A Visible QCD Axion Portal to GeV-Scale Dark Matter

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Motivation

- Strong-CP problem (and Peccei-Quinn quality problem)
- Interesting region of the parameter space
- Visible QCD axions at the MeV scale have recently been reconsidered as viable candidates
- $(g-2)_\mu$
- XENON1T excess could be fit by GeV Dark Matter (DM) with pseudoscalar mediator in the MeV range
  [Buttazzo et al., 2021, arXiv:2011.08919]

Model

- Write down a general Lagrangian for an ALP field a that couples to Standard Model (SM) fermions f_i

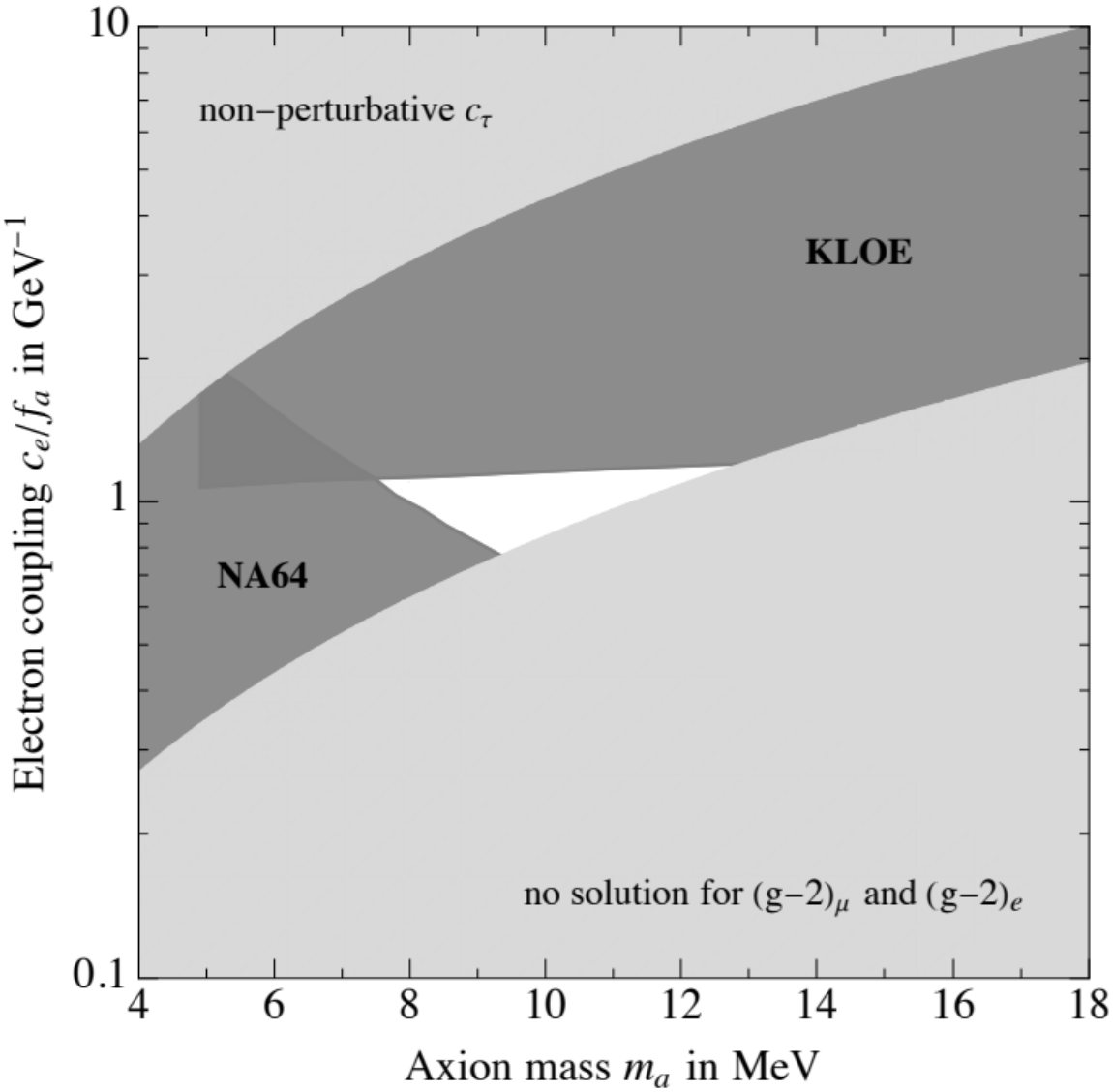
$$\mathcal{L} \supset \frac{\partial_\mu a}{2f_a} \sum_i c_i \bar{f}_i \gamma^\mu \gamma_5 f_i + c_\gamma \frac{\alpha}{8\pi f_a} \epsilon^{\mu\nu\rho\sigma} a F_{\mu\nu} F_{\rho\sigma}$$

