The ORGAN Experiment: First Results and Future Plans

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We discuss the Oscillating Resonant Group AxioN (ORGAN) experiment, a high mass axion haloscope hosted at the University of Western Australia (UWA). The path-finding experiment placed limits in a narrow frequency range around 26 GHz, and the future searches, which will be enabled by novel resonator designs based on dielectric structures, will focus on wider mass ranges with increased sensitivity. The next stage of the experiment will scan from 26-27 GHz, whilst the subsequent searches will focus on the 15-50 GHz range.

1 Introduction

Several haloscope searches for dark matter axions are already underway [1, 2, 3], and all focus on axion mass ranges up to a few GHz (corresponding to masses up to a few 10s of $\mu$eV). Despite this, there is mounting motivation for higher mass axion searches. Claimed results from Josephson junctions [5], and the exciting SMASH result [4] both point to axions in the mass range 50 - 200 $\mu$eV, which corresponds to 12.5-50 GHz in photon frequency for a haloscope.

In order to test these results a collaboration of research groups from the ARC Centre of Excellence for Engineered Quantum Systems (EQnS), hosted at UWA is building a multi-stage haloscope designed to operate over the next seven years. The path-finding run of the experiment is complete, and limits axions in a very narrow range.

The second phase of the experiment, scheduled to commence in 2018 will search the entire mass range of the claimed Josephson junction results, corresponding to 26-27 GHz. After this is complete, the experiment will focus on 5 GHz windows beginning at 15 GHz and finishing at 50 GHz, in order to cover the range suggested by the SMASH result that will not be accessed by other haloscopes.

In order to achieve sensitive searches in these high mass ranges novel resonator design is critical. We have developed and prototyped dielectric loaded resonant cavities optimised for axion detection, based on both the well known Bragg effect and a new effect designed to maximize the axion haloscope form factor by suppressing out of phase field components.
Figure 1: Left: the 90% confidence exclusion limits from the pathfinder experiment as discussed in the text. Right: the projected limits for Stage-I of ORGAN, the targeted search of the Beck Result. On both plots CAST limits are shown in orange, whilst KSVZ and DFSZ model bands are in yellow and blue respectively.

2 Path-finding Result

The path-finding experiment was conducted in December 2016. A stationary frequency (untuned) copper resonant cavity was embedded in a 7 T static magnetic at 4 K for 4 days of continuous measurement. The cavity employed a TM_{020} mode with a central frequency of 26.531 GHz, and a cryogenic loaded quality factor of \( \sim 13,000 \). The cavity was critically coupled to a cryogenic HEMT-based amplifier provided by Low Noise Factory. The primary purpose of this experiment was to familiarize ourselves with the necessary components of a haloscope, to verify that our cryogenic system was capable of sustained high field, 4 K operation, and to gain experience with the data acquisition and processing required. As a consequence of running the entire experiment simultaneously we are able to place narrow exclusion limits on axions as presented in fig 1.

3 Future Searches

The future searches of the ORGAN Experiment are broken down into two broad phases, Stage-I and Stage-II. Stage-I, currently planned for 2018, will see a magnetic field upgrade from 7 to 14 T, with two small cavities at 30 mK amplified via traditional HEMT amplification at 4 K. The resonant structures to be employed are discussed briefly below. The search will focus on the 26-27 GHz range, in order to provide a direct test of the claimed Beck result [5]. Stage-II of the experiment is current scheduled to commence in 2019 and run for 6 years. This search will be broken down into a number of 5 GHz search regions, beginning at 15 GHz and concluding at 50 GHz. The multi-staged nature of this search will allow for continued research and development of new resonators and amplifiers. It is the goal of the collaboration to install quantum-limited amplification at the beginning of Stage-II in the 15-20 GHz search range, and develop new amplifiers as the search continues, with the ultimate goal of synchronizing more cavities, further upgrading the magnetic field, and achieving sub-quantum limited amplification via squeezed states or some other technology. The projected limits for the future of ORGAN are shown in fig 2. For more detail see [6].
4 Dielectric Resonators

The resonators to be employed in Stage-I and II of the ORGAN Experiment are based on a dielectric structure. The design involves careful placement of one or several dielectric rings in a location to capture and suppress the out of phase field contributions of a $TM_{0n0}$ mode electromagnetic field to the axion haloscope form factor, thus maximizing sensitivity. Such a resonator can be tuned very rapidly with minimal position displacement via the usage of a supermode tuning mechanism. These types of resonators are most applicable to $TM_{0n0}$ modes where $n$ is an odd number greater than 1. The resonators for the ORGAN experiment will be based on $TM_{030}$ and $TM_{050}$ modes with carefully placed rings and supermode tuning. Further details of these resonators can be found in [7], and an electric field diagram of a $TM_{030}$ mode with such a carefully placed dielectric ring is shown in fig 3. In this set-up, the ring is split and separated, enabling the supermode tuning as discussed. In this way, tuning of a few GHz is possible with small (order of mm) position displacements.
Higher Frequency Anti-Symmetric Supermode

Lower Frequency Symmetric Supermode

Figure 3: $E_z$ field for a TM$_{031}$-like mode (top) and a TM$_{030}$-like mode (bottom). A dielectric ring is placed to suppress the out of phase field, and as the ring is split the frequency of the TM$_{030}$-like mode tunes upwards towards the TM$_{031}$-like mode.

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