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Dark Matter Search with ADMX

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Exploring the Dark Universe

XIIIth Rencontres du Vietnam

July 28, 2017, Quy Nhon, Vietnam

U.S. DEPARTMENT OF
ENERGY

ADMX
AXION DARK MATTER EXPERIMENT

Overview

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

Why Axions?

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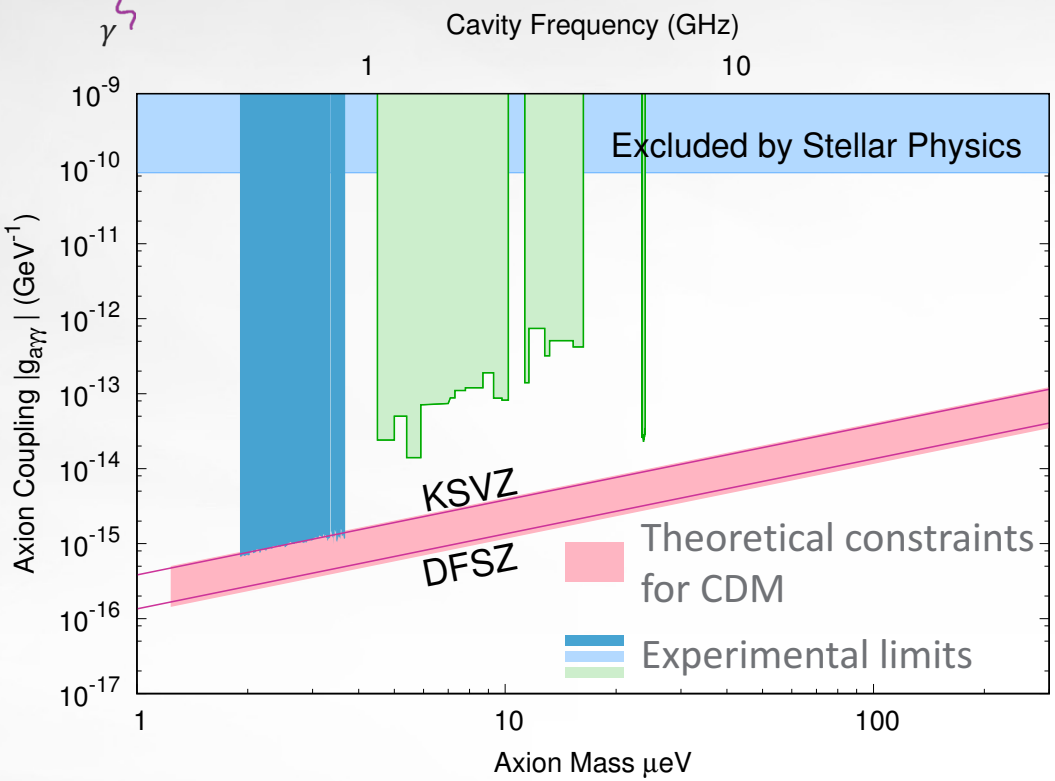
- Original motivation: axions are a result of the symmetry proposed by Peccei and Quinn to solve the Strong CP problem
- They satisfy the basic properties of “standard” cold dark matter
  - Weakly interacting with normal matter
  - Gravitational interactions
  - Long-lived
  - Cold
- Axions are an ideal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

