CP-violating portal to the Dark Sector

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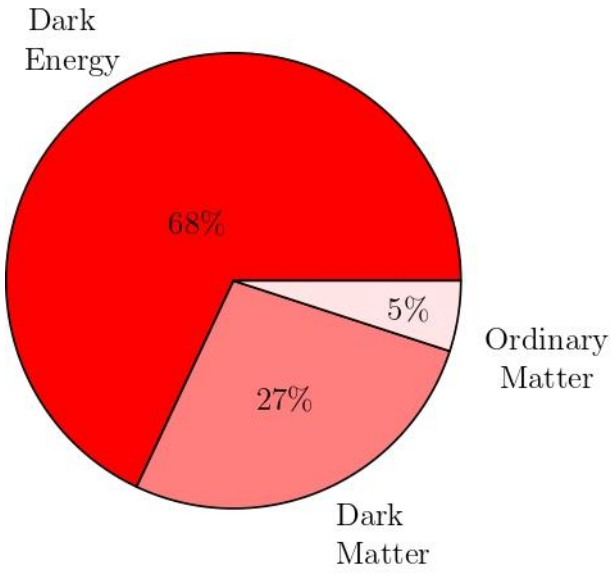
WORK IN PROGRESS!

In collaboration with **M. Ardu, M.H. Rahat, O.Vives**

Motivation

Particle Dark Matter:

- **Dark Matter** comprises almost ¼ of the whole energy budget.
- **Dark Matter Production** (usually) requires interaction with SM.
- If DM ∈ DS**: Portals** between the visible and dark sector.



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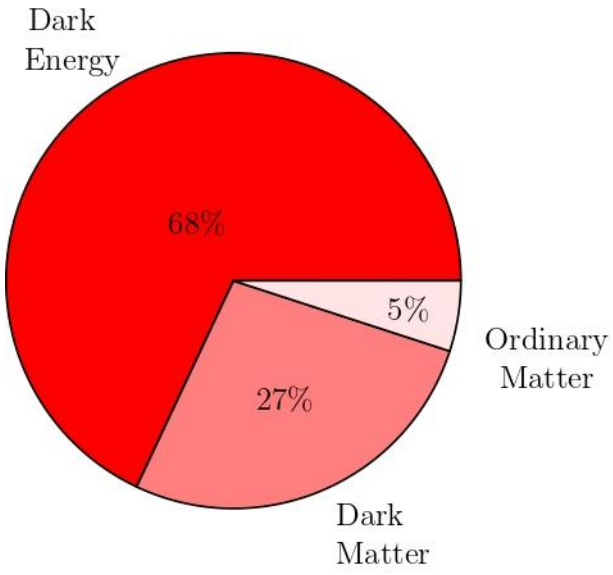


CP-violation :

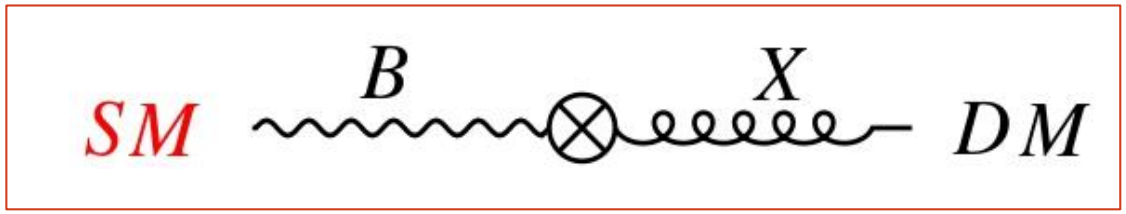
- The SM of particle physics allows for **CP-violation** (CKM matrix)
- CP-violation in the SM is not enough to explain matter-antimatter asymmetry
- CP-violation in Hidden sectors or **Portals** ?

