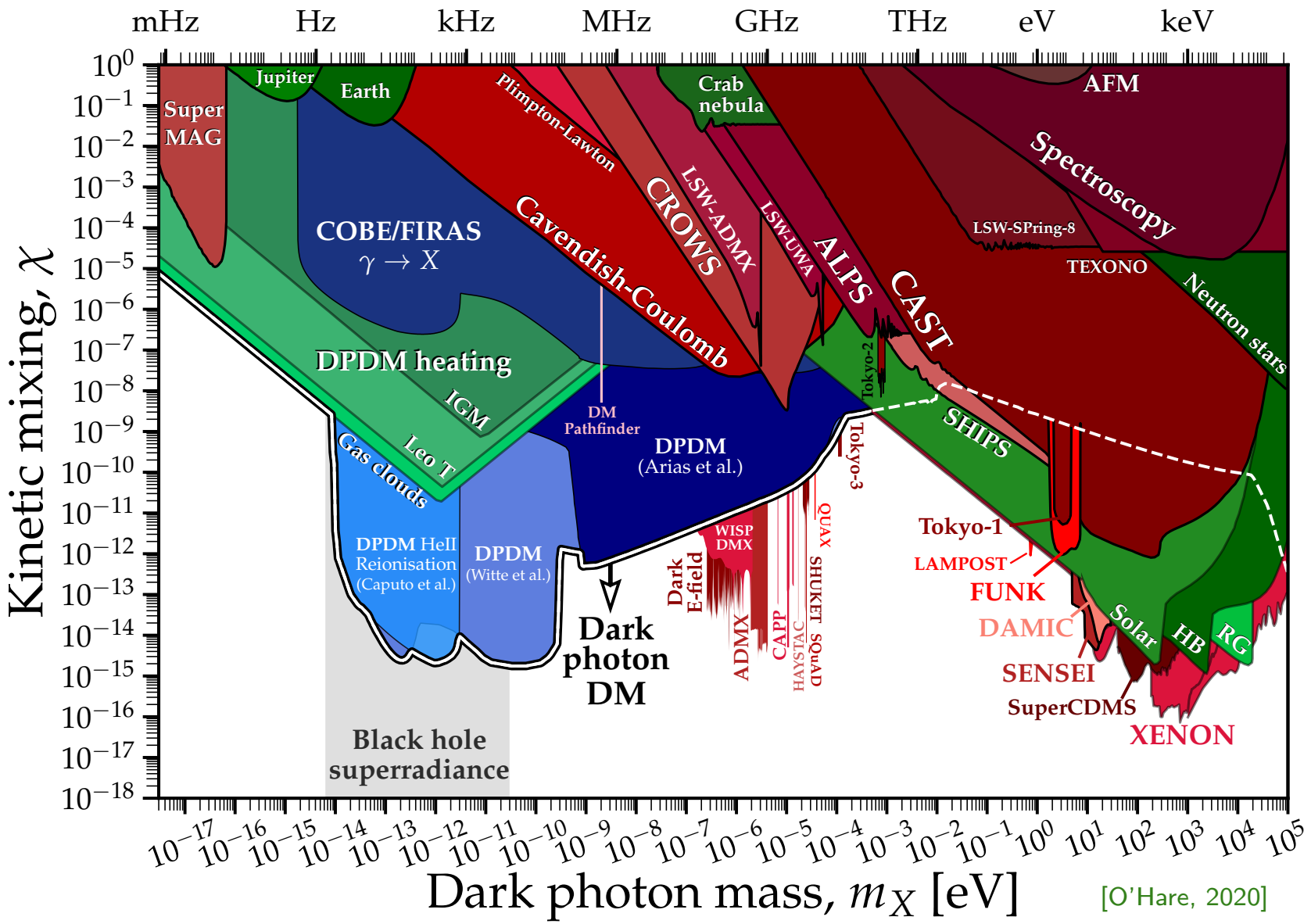
- χ_{ab} can be generated by a heavy particle running in a loop



- KM observability: $\curvearrowright$ charged states $j^{\mu}_{(a)}$ and $j^{\mu}_{(b)}$
  $\curvearrowright$ mass m_X for hidden photon $A^{\mu}_{(b)}$