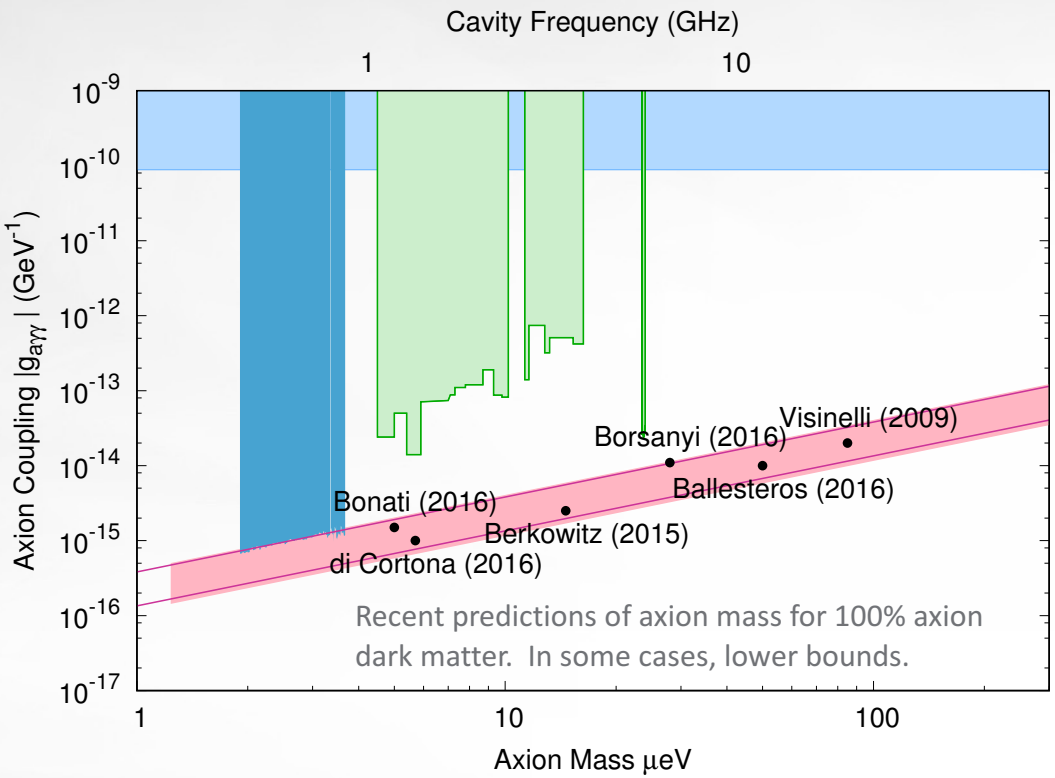
Where to Look for Axions: Coupling

- 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 μeV 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 μeV mass range
- This provides a "sweet spot" for performing a dark-matter axion search