Portals

Portals

Abelian Kinetic Mixing:

- Additional **U(1) abelian** dark gauge group
- **Kinetic Mixing** at renormalizable level: $\frac{\epsilon}{2} B^{\mu\nu} X_{\mu\nu}$
- ϵ can naturally be O(1) but experiments yields $\epsilon << 1$



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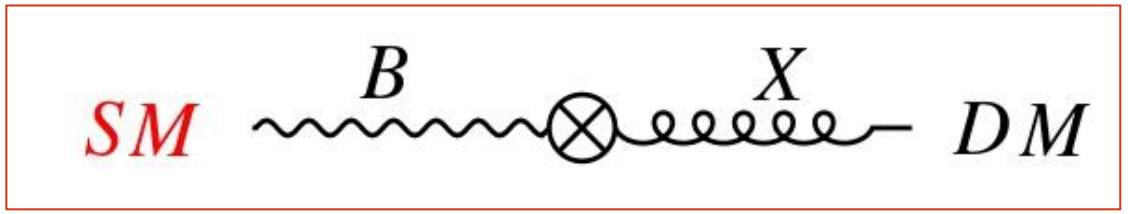
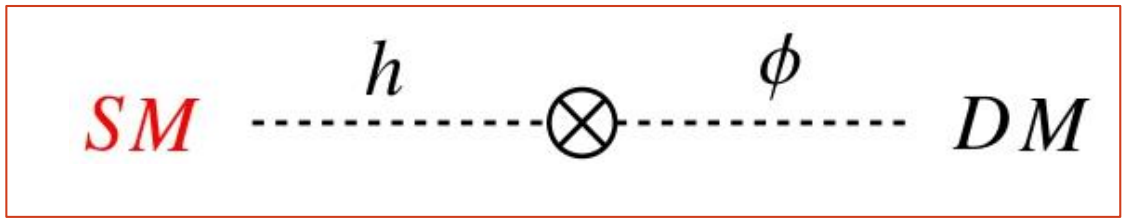


Scalar Portal:

- Additional **Dark Scalar** neutral under SM
- **Interaction** at renormalizable level: $k|H|^2|S|^2$
- SSB ($\langle S \rangle \neq 0$) and mixing.



Non Abelian Kinetic Mixing

- Introduction of a SU(N) **Non Abelian Dark Sector**
  - Σ_a : Scalar fields in the adjoint of SU(N)
  - X_a^μ: $N^2 - 1$ gauge bosons

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- Kinetic Mixing parameters **naturally** small
- New source of **CP-violation**

EDM

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- CPV interaction of spin 1/2 particles with EM fields
- QFT description: $\mathcal{L} = -\frac{i}{2} d\, \bar{\psi} \sigma^{\mu\nu} \gamma_5 \psi F_{\mu\nu}$

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JILAeEDM	4.1 x 10^{-30}
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Expect significant improvements of the current JILAeEDM sensitivity in the coming years!

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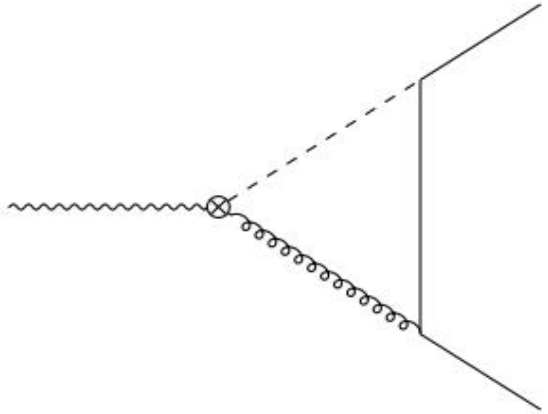

