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Editorial: New developments in the quest for discovering axions and axion-like particles

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Editorial on the Research Topic
New developments in the quest for discovering axions and axion-like particles

The axion is a Goldstone particle resulting from a broken global U(1) global symmetry in the theoretical proposal by Roberto Peccei and Helen Quinn. Their theoretical approach cancels the anomalous Charge Parity (CP)-violating term in the Quantum Chromodynamic (QCD) Lagrangian, making QCD CP-conserving. Axions interact with electromagnetism and are proposed as candidates for cold dark matter. They also participate in other phenomena, including contributing to stellar cooling through their emission. In another example, axions or axion-like particles (alps) could explain the mystery of how ultra-high energy gamma rays, emitted from Blazars many mega-parsecs from Earth, survive pair-production extinction in the background radiation during their transit. In a series of publications, Pierre Sikivie formulated the principles governing their interaction with electromagnetism, resulting in many of the search techniques used to date. Yet, after almost 40 years of experimental searches, axion dark matter has eluded detection. The articles presented herein represent advances in experimental techniques intended to increase the sensitivity of axion-photon coupling of several search techniques in different axion-mass regions.

Axion Haloscopes are tuned RF cavities that absorb increased energy when the tuned frequency matches the axion mass; they have been very successful in searching for axion/alp dark matter in the mass range of μeV mass region. More recent cosmological estimates predict that the interesting mass region could be of order 10^2 μeV. Sensitivity in this mass region requires higher frequency waves and smaller resonant cavities. The article "*Development of axion haloscopes for high-mass search at CAPP*" presents new approaches for solving the challenging problem of sensitive higher frequency resonant cavities for moving the dark-matter axion searches to higher mass ranges (Youn et al.).

The article "*GrAHal-CAPP for axion dark matter search with unprecedented sensitivity in the 1–3 μeV mass range*" describes a detector under design by a CNRS-Grenoble -IBS-CAPP Daejeon Collaboration (Pugnat et al.). The device's hybrid magnet has been tested up to 8.5T of the final design 9T field. This haloscope will operate in the light axion-dark matter range but with double-dilution-refrigerator cooling for noise reduction. While this mass range is already being covered by other experiments, this design is predicted to enter a new range of sensitivity in axion-photon coupling. If the design results in an instrument with the intended design sensitivity, it will represent an improved technique for testing the DFSZ axion-model in this mass range.

Haloscopes in general represent a well-established technique for searching for the axion cold dark matter in our corner of the galaxy. While there are a number of haloscopes operating already, the main goal of three of the articles in this Research Topic is to investigate new designs to increase search sensitivities. Traditionally, the cavities are tuned by introducing dielectric rods of various geometries into the tuned cavity. This introduces small distortions in the resonance behaviors. The article "*Split-cavity tuning of a rectangular axion haloscope operating around 8.4 GHz*" presents an innovative design to minimize the negative effects suffered with conventional tuning methods that introduce various geometric shapes of dielectric materials into the cavity (Golm et al.).

The most sensitive experiment to search for axion-photon coupling was the CERN Axion Solar Telescope "CAST," which was a 10-meter 9T magnet that tracked the sun part of the day and searched for axion/alps emitted from the solar core. CAST resulted in the most sensitive limit on axion/alp coupling to photons to date. Many members of the CAST collaboration formed a larger group in proposing the International Axion Observatory (IAXO). The IAXO design has eight, 20 m-long magnet bores, representing a giant investment; accordingly, BabyIAXO, a version with two 10 m magnets to be located at DESY in Hamburg, Germany, was proposed and approved. It is designed to test all IAXO systems and will significantly increase the sensitivity of axion-photon coupling. One of the critical components is the low-background x-ray detector, termed the Micromegas gas-filled time projection chamber, which records the x-rays from solar axions converted to photons in the magnetic field of one of the magnets. The background in the detector would be a serious threat to sensitivity. The article "*Background discrimination with a Micromegas detector prototype and veto system for BabyIAXO*" describes experimental efforts to test the backgrounds in the detectors of the type that will be used in the actual axion searches (Altenmüller et al.).

The application of haloscopes to search for cold dark matter axions has been described in three other articles in this Research Topic. Several developments in sensitivity improvement have been described. It is a fact that the signal of conversion of axions to photons in haloscopes is extremely weak; therefore, electronic noise is the enemy of sensitivity. The standard cryogenic low-noise signal amplifiers, High-Electron-Mobility Transistors (HEMTs), have been the technology most applied to the haloscope axion searches. Their noise level, however, is several orders of magnitude higher than the quantum noise limit. The article "*Josephson Parametric Amplifier-based Quantum Noise Limited Amplifier Development for Axion Search Experiments in CAPP*" presents a comprehensive review of the development and experimental testing of JPAs (Uchaikin et al.). The goal is to produce amplifiers with quantum-limited noise. This would increase the sensitivity of haloscope axion searches by reducing the noise, thereby significantly increasing the sweep-speed. The article gives many details of testing techniques and results.

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