Constraints on Kinetic Mixing



Outline

1. Kinetic Mixing in String Theory
2. Bounds on Kinetic Mixing
3. Obtaining small Kinetic Mixing

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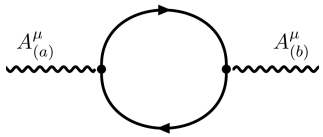
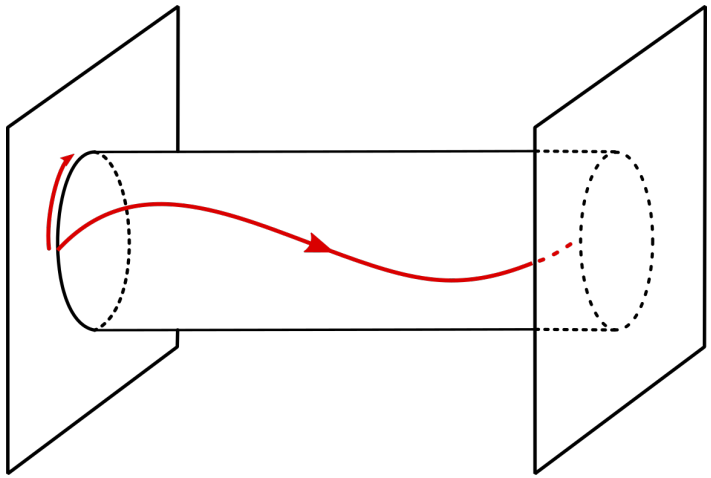
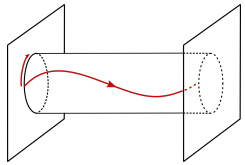
Kinetic Mixing in String Theory

- Stringy analog of 

is an open string running in a loop

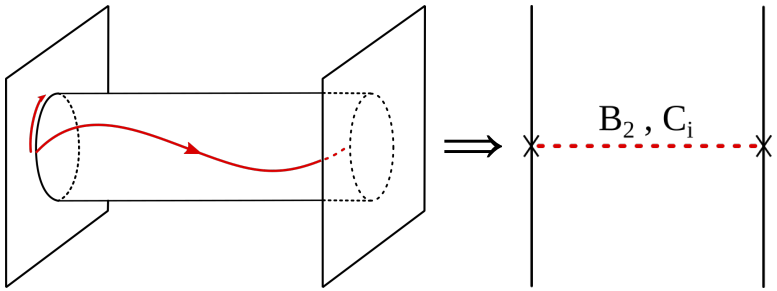


[Dienes,March-Russell,1996]
[Abel and Schofield, 2004]

- Famously dual to closed string, exchanged between the D-branes
- Direct computation of  in relevant scenarios is very tricky

Extracting Kinetic Mixing from EFT

- Restrict to 10D EFT and compute closed string exchange diagrams of mediating fields



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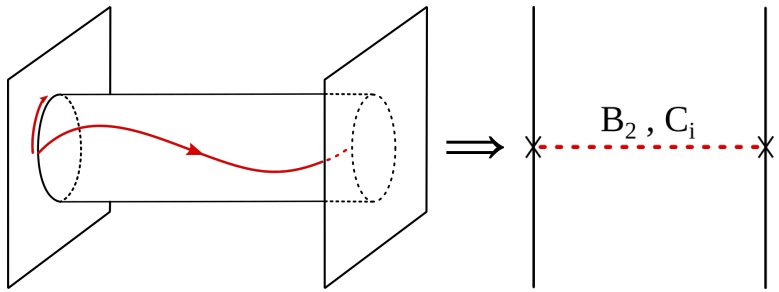

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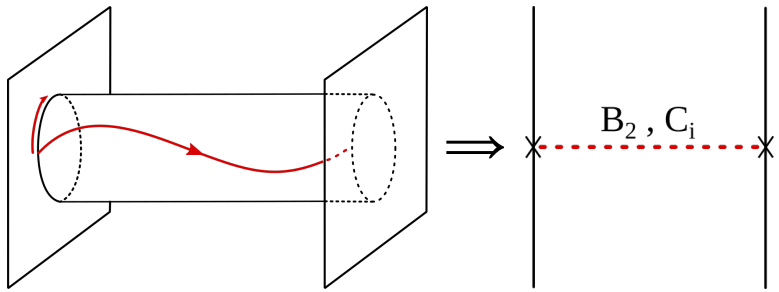
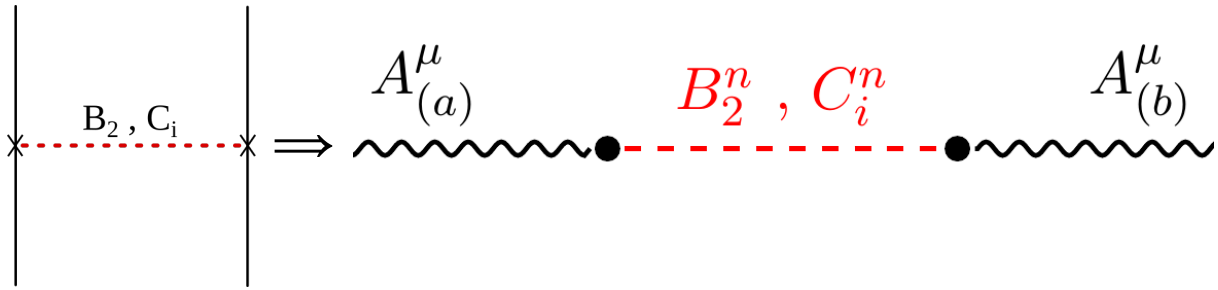