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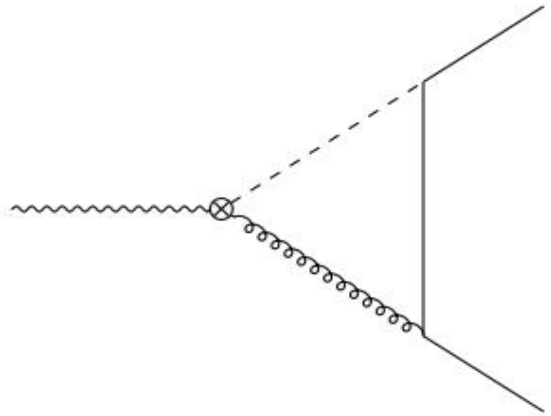

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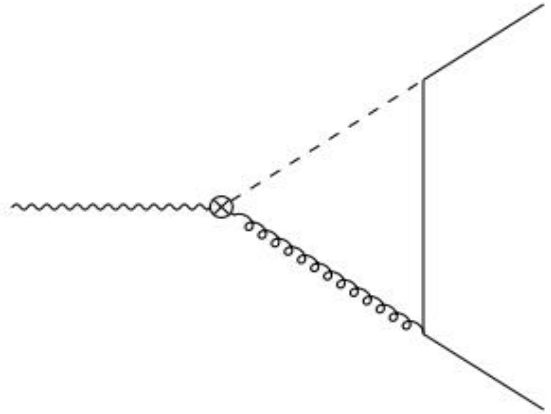

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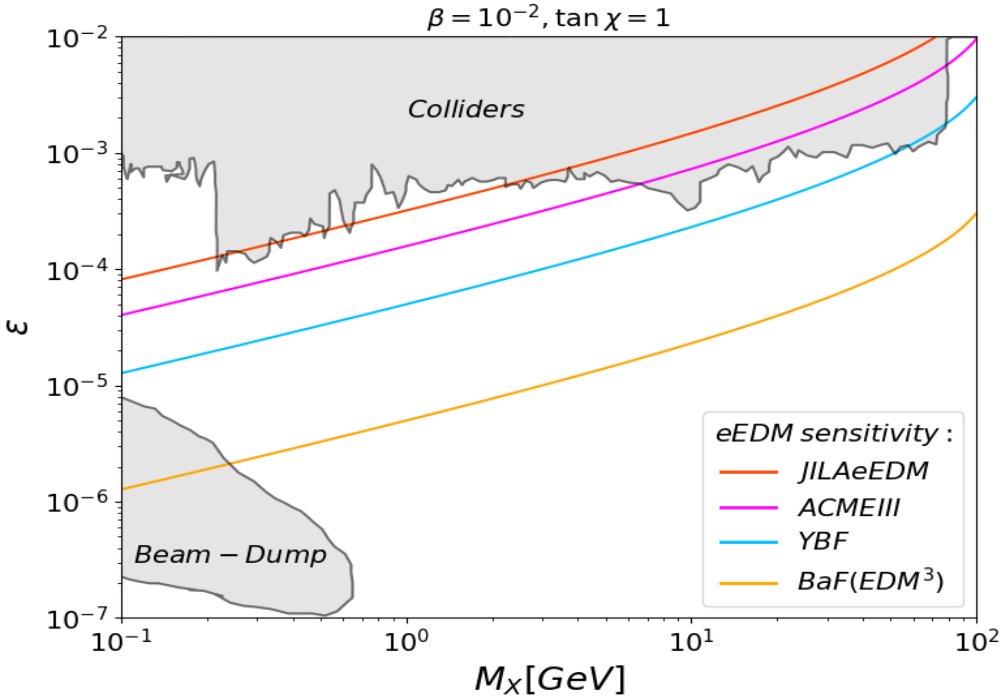

- Parameter space probed by eEDM sens.
- Scalar mixing parameter $\beta \lesssim 10^{-2}$

[T.Ferber et al. (2024)]

