Snowmass2021 - Letter of Interest

Searching for complex Dark Sectors with KIDs and CCDs

Thematic Areas: (check all that apply □/■)

■ (CF1) Dark Matter: Particle Like
■ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
□ (CF7) Cosmic Probes of Fundamental Physics
■ (Other) (IF1) Quantum Sensors, (IF2) Photon Detectors

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Abstract:

Just as the Standard Model has a wealth of particle content, Dark Matter (DM) may reside in a complicated Dark Sector comprising a number of new particles. We propose to study the *joint sensitivity* of two different detector technologies, in particular to Dark Sectors in which multiple species can contribute to the DM density today. Kinetic Inductance Detector (KID) technology, currently in development for CMB polarization measurements, can also be used to search for polarized photons from the conversion of meV-scale cosmic axions in a strong magnetic field. Meanwhile, low-threshold Charge Coupled Devices (CCDs) have demonstrated sensitivity to ionization signals from the absorption of eV-scale dark photons. In models which give rise to both axion DM and dark photon DM, such as the recently proposed 'Dark Axion Portal', both technologies can be used to simultaneously shed light on the Dark Sector. We motivate a thorough exploration of the parameter space of such models, which can ultimately be constrained using both KID-based and CCD-based detectors.

Introduction

Motivated by the complexity of the Standard Model (SM) and the lack of a detection of Dark Matter (DM) thus far, it is natural to consider that DM may reside in a more complicated *Dark Sector*[1]. Such a Dark Sector would be very weakly interacting, but is likely to be connected to the Standard Model by one or more *portals* – interactions which allow for communication between the Dark and Visible Sectors.

The question of the particle content of the Dark Sector is, of course, an open one. The Strong CP problem provides strong evidence for the existence of the *QCD Axion*[2;3], which may also provide the Dark Matter in the Universe[4;5]. Furthermore, axion-like particles are expected to arise naturally in ultraviolet completions of the Standard Model[6]. At the same time, *Dark Photons* (or *Hidden Photons*) have been proposed to explain a number of anomalies including measurements of $(g-2)_\mu$ [7;8], or simply as a reasonable extension of the already-complicated Standard Model[9]. Depending on the mass and couplings, dark photons may also contribute significantly to the DM relic abundance[10].

Below, we outline two proposed technologies in the search for *Axions* and *Dark Photons*. We then highlight a possible synergy between these two approaches, in models such as the 'Dark Axion Portal' which give rise to *both* axion and dark photon Dark Matter. We note that these detector technologies will also be of interest to other topical groups such as quantum sensors (IF1) and photon detectors (IF2), since the technologies we discuss enable highly efficient single-photon detection.

KIDs-based detectors

At $\sim 90\,\mathrm{GHz}$ (W band) and higher frequencies, kinetic inductance detector (KID) technology has been demonstrated[11;12] as an effective method to measure the CMB polarization due to its sensitivity, relatively low cost, inherent multiplexing capabilities, and readout simplicity. Groups at IFCA (CSIC/UC), DICOM (UC) and CAB (CSIC/INTA) in Spain are working in the development and calibration of dual-polarization KID designs focusing on the W frequency band[13]. This technology can also be applied to the direct detection of DM particles such as axions. The idea is to search for W-band polarized photons produced by the conversion of cosmic axions in the presence of a magnetic field, via the Primakoff effect[14]. The generated photons are expected to be totally (100%) polarized and, by directing them to the KID camera by means of horn antennas coupled to the microwave resonators[15], can be detected using a relatively small number of detectors (compared to CMB applications for which tens of thousands of detectors are required). Using this proposed method, the axion mass range that could be covered with KIDs is in the range $\mathcal{O}(0.1)$ meV to several meV, with a sensitivity to axion-photon couplings smaller than about $g_{a\gamma\gamma} < 5\times10^{-12}\,\mathrm{GeV}^{-1}$. QCD axions at the lower end of this mass range may be produced with the correct relic abundance to account for all of the DM[16;17], while heavier meV-scale axions would instead be a sub-dominant DM particle[5]. Lower masses down to the μeV-scale could be accessible using ultra-low noise high-electron-mobility transistor-based radiometers, a different technology also used in the CMB field.