- KM term becomes apparent only from 4D perspective
- Compactify & integrate out KK modes of mediating fields [Abel et al., 2008] [Goodsell et al., 2009]



- generically: $\boxed{\chi_{ab} \sim g_a g_b}$

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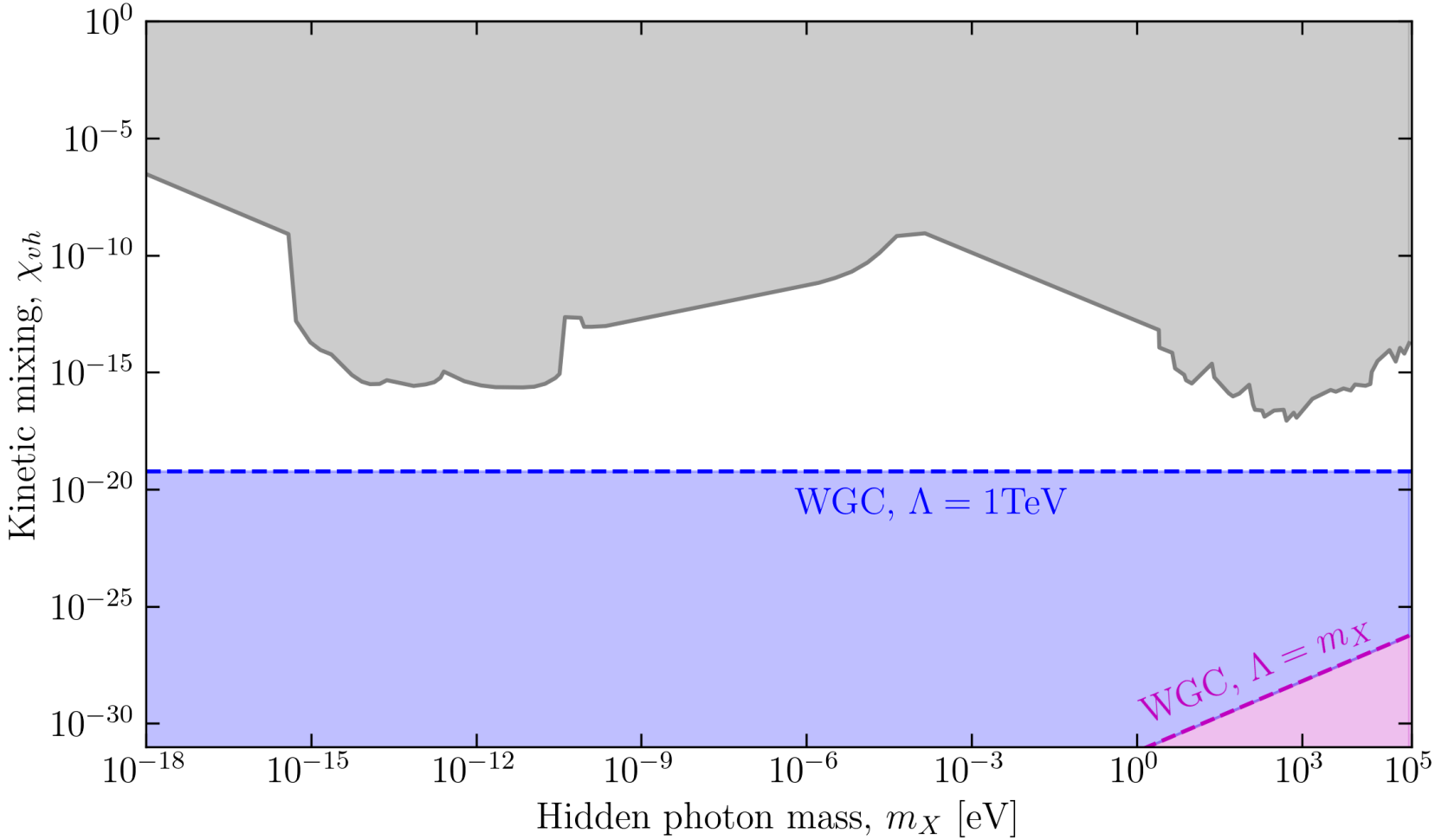
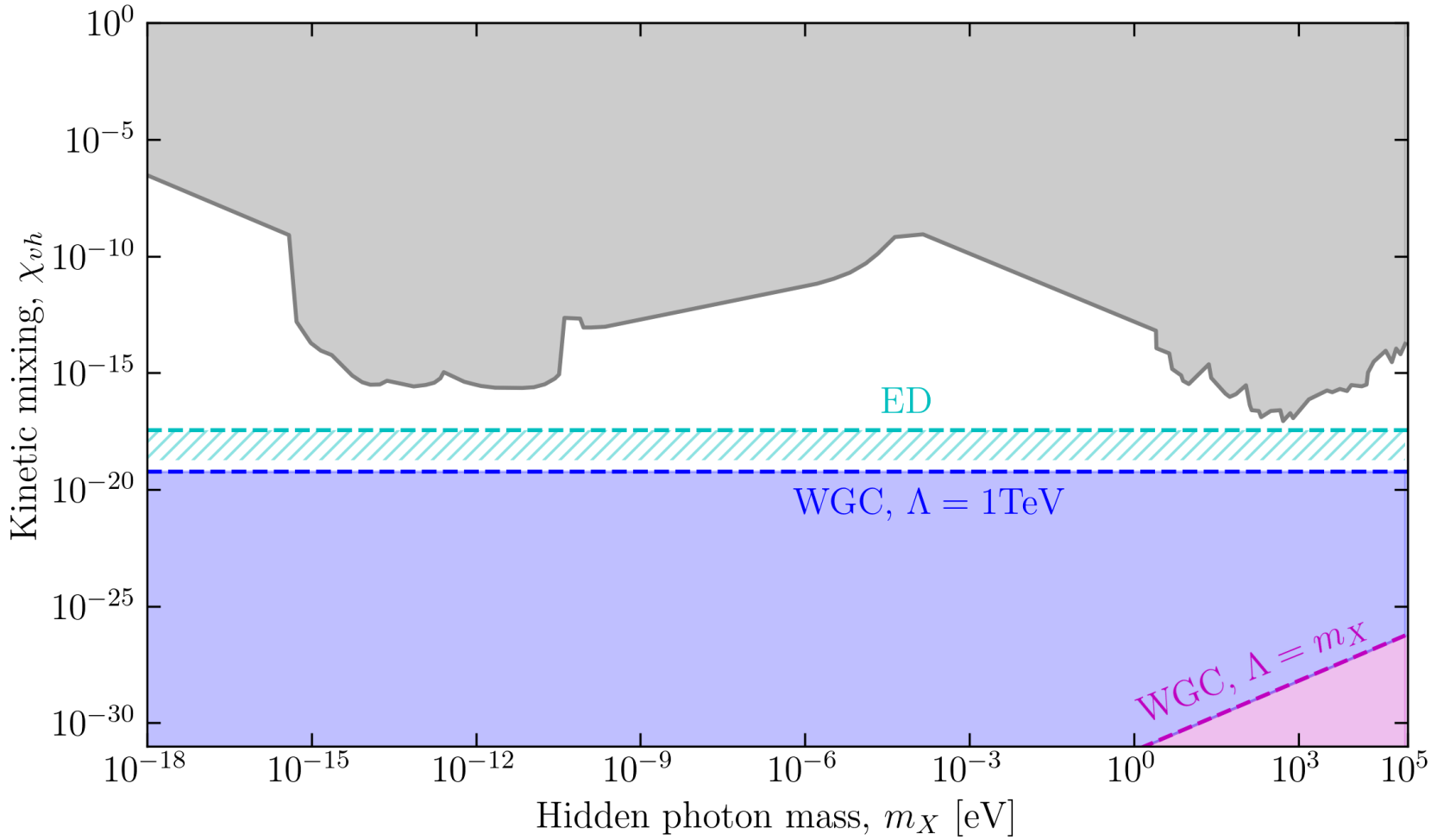