- Constraints on ϵ mainly from colliders

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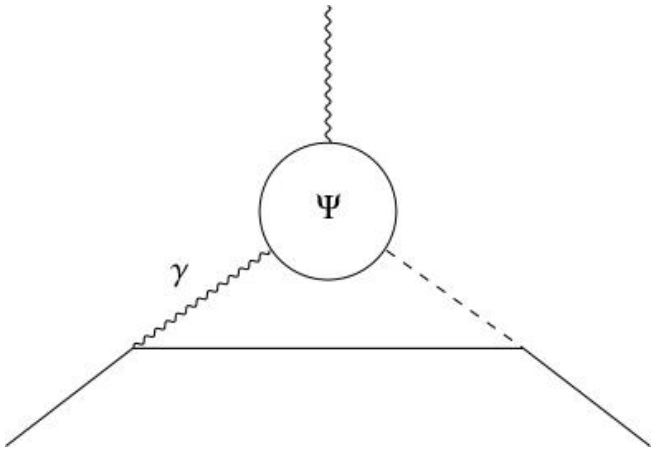
UV-completion

Barr-Zee diagram



$$d_e = \frac{e\alpha}{24\pi^3}\frac{Y_e \mathrm{Im}[\mathcal{Y}]}{\Lambda}\beta \log\left(\frac{m_h^2}{m_\phi^2}\right)$$

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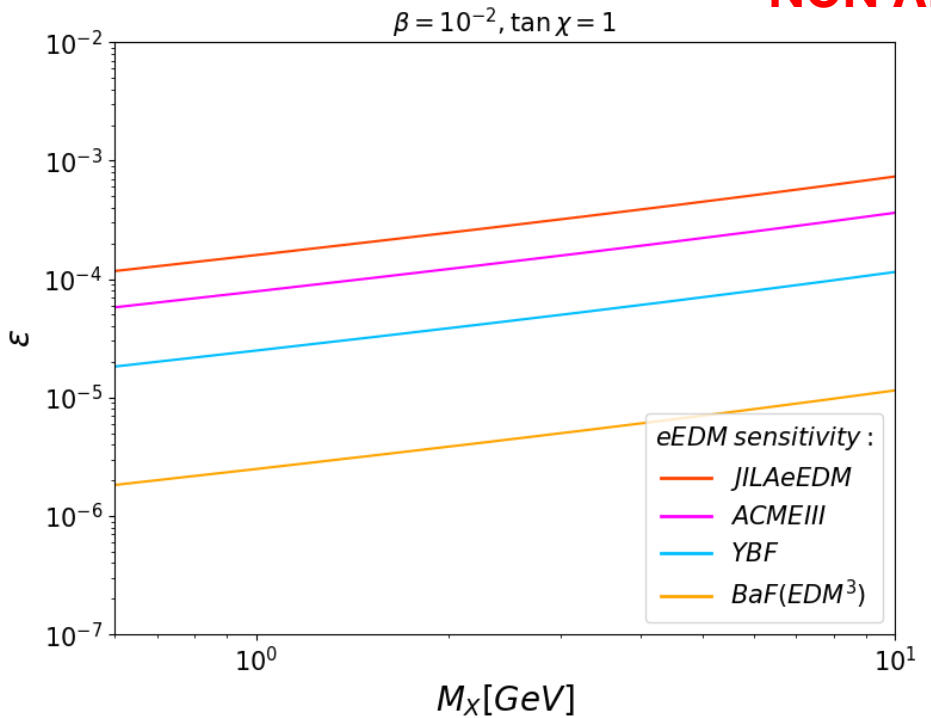


- $m_{\chi_S} \lesssim m_{\chi_H} \lesssim M_X$ ~ GeV scale
- Dark Matter relic abundance via $\chi_H\chi_S \rightarrow$ SM
- WIMP miracle for $\epsilon \sim 10^{-5} \div 10^{-3}$
- Future eEDM sensitivities can probe the model!