- $m_a \sim$ MeV implies constraints from collider and beam dump experiments

- Constrain couplings to leptons using $(g-2)_e$ and $(g-2)_\mu$

$\rightarrow \; c_e/f_a \sim 1 \text{ GeV}^{-1}$, $c_\mu/f_a \sim 0.01 \text{ GeV}^{-1}$, $c_\tau/f_a \sim 0.3 \text{ GeV}^{-1}$

Model


10
1
0.1
non−perturbative c_τ
KLOE
NA64
no solution for $(g-2)_\mu$ and $(g-2)_e$
Electron coupling c_e/f_a in GeV^{-1}
4
6
8
10
12
14
16
18
Axion mass m_a in MeV

QCD Axion

- The QCD axion is an immediate choice

$$m_a \simeq 5.7 \text{ MeV} \left(\frac{\text{GeV}}{f_a} \right)$$

  $f_a \sim$ GeV yields the desired axion mass

- Solves the Strong-CP problem

- $f_a \sim$ GeV yields an immediate solution to the PQ quality problem

A QCD axion at the MeV scale

- Recently shown that a QCD axion with $m_a \sim$ MeV is viable despite strong experimental constraints [Alves and Weiner, 2017, arXiv:1710.03764]

- Must promptly decay into electrons (beam-dump constraints)
  $\rightarrow$ Naturally fulfilled in our scenario

- Must have suppressed couplings to heavy quarks (quarkonia decays)
  $\rightarrow$ Small PQ charges of heavy quark generations

- Must be "pion-phobic", i.e. have suppressed mixing with the neutral pion

$$\rightarrow \quad c_u \approx 2/3, \quad c_d \approx 1/3$$

Dark Matter

- Let the axion couple also to a DM fermion χ

$$\mathcal{L} = -i\frac{a}{f_a}\sum_{i=\chi,u,d,e,\mu,\tau} c_i m_i \bar{f}_i \gamma_5 f_i - m_\chi \bar{\chi}\chi$$

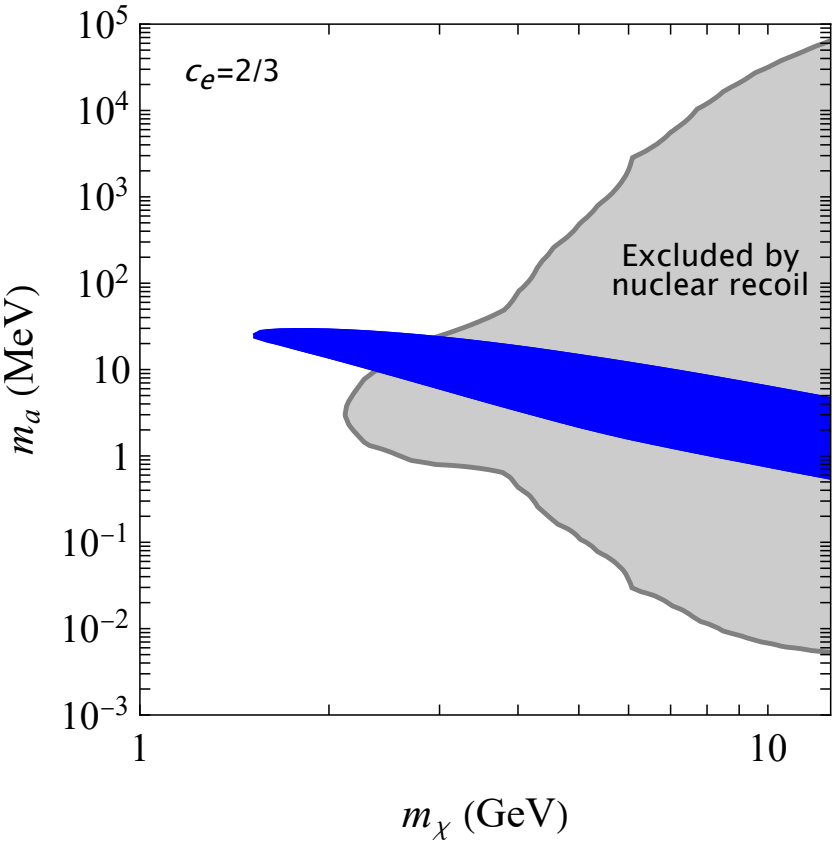
- Coupling to quarks will induce nuclear recoils, but suppressed due to pion-phobia