Bounds on Kinetic Mixing - II

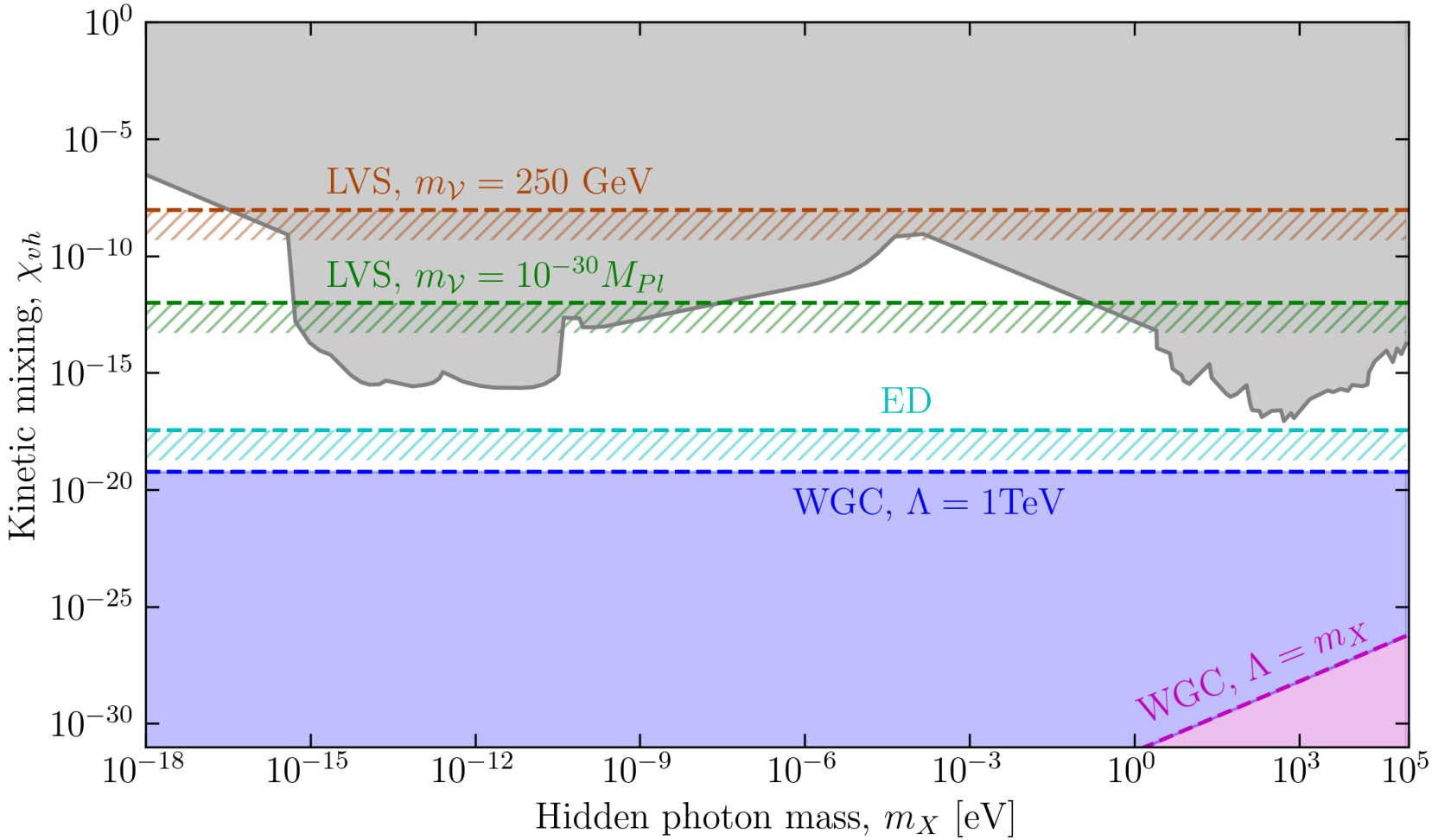
- The cutoff for the 4D theory is given by $\Lambda = M_{\mathrm{KK}} \sim 1/R$ and $g_b^{-2} \sim \mathrm{vol}(\Sigma_{p-3}) \sim R^{p-3}$ [Benakli et al., 2020, Obied and Parikh, 2021] [Hannestad and Raffelt, 2003, Sirunyan et al., 2018]



Bounds on Kinetic Mixing - III

- In LVS, the mass of volume modulus is bounded to evade fifth forces constraints [Kapner et al., 2007]

$$m_{\mathcal{V}} \sim \frac{g_s^2 W_0}{\mathcal{V}^{3/2}} M_{\rm Pl} \gtrsim 10^{-30} M_{\rm Pl}$$