Summary

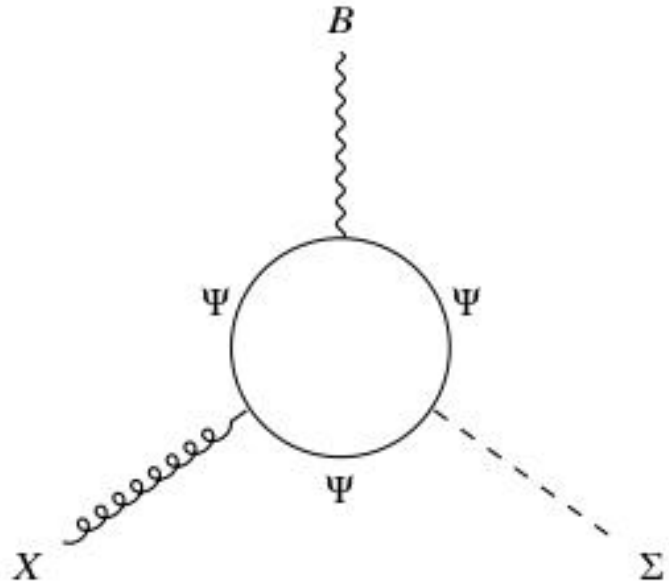
- Non-abelian Dark sector allows for kinetic portals with small ϵ
- Non-abelian Dark sector allows for a CP-violating phase
- Scalar and kinetic mixing + CP-violation signals can be traced in eEDM
- Model of iDM can be probed by the future searches for a permanent eEDM!

Thank you for your attention!

BACK UP

UV completion

- **EFT** call for UV completion
- Heavy vector-like fermion Ψ charged under $SU(N) \otimes U(1)_Y$
- Physical phase χ in Yukawa-like scalar couplings $\mathcal{Y}$



UV Lagrangian:

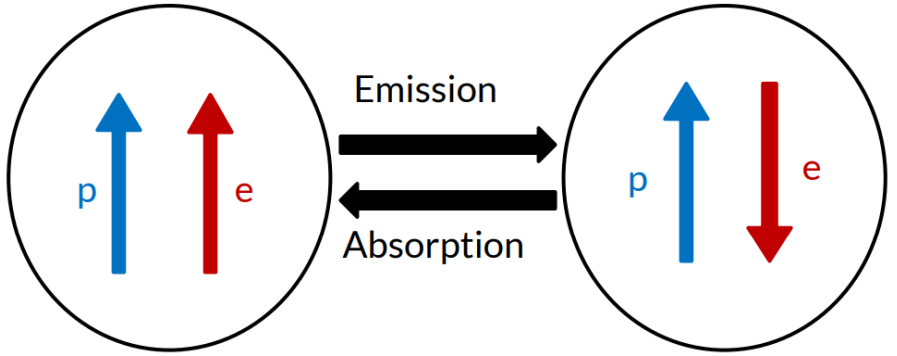
$$\mathcal{L}_\Psi \supset ig Y \bar{\Psi} \gamma_\mu \Psi B^\mu + i g_D \bar{\Psi} X^\mu \gamma_\mu \Psi - \Lambda \bar{\Psi}_R \Psi_L - \mathcal{Y} \bar{\Psi}_R \Sigma \Psi_L + h.c$$

