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# DIRECT DETECTION OF DARK MATTER THROUGH MAGNETIC CONVERSION OF AXIONS WITH A HYPER-FREQUENCY DETECTOR

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## Theoretical context

Strong interactions, related to SU(3) symmetry are described by quantum chromodynamics (QCD). The QCD lagrangian density inevitably contains terms that are not CP-invariant, for two reasons. First, weak interactions do not preserve the CP symmetry and that induces a similar effect in QCD through the CKM quark mixing matrix. Second, the topological structure of the QCD vacuum imposes a term that is explicitly CP-odd. Measurements, on the other hand, show that strong interactions and QCD respect CP symmetry to a high level of precision.

It seems that two parameters, seemingly totally unrelated (CP violation in the weak sector and the topology of the SU(3) group) have very specific values, such that their sum vanishes up to the tenth decimal at least. As soon as 1977, a new symmetry —broken at high energy— was introduced to explain this dubious coincidence. In particle physics, to a new symmetry can be associated a new particle. In that case, the new particles associated with this new symmetry is called the axion. The reality of the axion would explain why CP symmetry is conserved in strong interactions. Since its prediction, this particle has been actively searched for, in laboratory experiments, and astrophysical environments. It still evades detection. Axion models are quite predictive, in the sense that the form of its interaction with the classical electromagnetic field is given. The axion would have a two-photon effective vertex, with a coupling strength proportional to its mass. In practical situations, axion searches involve either strong or very extended magnetic fields. The magnetic field provides one of the two photons, while the other photon is the signal that is searched for.

## Observational context

Observations of the universe at all scales, from dwarf galaxies to the Hubble radius indicate the presence of an unknown type of matter, invisible and transparent. This is commonly referred to as dark matter. Not only its nature is unknown, but it is established that it cannot be made of any type of known element or particle, nor any type of assemblage of. The identification of the dark matter is one of the most studied problem in contemporary cosmology and high-energy physics.

In addition to their link with QCD, axions could be the dark matter, partly or in totality. They would be produced through non-thermal mechanisms, during a very early phase of the evolution of the universe. Because of that, and in spite of their small mass, they can be non-relativistic, which is a *sine qua non* condition for dark matter to efficiently lead to structure formation in the universe. In axion models, requiring that they solve simultaneously the strong-CP problem and the dark matter problem leads to narrowing down the possible values for their free parameters. In particular, the axion mass would preferably lie in the range form 10 μeV to 1 meV, and the value of the effective coupling to photons would be more or less fixed. This is a very interesting situation for experimentalists, as these values constitute clear targets. Axion models are at the heart of the most important issues of contemporary physics, and they contain prescription on the numerical values of their own free parameters.

### Experiment and proposed work

From the moment target values in terms of mass and coupling are fixed, one can design specific experiments. At the Particle Physics Department (DPhP) of the CEA, we benefit from funding from the European Research Council (ERC) that allows the building of an experimental setup. We hope that the latter could convert dark matter that is naturally present around us, in the lab, into observable photons. In the absence of a detection, we will publish constraints on axion parameters. These constraints are hard to derive and their publications are always high-impact communications. The experiment involves strong magnets to trigger the conversion of axions into almost monochromatic radio waves. The frequency of these waves depends on the mass of the axion, and could range between 2 GHz and 200 GHz. In a first phase, the magnets will be permanent magnets, operated at 4K. Then in a second phase we will use high-critical-temperature superconducting magnets at 4 K. This axion converter will face a radiometer, which role is to detect the axion signal, whose spectral signature is known. The whole setup will be placed in a 5 m-long, 2m-diameter cryostat, cooled down by the mean of liquid helium. The setup is currently being built in a CEA experimental hall, a few steps away from the Particle Physics Department building.

The PhD student will join the DPhP team. The project involve a dozen full-time equivalent, physicists, engineers, and technicians from the DPhP, the Department of Electronics, Detectors, Instrumentation for Physics, the Department of Accelerators, Cryogenics and Magnetism, and the Department of System Engineering. The proposed work is experimental. The first part will consist in the characterization of the radiometer, comprising a horn antenna, a series of low-noise amplifiers and a spectrum analyzer. The primary objective is to accurately estimate the sensitivity of the final apparatus to an axion signal, and compute the level of constraints one can set in the absence of a signal. The work will include some hardware, with the set up of cryogenic test benches, data taking, signal processing and data analysis. The second part of the job will be related to the data obtained with the full experiment, both in phase 1 and phase 2. The setup will be built within the first years of the PhD work so the candidate will participate to the full experiment, first with permanent magnets and then with high-critical-temperature superconducting magnets.

This project is a unique opportunity to participate in an experiment that is completely designed and built in Saclay, with the whole team on site. It offers the possibility to comprehend a physics experiment from A to Z. This goes from the building to the physics papers, going through all steps of testing, calibration, data taking, data analyses and publication of the results.

### Education and required skills

A master 2 degree in particle physics, astrophysics, theoretical physics or instrumentation is a prerequisite. Many skills are important to participate in the project: general knowledge in physics, instrumentation, programming and data analysis. The candidate must have a particular interest for experimental physics, and has to be motivated in addressing physics problems in many different fields. Indeed our project requires to deal with telecommunication techniques, signal processing, magnetism, particle physics, cosmology, data analysis and specific statistical methods.

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