CCD-based detectors

Fully-depleted Charge Coupled Devices (CCDs) integrating a non-destructive repetitive charge amplifier (skipper) have recently demonstrated sub-electron noise levels, enabling the search for low-mass particle-like DM. This includes the search for ionization signals from the scattering of MeV-scale DM particles with valence electrons[18], giving unprecedented sensitivity to the DM-electron cross section $\bar{\sigma}_e$. In addition, CCDs are sensitive to ionization signals from the absorption of dark photons A' by electrons, with the rate depending on the size of the mixing ϵ between the Dark and SM photons. The mass scale of interest is

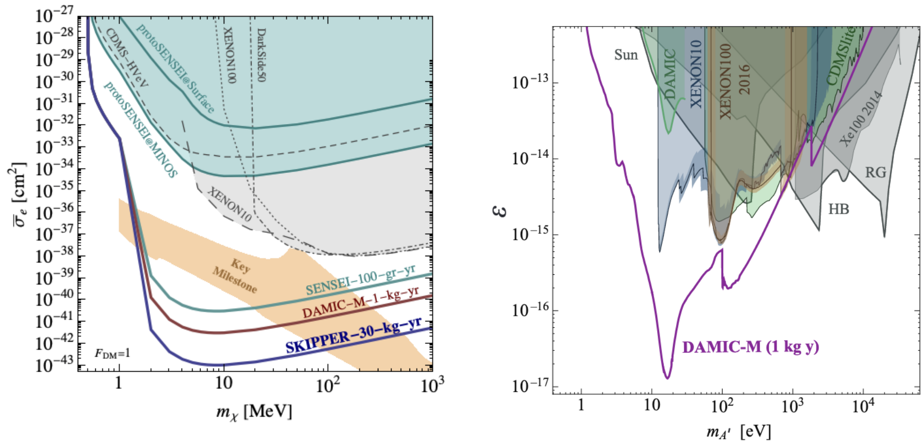

Figure 1: Projected sensitivity of CCD-based detectors to hidden sector Dark Matter. *Left:* DM-electron scattering[26]. *Right:* Absorption of dark photons A' (which is most relevant for this LoI)[27].

$m_{A'} \gtrsim 1\,\mathrm{eV}$ (set by the silicon band gap energy of 1.1 eV). The CCDs of experiments such as DAMIC have a very low dark current $\leq 10^{-21}$ A/cm^2 that enable a threshold of 2 or 3 electrons (corresponding to DM energy transfers as low as $\sim$ 3 eV)[19;20]. Understanding the origin of this dark current background and reducing it are crucial to boosting the sensitivity of CCDs to DM. R&D in this direction includes the study of silicon defects and impurities, as well as the fabrication of CCDs from silicon of the highest available purity. Experiments such as SENSEI $(100\,\mathrm{g})$[21;22], expected to be ready during 2020/21 at SNOLAB, or DAMIC-M (1 kg)[23;24], to be installed at Modane during 2023, will use these sensors in the near future, with the final idea being to develop a 10 kg detector (OSCURA) based on this technology[25]. The projected sensitivity of CCD-based detectors to hidden sector DM is illustrated in Fig. 1.

Detecting Dark Sectors

A number of models have recently been proposed in which the Dark Sector includes both an axion-like particle and a dark photon[28–32], giving rise to a so-called 'Dark Axion Portal'. In such models, both axions and dark photons may contribute significantly to the present-day DM density[29;33]. This means that searches for meV-scale axions with KIDs and searches for eV-scale dark photons with CCDs may simultaneously shed light on the nature of the Dark Sector. This approach would be complementary to searches at beam-dump experiments[34] and other colliders. For example, LHC experiments such as CMS can be used to constrain the axion couplings through precision measurements of the SM Higgs[35] and to search for new heavy colored particles coupled to a dark photon[36].

We aim to investigate the *joint sensitivity* of KID- and CCD-based detectors to more complex Dark Sectors. We propose a thorough exploration of the phenomenology of these models, including a study of the relic abundance of multi-component axion-dark photon DM, as well as its possible observational signatures, which may require dedicated searches[29]. We then aim to take advantage of experiments using both KIDs and CCDs (along with established collider experiments such as CMS) to constrain the global parameter space of these models. Finally, such joint approaches provide an excellent opportunity for cooperation and collaboration between otherwise competing experimental efforts. For example, innovative and complementary cryogenic detection techniques based on Transition Edge Sensors (TES) are currently under discussion with researchers from INMA (Zaragoza) and ICMAB (Barcelona) and may yield new opportunities for both axion and dark photon searches.

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