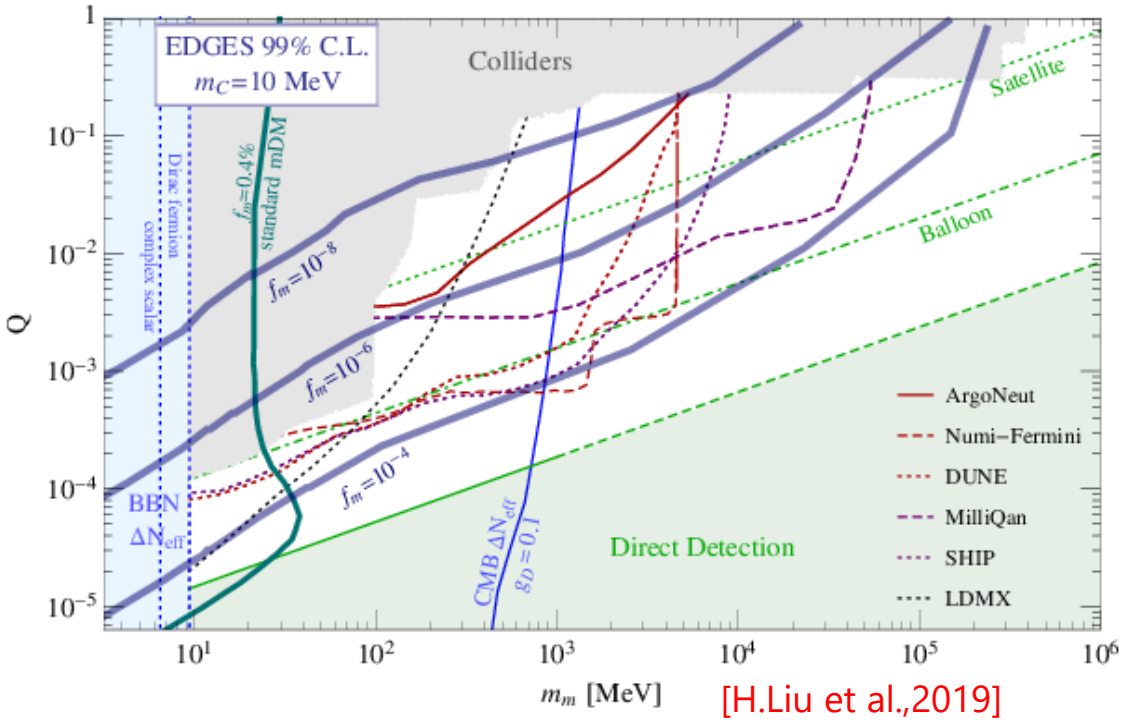
UV-EFT matching

$$\epsilon^a = \frac{g_d Y g \mathrm{Re}[\mathcal{Y}]}{12\pi^2} \frac{v^a}{\Lambda} \qquad \tilde{\epsilon} = \frac{g_d Y g \mathrm{Im}[\mathcal{Y}]}{16\pi^2 \Lambda} \longrightarrow \boxed{\tilde{\epsilon} = \frac{3}{4} \frac{\tan\chi}{v_a} \epsilon_a}$$

EDGES anomaly and milli-charged particles

- Spin flip of an electron after recombination epoch results in emission/absorption of 21-cm radiation
- This can give important information on the Universe
- EDGES has detected a primordial abosorption corresponding to to a 21 cm radiation at z ~15-20
- This would suggest a lower baryons temperature
- Baryons-mDM could cool T_B through Rutherfor scattering
- Small fraction of DM can cool the gas efficiently over a wide range of mass





[H.Liu et al.,2019]

A model for Inelastic Dark Matter

- SU(2) Dark Gauge group with the following matter content:
  - 3 gauge fields X_i^μ
  - 2 scalar fields in the adj. Σ_2^a, Σ_3^a
  - Majorana SU(2) doublet $\chi_L = (\chi_L^1, \chi_L^2)$

- Majorana mass term: $y_2\overline{\chi_L^c}i\sigma_2\Sigma_2\chi_L + y_3\overline{\chi_L^c}i\sigma_2\Sigma_3\chi_L$
- SU(2) fully broken by: $\langle\Sigma_2\rangle = (0, v_2, 0); \langle\Sigma_3\rangle = (0, 0, v_3)$
- Majorana masses: $m_{H/S} = y_2v_2 \pm y_3v_3;\ \chi_H = \frac{\chi_1+\chi_2}{\sqrt{2}};\ \chi_S = \frac{\chi_1-\chi_2}{\sqrt{2}}$
- Off-diagonal current: $\mathcal{L}_f = \frac{g_D}{\sqrt{2}}\overline{\chi_H}\gamma^\mu\chi_S X_+^\mu + h.c.;\ X_+^\mu = \frac{X_3+iX_2^\mu}{\sqrt{2}}$