Dark Matter Search with ADMX

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Exploring the Dark Universe
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Overview

- Motivation for axions as cold dark matter
- The Axion Dark Matter eXperiment (ADMX)
- Preliminary Sensitivity
- Moving to higher masses
Why Axions?

- Original motivation: axions are a result of the symmetry proposed by Peccei and Quinn to solve the Strong CP problem.
- They satisfy the basic properties of “standard” cold dark matter:
  - Weakly interacting with normal matter
  - Gravitational interactions
  - Long-lived
  - Cold
- Axions are an ideal dark-matter candidate.
Where to Look for Axions: Coupling

- Primakoff conversion

- Axion coupling to photons is via a fermionic loop

- In the KSVZ model axions couple only to quarks

- In the DFSZ model axions couple to both quarks and charged leptons
Where to Look for Axions: Mass

- Lower bound at 1 \( \mu \text{eV} \) from CDM constraints
- Upper bound at 1 meV from SN1987A
- Theoretical predictions of the dark-matter axion mass tend to fall in the 1-100 \( \mu \text{eV} \) mass range
- This provides a “sweet spot” for performing a dark-matter axion search

Recent predictions of axion mass for 100% axion dark matter. In some cases, lower bounds.
The ADMX Generation-2 (G2) program will cover the most likely parameter space for cold dark matter.

Sensitivity will reach the DFSZ bound between 2 and 41 $\mu$eV.
ADMX is an Axion Haloscope

- ADMX is an ultra-sensitive microwave detector, capable of measuring $10^{-23}$ W signals
- Axions continuously convert to microwave photons (GHz)
- We measure the amount of power in the cavity in a small frequency band

\[
\text{SNR} \propto \frac{P_{\text{sig}} \sqrt{t}}{T}
\]
\[
P_{\text{sig}} \propto B^2 V
\]
The ADMX Detector

Field cancellation coil
SQUID amplifier package
Dilution refrigerator
Antennas
8-Tesla solenoid magnet
Microwave cavity
Cryogenics

- Cavity and electronics are cooled with a dilution refrigerator to minimize system noise

![Cryogenic equipment](image)

**ADMX G2 Temperature**

- **Design requirement:** 150 mK

Preliminary
Quantum-Limited Amplifiers

- Quantum mechanics forces a linear amplifier to contribute at least half a photon per resolution bandwidth to the system noise.

- We have amplifiers that operate near that limit.

Gain = 20 dB

At $T_{\text{bath}} = 50 \text{ mK}$
Noise temperature: $T_{N,\text{opt}} = 48 \pm 5 \text{ mK}$

Quantum limit $T_Q = 30 \text{ mK}$

Clarke Group, UC Berkeley
Quantum-Limited Amplifiers

Figures from 2nd Workshop of Microwave Cavities and Detectors for Axion Research
Determining the System Noise

- Need to understand the system noise temperature to accurately assess sensitivity
- Perform a Y-factor measurement using two known physical temperatures
- System noise determined to be ~0.5K
Synthetic Axion Injection

- We can inject synthetic axions through a weakly-coupled port
- Can run in blinded mode where operators are unaware of injections
- Unblinded mode is used for signal verification and calibration

![Graph showing raw data with a peak labeled as Expected axion signal x100.](image-url)
Operating ADMX

Live analysis

- Cavity frequency scanned until a desired signal-to-noise level is reached
- Regions with power above trigger threshold are flagged as potential candidates
  - Could be statistical anomalies, external RF leakage, synthetic injected axions, or real detected axions
- Candidates are rescanned to see if they persist
- For persistent candidates, perform confirmation tests:
  - Switch to resonant mode that doesn’t couple to axions
  - Turn B field down (axion power scales as \( B^2 \))

Offline analysis

- Vary bin size to look for higher-frequency structure
- High resolution analysis looks for ultra-sharp lines
Current Status

- Pursuing first measurement down to DFSZ sensitivity

- Science data taken from January-June 2017

- Data is being analyzed

- The insert is being refit for a new frequency range

- Will complete up to 1 GHz over the next year

![Graph showing Axion Coupling vs. Axion Mass and Cavity Frequency](attachment:image.png)
First Axion Search at DFSZ Sensitivity

Axion Mass (μeV)

KSVZ

DFSZ

ADMX 2004

ADMX G2 May 2017
90% Sensitivity Estimate

PRELIMINARY
Moving to Higher Frequencies

- Goal: search for axions with higher masses → higher frequencies

- As we increase frequency
  - Expected axion coupling increases
  - Cavity volume decreases → lower signal
  - Cavity Q decreases → lower signal
  - Quantum limit increases → higher noise

- Use multiple cavities with signals added coherently
Current Single-Cavity System

Frequency range: 500 MHz – 1 GHz
Operating at DFSZ sensitivity now!
Data-taking for the 5-7 GHz range is complete

Prototype for using piezoelectric controls, and data-taking at higher frequencies
1-2 GHz: Four-Cavity Array

Frequency range: 1-2 GHz

Prototype being fabricated now
2+ GHz: Cavity Arrays and Other Designs

| Cavity Frequency (GHz) | Axion Coupling $|g_{\text{array}}|$ (GeV$^{-1}$) |
|------------------------|---------------------------------------------|
| 1                      | $10^{-9}$                                   |
| 10                     | $10^{-10}$                                  |
| DFSZ                   | $10^{-12}$                                  |
| ADMX G2                | $10^{-14}$                                  |

Axion Mass $\mu$eV

Cylindrical cavities from 2-6 GHz

Other resonator designs for 6-10 GHz
Beyond ADMX G2: 10+ GHz

Periodic Dielectric Resonator

Superconducting Qubit Detector
Summary

- Axions solve the Strong-CP problem and are a compelling dark-matter candidate
- ADMX will search for axions between 500 MHz and 10 GHz
- We took science data from January to June 2017
- First experiment to reach sensitivity for DFSZ axions, and final results are coming soon
- Higher-frequency systems will follow for 1+ GHz
The ADMX Collaboration

University of Washington

University of Florida

Lawrence Livermore National Laboratory

Fermilab

University of California, Berkeley

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