A Visible QCD Axion Portal to GeV-Scale Dark Matter

Giovanni Armando

Università di Pisa & INFN

NePSi 23

17 February 2023

Collaborators: F.P. Di Meglio, P. Panci, J. Weiss, R. Ziegler

UNIVERSITÀ DI PISA

Istituto Nazionale di Fisica Nucleare

Table of Contents

Why axions at the MeV scale?

- 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
- $(g-2)_\mu$
- Initially, XENON1T excess $\rightarrow$ R.I.P.

Model

- Write down a general Lagrangian for an axion-like particle a that couples to Standard Model (SM) fermions f_i

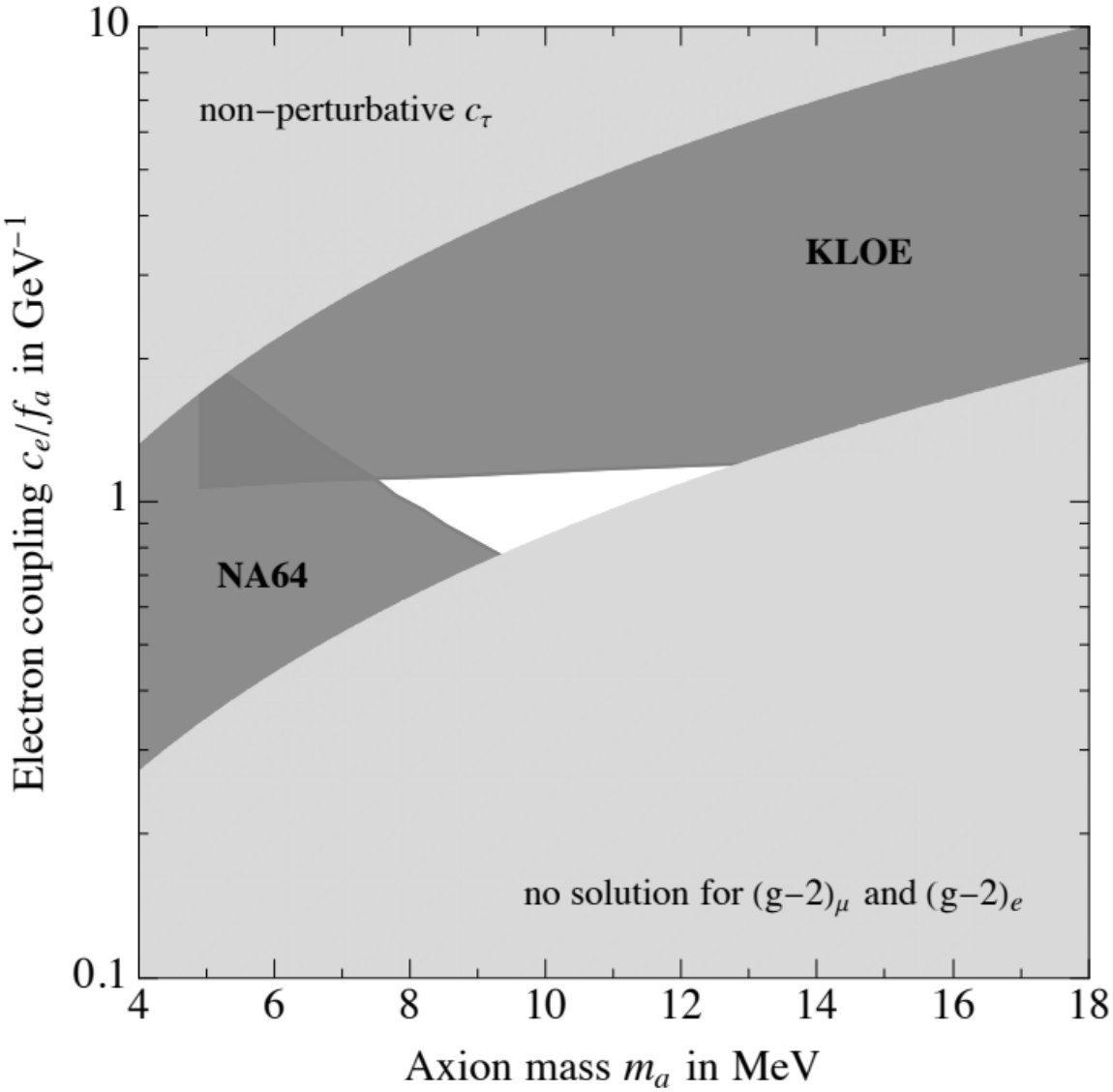
$$\mathcal{L} \supset \frac{\partial_\mu a}{2f_a} \sum_i c_i \bar{f}_i \gamma^\mu \gamma_5 f_i + c_\gamma \frac{\alpha}{8\pi f_a} \epsilon^{\mu\nu\rho\sigma} a F_{\mu\nu} F_{\rho\sigma}$$