ADMX G2 Program

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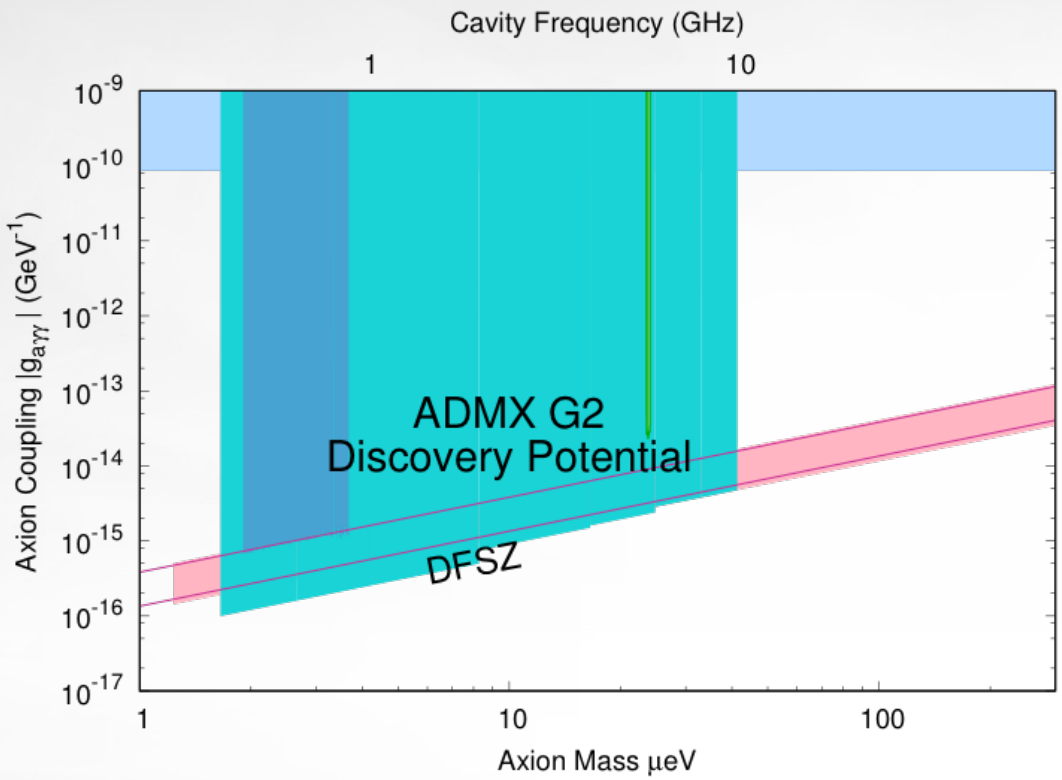
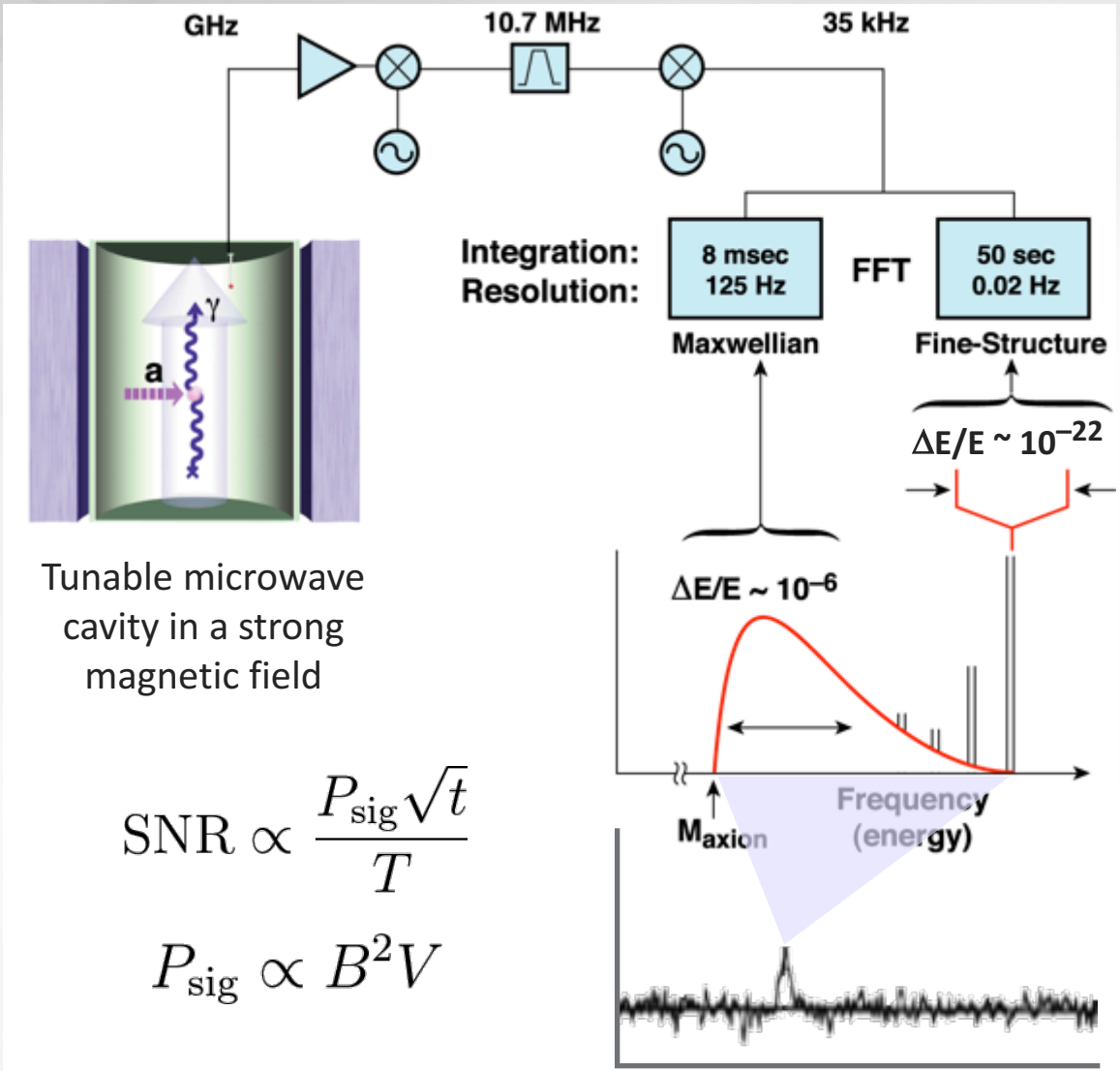
- The ADMX Generation-2 (G2) program will cover the most likely parameter space for cold dark matter
- Sensitivity will reach the DFSZ bound between 2 and 41 μeV



