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Next Generation Search for Axion and ALP Dark Matter with the International Axion Observatory

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I. Introduction

MORE than 80 years after the postulation of dark matter (DM), its nature remains one of the fundamental questions in cosmology. Axions [1] are currently one of the leading candidates for the hypothetical, non-baryonic dark matter that is expected to account for about 25% of the energy density of the Universe. Especially in the light of the Large Hadron Collider at CERN slowly closing in on weakly-interacting massive particle (WIMP) searches, axions and axion-like particles (ALPs [2]) provide a viable alternative approach to solving the dark matter problem.The fact that makes them especially appealing is that they were initially introduced to solve a long-standing problem in quantum chromodynamics (QCD) and the Standard Model of particle physics [3].

Helioscopes [4] are a type of axion experiment searching for axions produced in the core of the Sun via the Primakoff effect [5]. The International Axion Observatory (IAXO [6], [7]) is a next generation axion helioscope aiming at a sensitivity to the axion-photon coupling of 1 - 1.5 orders of magnitude beyond the current most sensitive axion helioscope which is the CERN Axion Solar Telescope (CAST, e.g. Ref. [8]). IAXO will be able to challenge the stringent bounds from supernova SN1987A and test the axion interpretation of anomalous white-dwarf cooling [9]. Beyond standard axions, this new experiment will also be able to search for a large variety of ALPs and other novel excitations at the low-energy frontier of elementary particle physics. BabyIAXO is proposed as a small pilot experiment increasing the sensitivity to axion-photon couplings down to a few 10×11 GeV^{-1} and thus deliver significant physics results while demonstrating the feasibility of the full-scale IAXO experiment. This contribution will introduce the IAXO and BabyIAXO experiments (including their major components), report on the current status of both and outline the expected IAXO science reach.

II. The BabyIAXO and IAXO Experiments

Helioscopes use a strong magnetic field to reconvert solar axions into x-ray photons via the inverse Primakoff effect. Telescopes can be used to focus the putative signal from axions into a small spot on a low-background x-ray detector significantly increasing the experimental sensitivity by allowing for small-area detectors and simultaneous data and background acquisition. BabyIAXO (see Fig. 1, top) has been proposed as a test bench for the IAXO magnet, optics and detectors. This will help to reduce remaining risks of the generally mature technologies and provide the opportunity to implement improvements that might enable IAXO to go beyond its proposed baseline performance (which would then be dubbed IAXO+) while delievering new and relevant physics results pushing further into unexplored, but well-motivated regions of the axion parameter space. To achieve this goal, BabyIAXO will feature a single-bore, 10 m toroidal magnet of an average magnetic field strength of 2.5 Tesla within the bore of diameter 0.6 m. The peak magnetic field is 4.1 T with a stored energy of 27 MJ. A saddle dipole configuration to boost performance is currently as well under study and could possibly replace the toroidal configuration. In any case, the bore dimensions will be similar to those of the full-scale IAXO, however, IAXO is expected to consist of 8 bores, each 20 m in length (Fig 1, bottom). The total stored energy will then be 500 MJ, with average and peak fields similar to BabyIAXO (2.5 T and

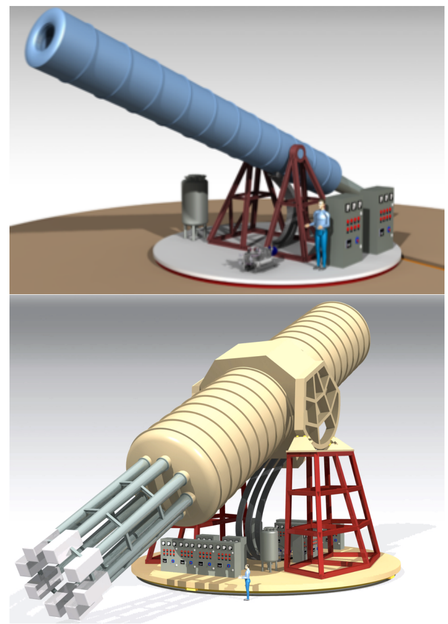

Fig. 1. Schematic experimental setup for BabyIAXO (top) and IAXO (bottom). The main difference is that the intermediate-stage experiment BabyIAXO has only one 10 m long magnet bore, while this will be replaced by 8 coils of 20 m length each for IAXO.

