# Broadening Frequency Range of a Ferromagnetic Axion Haloscope with Strongly Coupled Cavity-Magnon Polaritons THE UNIVERSITY OF **Graeme Flower**

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## Introduction

#### What is a Ferromagnetic Haloscope?

A ferromagnetic axion haloscope detects dark matter axions from the galactic halo through their coupling to electrons. The dark matter wind is expected to induce a magnetization in a ferromagnetic ensemble. This is typically measured by coupling a ferromagnetic resonance with a microwave cavity resonance forming the hybrid cavity-magnon polariton system.

#### How does it detect the Axion Wind?

An analogy can be made between the interaction of the axion field and electrons, and a magnetic field and electrons. The driving field is thus typically expressed as

## **Experimental Setup**

Our ferromagnetic axion haloscope consisted a 2mm sphere of Yttrium Iron Garnet (YIG, a ferrimagnet) which is place inside a two post re-entrant cavity. This is cooled cryogenically and readout with a low noise amplifiers to an FFT.





#### an oscillating pseudo-magnetic field in the direction of the axion wind. [2, 3]





Grad of oscillating axion field (axion wind)

Figure 1: The Dark matter axion wind produced as the earth moves around the galaxy

# Main Objectives

- 1. To build a robust model for the photon/magnon/axion system.
- 2. To investigate how this system behaves in the dispersive regime
- 3. To implement a tunable haloscope.
- 4. To detect the axion dark matter wind!

# **The Model**

We construct a Hamiltonian for the ferromagnetic haloscope. This contains cavity and magnon terms as coupled bosonic modes as well as the axion interaction which drives the magnon mode. Note magnon frequency is set by applying a DC magnetic field and the axion-magnon driving term depends on the direction of the axion wind relative to this DC field making it a directional detector.

Figure 4: Left: Two post re-entrant cavity with YIG sphere. Right: Experimental setup

# Results

No signals were found to be significant over background noise. An exclusion limit is set on the axion-electron coupling parameter of  $g_{aee} > 3.7 \times 10^9$  in the range  $33.79 \mu eV < m_a < 33.94 \mu eV$  with 95% confidence. Note axion mass  $(m_a)$  can be converted to signal frequency  $(f_a)$  by  $f_a \approx m_a \frac{c^2}{h}$ , where c is the speed of light and h is planck's constant.





Figure 2: Hamiltonian model used with each term described.

## **Searching in the Dispersive Regime**

Past efforts have focussed on the fully hybridized regime [4], when cavity and magnon frequencies are the same. However, operating in the dispersive regime, when cavity and magnon frequencies are different, allows for a larger range of searchable frequencies and thus axion masses. The potential range of operation of our experiment is calculated to be in bands:  $4.1\mu$ eV centred around  $34.1\mu$ eV and  $6.6\mu$ eV centred around  $41.4\mu$ eV. Signal power from the detector can also be optimised in this regime.

**Figure 5:** The DFZS axion model band and exclusion plot for axion-electron coupling strength  $q_{aee}$  as a function of axion mass: limits due to white dwarf cooling are in light blue, this work limits are in dark blue, dashed lines show several predictions for the future work.

## **Improvements and Future work**

Existing Amplifiers (Improved sample): Larger ferrimagnetic samples with more spins and lower loss are readily available and would improve signal power. Standard Quantum Limited (SQL) Amplifiers: Minimizing the back-action on the system with SQL amplifiers would allow small signals to be more easily resolved

Quantum non-demolition (QND) measurements: To avoid back-action entirely. Single photon counters, ideally QND ones, can be shot noise limited, greatly improving the experiments viability.

Optimistic QND measurements: QND measurement combined with significant improvements in signal power are required to detect QCD axions. This demonstrates the need for both improved readout and future research into improving signal power.

# Conclusions

• Ferromagnetic Haloscopes detect the axion dark matter wind produced as the earth moves through the dark matter halo.



Figure 3: Signal power from the detector at one of the hybrid mode frequencies plotted against magnon detuning from cavity frequnecy normalised to cavity-magnon coupling strength for vairous cavity and magnon losses

- We have build a robust Hamiltonian model for this experiment which fully describes a ferromagnetic haloscope
- Operating in the dispersive regime allows a wide range of accessible frequencies to be searched and can better optimise for signal power.
- Our experiment sets laboratory limits on axion to electron coupling strength in our mass regime.

## References

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- [4] N. Crescini, et al. Operation of a ferromagnetic axion haloscope at  $m_a = 58 \mu \text{ev}$ . The European Physical Journal C, 78(9):703, Sep 2018.