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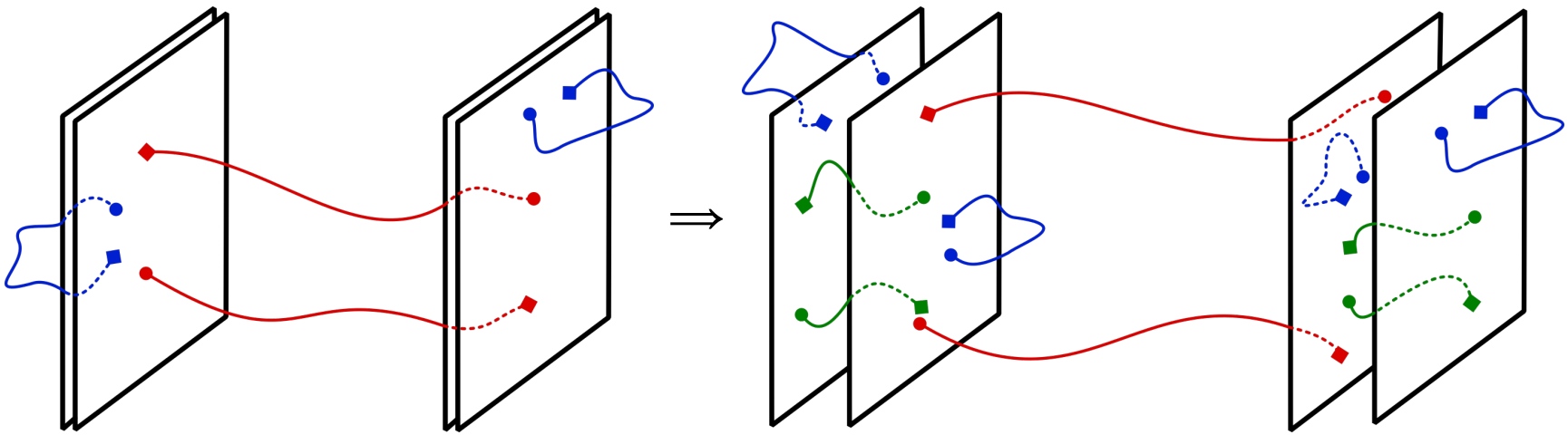

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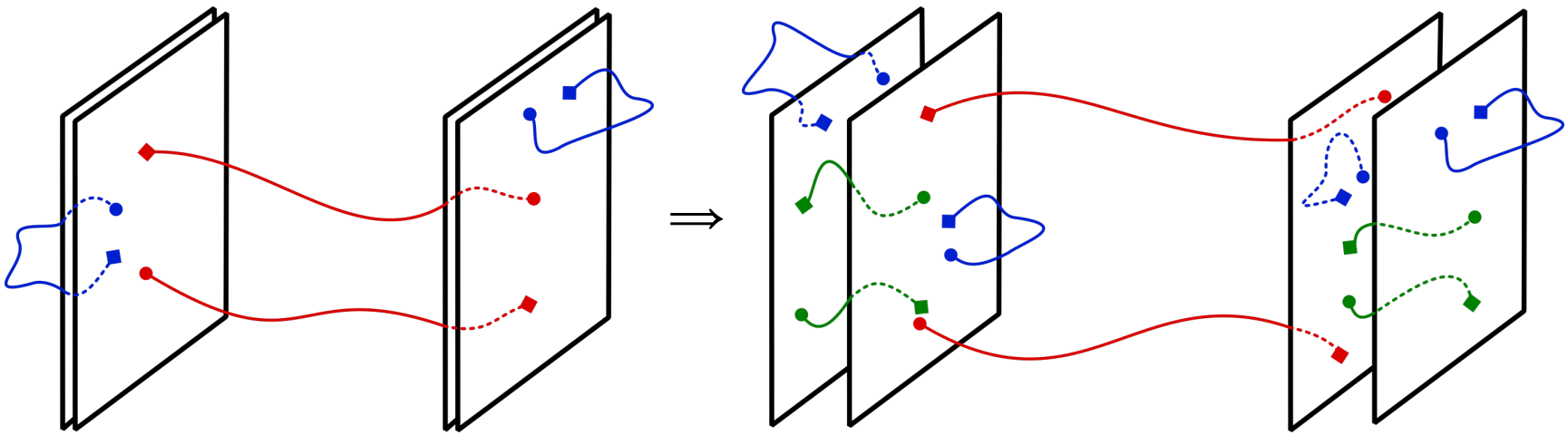