- Coupling a-DM fixed to the value given by perturbative unitarity: $c_\chi = \sqrt{8\pi/3}$

- $\chi\chi \to e^+e^-$ cross-section would imply $\Omega_\chi \sim 10^{-4}\Omega_{\rm DM}^{obs}$, so need asymmetric DM

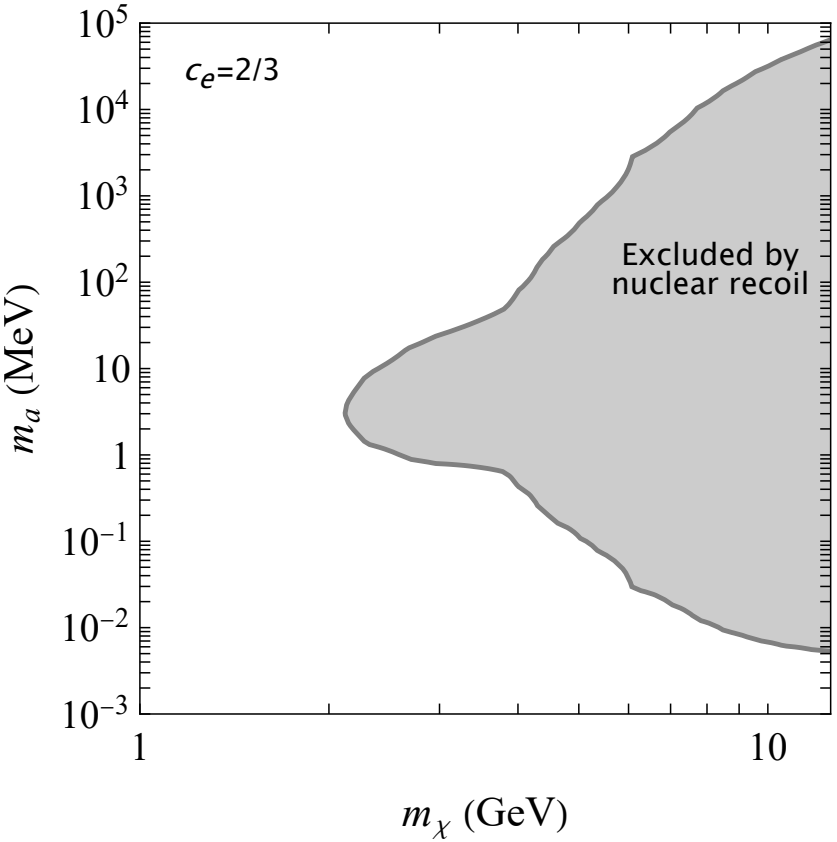
Dark Matter

- Constraints by direct detection experiments with nuclear recoils



Dark Matter

- Constraints by direct detection experiments with nuclear recoils



- No more XENON1T excess $\rightarrow$ Thermal WIMP instead?

Conclusion

- A QCD axion with $m_a \sim$ MeV is viable and appealing to solve $(g-2)_\mu$ and the PQ quality problem
- Constrain couplings to SM leptons using $(g-2)_e$ and $(g-2)_\mu$, and to quarks from quarkonia decay (heavy) and pion-phobia (light)
- XENON1T excess explained by coupling the axion to a DM fermion, with asymmetric DM
- With XENON1T excess gone, consider a thermal relic WIMP instead
- UV model under construction to obtain the right couplings in the IR