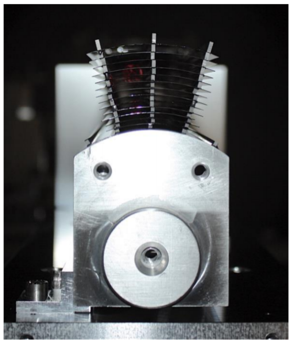

Fig. 2. IAXO segmented-glass pathfinder x-ray optic, based on NuSTAR technology [12].

5.1 T, respectively). Optics and detector for BabyIAXO will be representative of the final IAXO designs. Further details can be found in Ref. [7].

In preparation for IAXO and BabyIAXO, a pathfinder system [10], [11] consisting of a prototype x-ray telescope (XRT, shown in Fig. 2) and a novel low-background Micromegas detector was designed, built, tested and installed at CAST. The XRT is based on the same slumped-glass technology developed for NASAs NuSTAR satellite mission [12] and the pathfinder enabled new benchmark limits on solar axions at CAST [13], while demonstrating that this approach works well for axion physics experiments and is highly suitable for BabyIAXO and IAXO.

III. IAXO Physics Reach

IAXO s primary science driver is the search for solar axions and ALPs emitted via the generic Primakoff effect for which it will improve the sensitivity with respect to CAST by more than 1 order of magnitude in sensitivity to $g_{a\gamma\gamma}$, which corresponds to a factor of more than 10^4 in terms of signal to noise. The experiment will probe a large fraction of QCD axion models in the meV to eV mass band not accessible to any other proposed technique. In addition to exploring viable QCD axion DM models, IAXO will also probe large regions of theoretically-motivated parameter space for the "ALP miracle" models [14] solving both DM and inflation. Furthermore IAXO will also be sensitive to non-hadronic axions, i.e. axions coupling to electrons in addition to photons, and could directly measure the solar axion flux produced via BCA processes (Bremsstrahlung, Compton scattering, and axio-recombination) for the first time with sensitivities to values of g_{ae} relevant to test the hypothesis that the cooling of White Dwarfs is enhanced by axion emission [9]. Beyond this, IAXO can also be sensitive to other, more exotic, proposed particles at the low energy frontier of particle physics, such as hidden photons [15] or chameleons [16], and is able to study the ALP region invoked to solve the transparency anomaly [17]. It is worth noting that all these questions can be addressed independent of whether axions are a subdominant DM component or all of the DM, while the experiment is largely complementary to other axion and ALP search strategies. BabyIAXO could already start shedding light on some of these aspects and improve the state-of-the-art as shown in Fig. 3. Here the best currently available

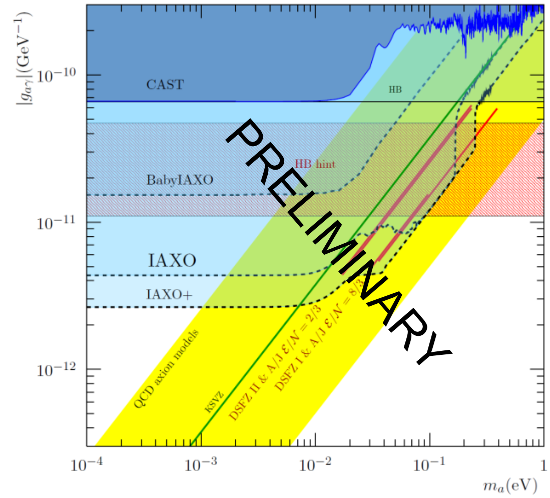

Fig. 3. Exclusion plot with current-best upper limits (CAST [13] on the axion-photon coupling constant $g_{a\gamma\gamma}$ as a function of axion mass together with sensitivity prospects for BabyIAXO, IAXO and IAXO+. The yellow band represents QCD axion models.

upper limits on the axion-photon coupling from CAST are shown as a function of axion mass in comparison with the prospects for BabyIAXO, IAXO and IAXO+.

IV. Conclusion

In this contribution, we present the basic layout of both the IAXO and BabyIAXO experiment and report on the results of our IAXO pathfinder line that includes a telescope and a low-background detector. This setup was successfully tested and aquired data leading to new world-best limits on solar axions. We furthermore outline the sensitivity prospects for IAXO/BabyIAXO to demonstrate their improvements over current-best helioscope experiments. We are currently working towards the technical design report for the BabyIAXO setup and are preparing to build a first set of magnet, x-ray optic and detector to be the key pieces of the BabyIAXO stage towards IAXO.

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