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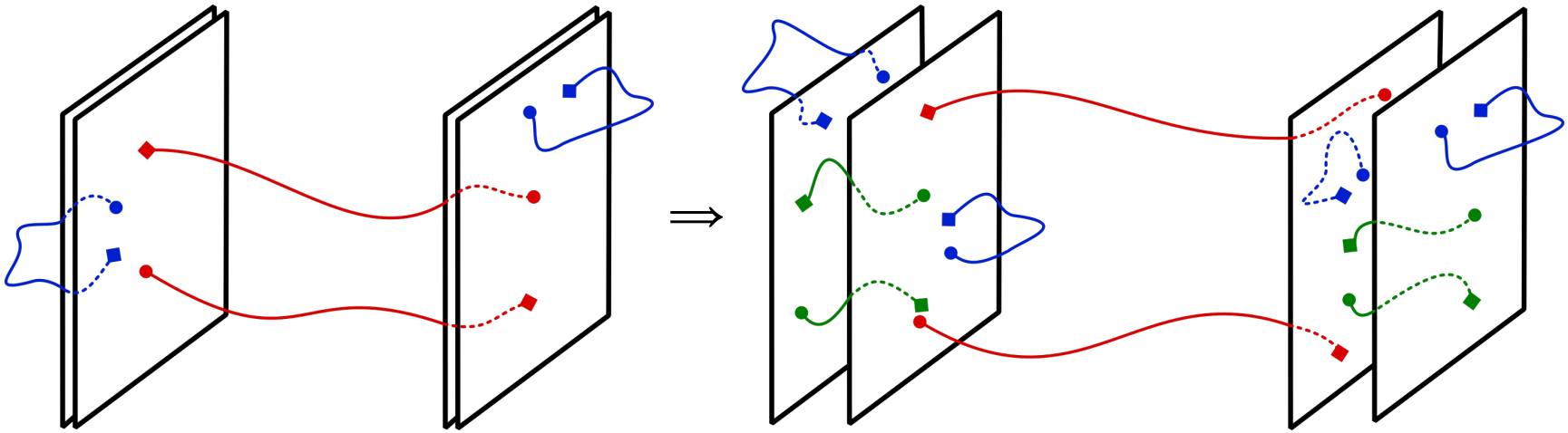
- $\Longrightarrow$ extra suppression due to symmetry breaking $\curvearrowright$ $\frac{\chi_{ab}}{g_a g_b} \sim \left(\frac{\Lambda_{\mathrm{SB}}}{M_{\mathrm{s}}}\right)^2$



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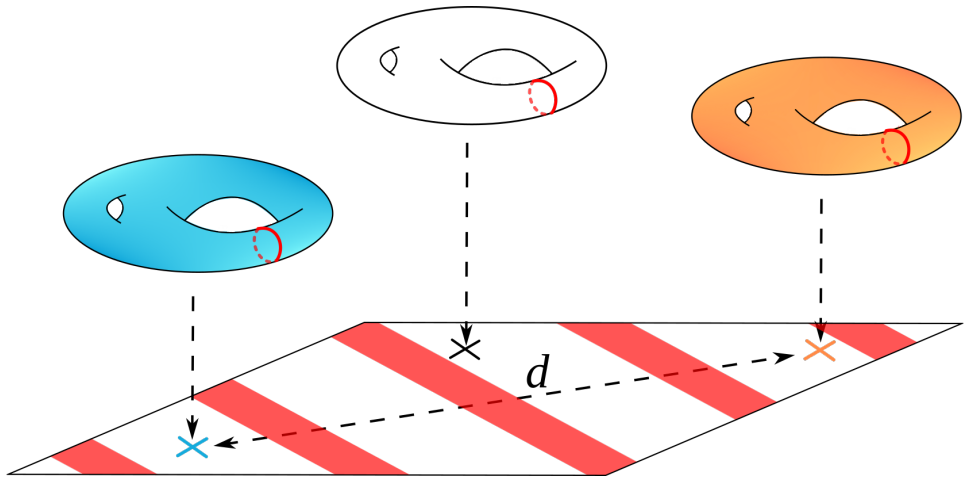

