Snowmass2021 - Letter of Interest

Wave-like searches with a G3 liquid xenon detector

Thematic Area: (CF02) Dark Matter: Wavelike

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Abstract:

The axion is the pseudo-Nambu–Goldstone boson that arises from the Peccei–Quinn solution to the strong CP problem and, at the $\mathcal{O}$ μeV scale, is well established as an excellent dark matter candidate. Ongoing production of axions may be expected in stellar environments including our Sun. Liquid xenon TPCs at G3 scale are both sufficiently radio-quiet and feature low enough energy thresholds to provide excellent sensitivity to solar axions.

QCD AXIONS

An enduring mystery of Nature is the absence of charge-parity violation in strong interactions. A widely accepted solution, introduced by Peccei and Quinn [1], postulates an additional global symmetry, spontaneously broken at some large energy scale. This generates a Nambu-Goldstone boson, the Weinberg-Wilczek axion [2, 3]. If there is more than one global symmetry the particle corresponding to the excitation of the field combination is then the axion. Experimental searches have already ruled out axions arising from symmetry breaking at electroweak scales, but axions resulting from much larger energy scales remain viable [4].

The mass of the QCD axion is given by $m_a = 5.7\mu$ eV $\frac{10^{12}}{f_a}$ GeV where f_a is constrained to be between 10^8 GeV [5] and 10^{17} GeV [6–8]. With a tiny mass and small coupling to matter, such axions would be an excellent candidate for possibly the entirety of the cold dark matter, with credible production mechanisms in both pre- and post-inflation scenarios [9]. Unfortunately, the signal from direct interactions of such axionic dark matter in a G3 instrument would be far too small to be registered.

However, if QCD axions do exist, they would be expected to transform into (and from) photons in external electric and magnetic fields, a process known as the Primakoff effect [10]. Hence, one should expect our Sun to be a prodigious source of an axion flux [11]. Three production mechanisms contribute: i) combined atomic recombination/de-excitation, Bremsstrahlung, and Compton, known as 'ABC interactions' [11, 12], ii) Primakoff conversion of photons to axions in the Sun [10, 13], and iii) de-excitations of a thermally excited low energy state of solar ^{57}Fe [14]. In liquid xenon TPCs, these axions would result, via axioelectric absorption [15], in electron recoils well above detection threshold. A G3 scale device would improve significantly upon previous experimental limits, approaching astrophysical bounds, as indicated in Figure 1. The limit here assumes a 75 ton fiducial mass, a 10 year exposure, and a low energy electron recoil background rate dominated by solar pp neutrinos and $2\nu\beta\beta$ of ^{136}Xe (as assumed for the NF05 NDBD LoI). The astrophysical bounds may be further relaxed in the case of inverse Primakoff scattering [16] such that G3 LXe detectors may exceed future helioscope experiments for a large region of the axion-photon coupling vs. axion mass parameter space.

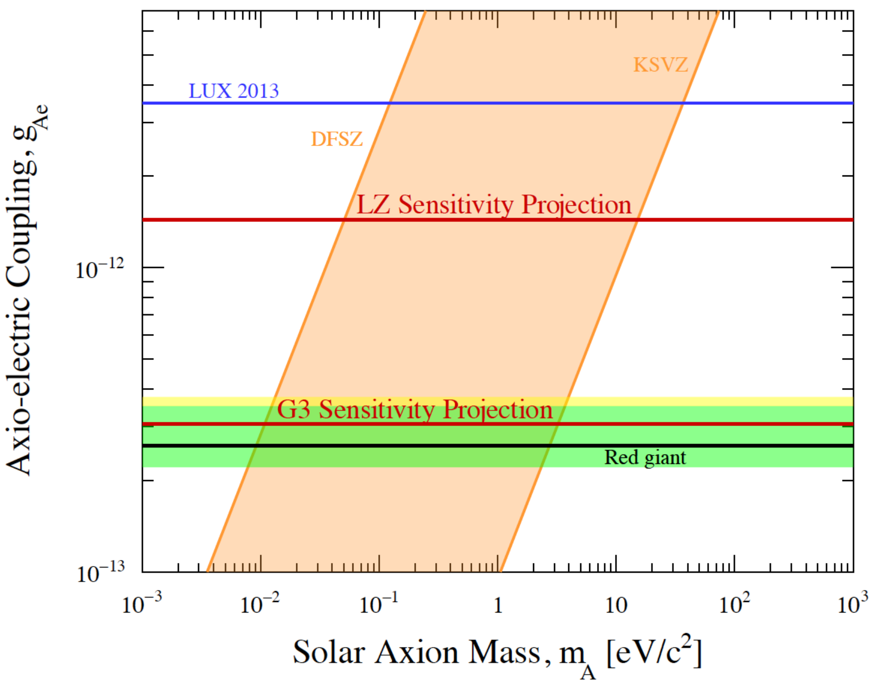

FIG. 1: 90% C.L. sensitivity anticipated for a G3-scale liquid xenon TPC to the axioelectric coupling constant, g_{Ae}. The green (yellow) bands indicate 1σ (2σ) uncertainties. Also shown is the current best limit on g_{Ae} from LUX [17], where only ABC axions were considered (the recent limit from XENON1T [18], which considered ABC, Primakoff and ^{57}Fe axions together, is similar), and the predicted sensitivity of LZ [19]. The black line shows the astrophysical constraint derived from the cooling rate of red giants [20]. The diagonal shaded band is bounded by theoretical models in which the axion arises as a the phase of a new electroweak singlet scalar field coupling to a new heavy quark [21] (labelled ‘DFSZ’), or which assumes the axion interacts with two Higgs doublets rather than quarks or leptons [22, 23], labelled ‘KSVZ’).

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