Contraints On Bosonic Dark Matter From Ultralow-Field Nuclear Magnetic Resonance (CASPEr)

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The nature of dark matter, the invisible substance that makes up over $4/5$ of the matter in the universe, is one of the most intriguing mysteries of modern physics. Elucidating the nature of dark matter would profoundly impact our understanding of cosmology and particle physics, providing key insights into physics beyond the Standard Model.

Recent theories of couplings between dark matter and nuclear spins have opened the possibility of directly detecting axion, axion-like and dark-photon dark matter via NMR spectroscopy [1]: as nuclear spins move through the galactic dark-matter halo, the spins couple to dark-matter particles and behave as if they were in an oscillating magnetic field, potentially generating a dark-matter-driven NMR signal. The Cosmic Axion Spin Precession Experiment (CASPEr) is multi-faceted NMR search for such particles [2]. Here, we will review a CASPEr experiment based on zero- to ultralow-field NMR (ZULF NMR).

We first review the physical principles enabling the detection of dark-matter via ZULF NMR and introduce the off-resonance-based measurement scheme used for such detection [4]. We expect dark-matter particles to induce modulation of the J-coupling energy levels of the NMR sample. Axions and dark-photons could then be detected by searching for frequency-modulation induced sidebands in the well-defined ZULF NMR spectrum of labelled formic acid.

We then describe the current ZULF NMR apparatus and present an exotic data processing scheme, which enables the possibility to perform coherent averaging of transient NMR signals induced by sources of unknown frequencies such as dark matter. Finally, we present our latest results on ultralight-axion dark-matter acquired through this search.

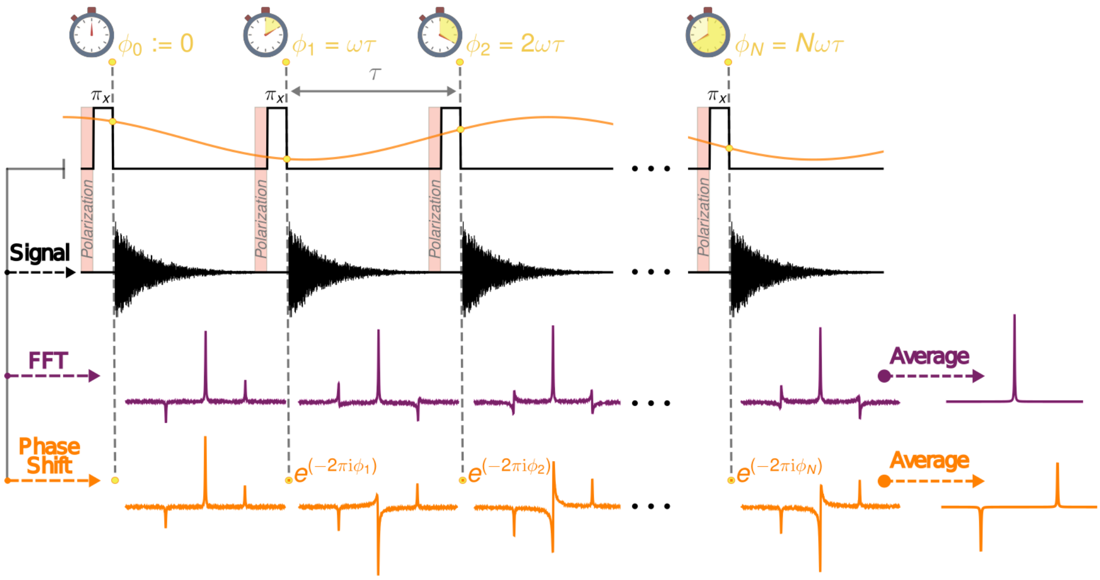

Figure 1: Data acquisition and processing scheme: post-processing phase-locking. The transient signals are acquired after applying a DC magnetic π-pulse on the NMR sample. As the phase of dark-matter-induced sidebands is unknown, the transient FFTs cannot be averaged. Applying a global phase shift to each transient FFTs enables recovery of the wanted signal, here sidebands around the J-coupling resonance line.

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