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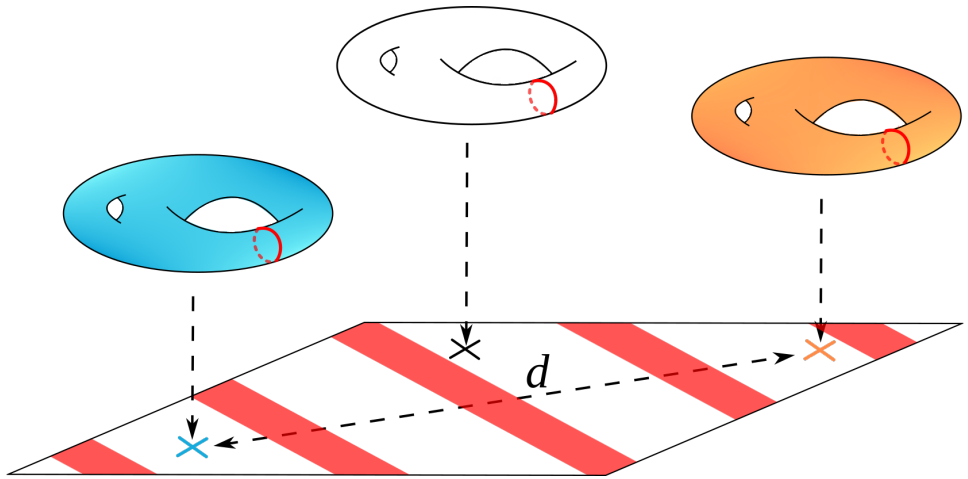

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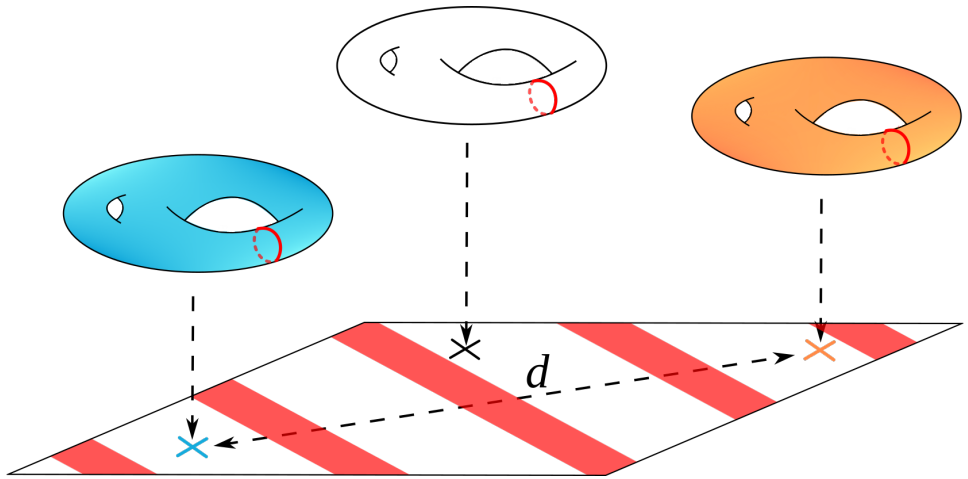

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- In 6D we have KK states with $m \sim 1/l_F$
- Heavy KK modes propagate over long distance in the base

$$\Longrightarrow \chi \sim \exp\left(-\frac{l_B}{l_F}\right)$$

Setups and Caveats

- focus on D3/D7 stacks: D3s $\curvearrowright$ symmetry breaking via separation
  D7s $\curvearrowright$ symmetry breaking via gauge flux
  [Beasley, Heckman, Vafa, 2008] [Donagi, Wijnholt, 2008]
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- Caveat:
  lower dim. SUGRA contains vector or 2-form in graviton multiplet
  $\curvearrowright$ only powerlaw suppressed KM due to massless mediation

Summary

- Small gauge couplings disfavored
- Phenomenologically interesting setups should involve brane stacks
- Sequestring provides other ways to generate small KM
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Thank you!

Extracting Kinetic Mixing from EFT - Example

Take two D3-branes filling 4D spacetime $\curvearrowright$ points in 6D internal dim.
Mediating fields follow from action:

$$S^{(\mathrm{i})}_{\mathrm{DBI}} = -\,T_3 \int_{\mathcal{M}_{1,3}} \mathrm{d}^4x e^{-\Phi} \sqrt{-\det G} \left[1 + \frac{1}{4}\left(F^{(i)}_{\mu\nu} F^{\mu\nu}_{(i)} + 2F^{(i)}_{\mu\nu} B^{\mu\nu} + B_{\mu\nu} B^{\mu\nu}\right)\right]$$

$$S^{(\mathrm{i})}_{\mathrm{CS}} = \mu_3 \int_{\mathcal{M}_{1,3}} C_4 + \left(F^{(i)}_2 + B_2\right) \wedge C_2$$

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To lowest order there are two exchange diagrams: