Quantum Sensing of Axion Dark Matter with a Phase Resolved Haloscope

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Abstract : There is a general consensus that only a small fraction of the matter and energy in the universe has been detected (about 5%), the rest being dark matter (about 27%) and dark energy (about 68%)[1]. Elucidating the nature and properties of such objects is one of the greatest challenges in physics. In general, dark matter is thought to consist of particles that « floods » galactic halos- and hence the Milky Way. Therefore, in principle it can be detected in laboratory experiments. One of the most promising candidates is the axion particle, originally proposed by Peccei and Quinn to address the strong CP (charge-parity) problem [2].

In 1983, Pierre Sikivie proposed the use of a microwave cavity to detect this field. Such a device is called by the community a « haloscope » [3]. The main difficulty of these experiments, besides the smallness of the signal, is the very low tunability of microwave resonances. All the experiments performed so far cover only a bandwidth of 100 MHz, while the frequency/mass range expected by the QCD ranges from 0.1 GHz to 100 GHz.

The main idea of the DETOX project is to build a new type of tunable haloscope combining a B-resilient GrAl circuit and a magnetic material (GdVO4 specifically) in a 3D microwave cavity. Our goal is to hybridize the magnons and the photons in the ultrastrong coupling regime to perform the quantum sensing of axions for a wide range of frequencies in a single run. The amplification of the potential axion signals will be implemented in-situ down to the standard quantum limit (SQL) using the anharmonicity of the superconducting quantum bit [4].

Our phase resolved haloscope is based on the Ramsey interferometry [5] : a fake axion signal (« faxion ») is simulated with additional weak power and interferes with the cavity photons. We then have a strong modulation of the Ramsey fringes, which evades the SQL. We demonstrate a sensitivity of 10^{-5} photon with an integration time of 400 ms.

References

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Figures

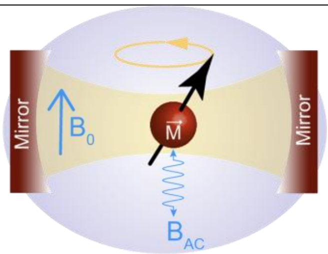

Figure 1: Principle of the DETOX experiment