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

- Constrain couplings to leptons further 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

$$\mathcal{L} \supset \frac{\partial_\mu a}{2f_a} \sum_{i=\chi,u,d,e,\mu,\tau} c_i \bar{f}_i \gamma^\mu \gamma_5 f_i - m_\chi \bar{\chi}\chi$$

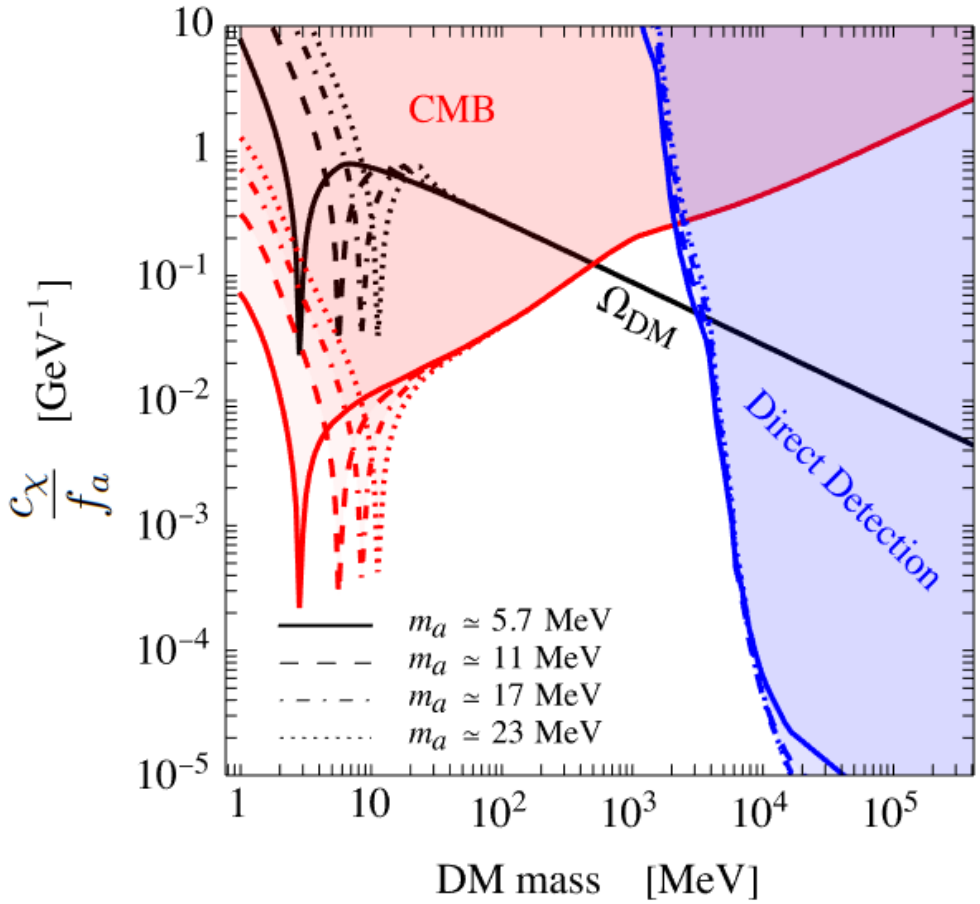
- Reproduce relic abundance through thermal freeze-out

- Annihilation channels: $\bar{\chi}\chi \to e^+ e^-$ s-wave
  $\bar{\chi}\chi \to a\, a$ p-wave

- Couplings to quarks and electrons yield constraints from direct and indirect detection, respectively

Dark Matter

- Constrain axion-DM coupling requiring correct relic abundance and applying bounds from direct and indirect detection



Conclusion

- A QCD axion with $m_a \sim$ MeV is viable and particularly appealing in light of the PQ quality problem
- Constraints to couplings to SM leptons from colliders, beam dump, and $(g-2)_{e/\mu}$, and to quarks from quarkonia decays and pion-phobia
- Couple axion to DM fermion $\rightarrow$ reproduce right relic abundance through thermal freeze-out
- Constraints from indirect detection (CMB) and direct detection (nuclear recoils)
- Sweet spot for $m_\chi \sim \mathcal{O}(\text{GeV})$ and $c_\chi/f_a \sim 0.06 - 0.1$ GeV^{-1}