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



$$\mathrm{SNR} \propto \frac{P_{\mathrm{sig}}\sqrt{t}}{T}$$

$$P_{\mathrm{sig}} \propto B^2 V$$

The ADMX Detector

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Field cancellation coil

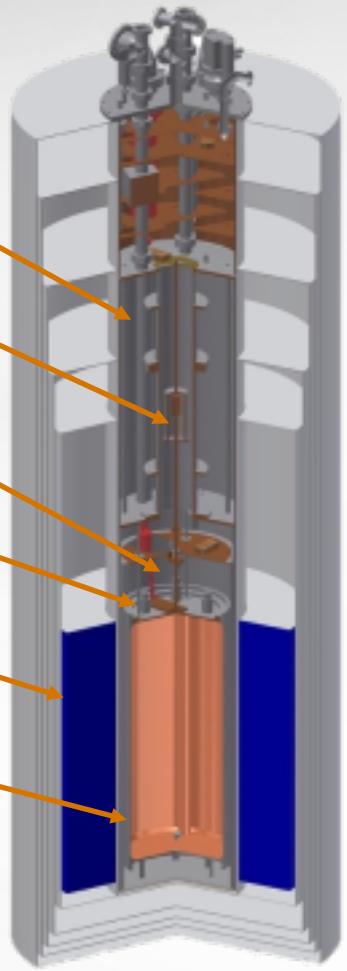
SQUID amplifier package

Dilution refrigerator

Antennas

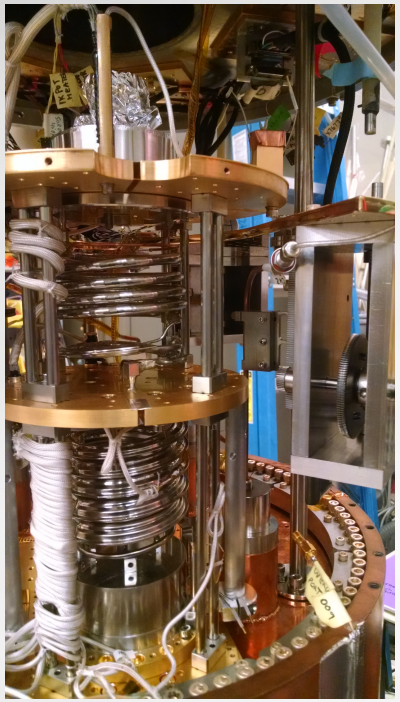
8-Tesla solenoid magnet

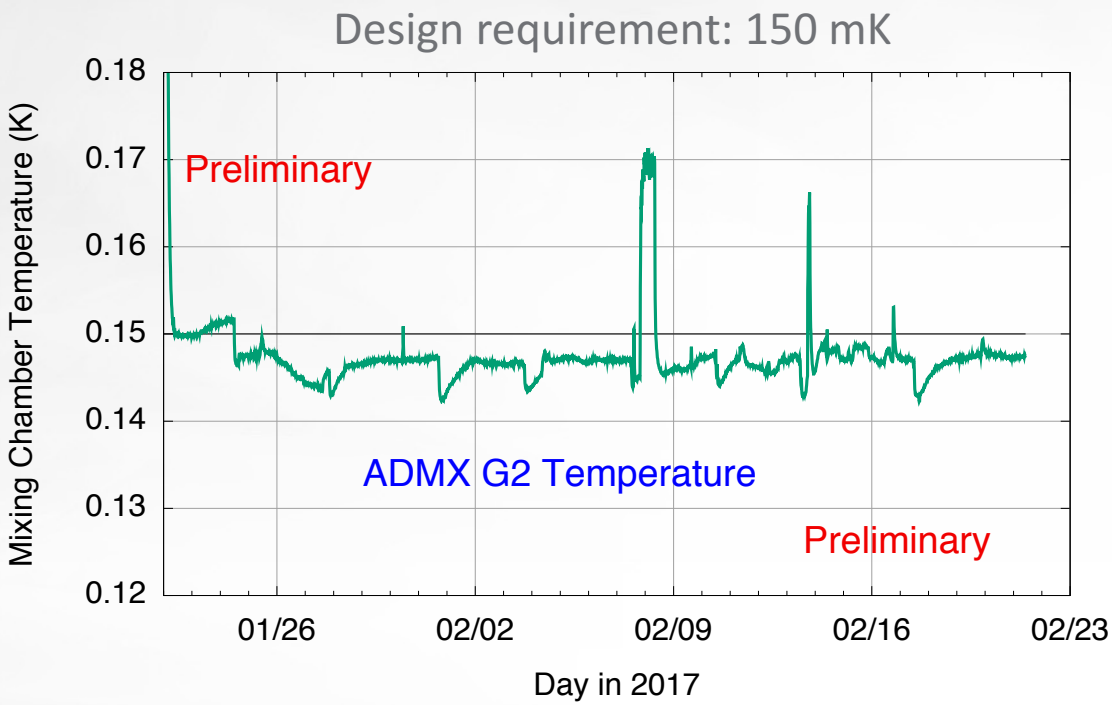
Microwave cavity



Cryogenics

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





Quantum-Limited Amplifiers

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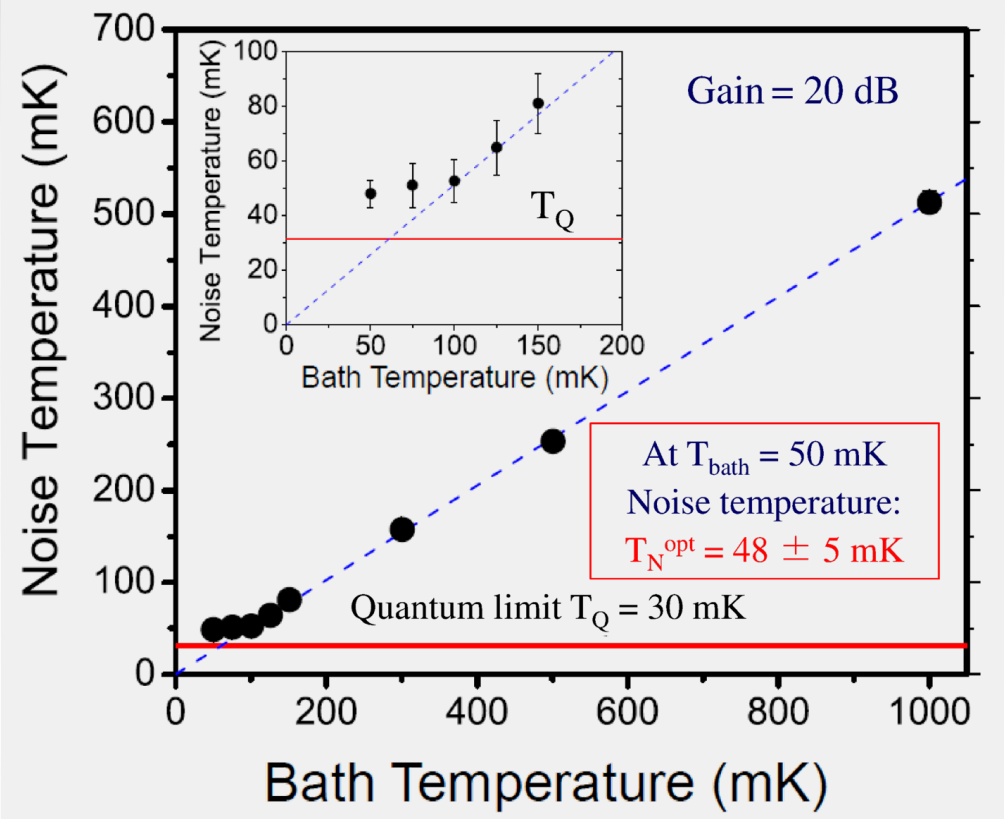
- Quantum mechanics forces a linear amplifier to contribute at least half a photon per resolution bandwidth to the system noise
- We have amplifiers that operate near that limit



Clarke Group, UC Berkeley

Quantum-Limited Amplifiers

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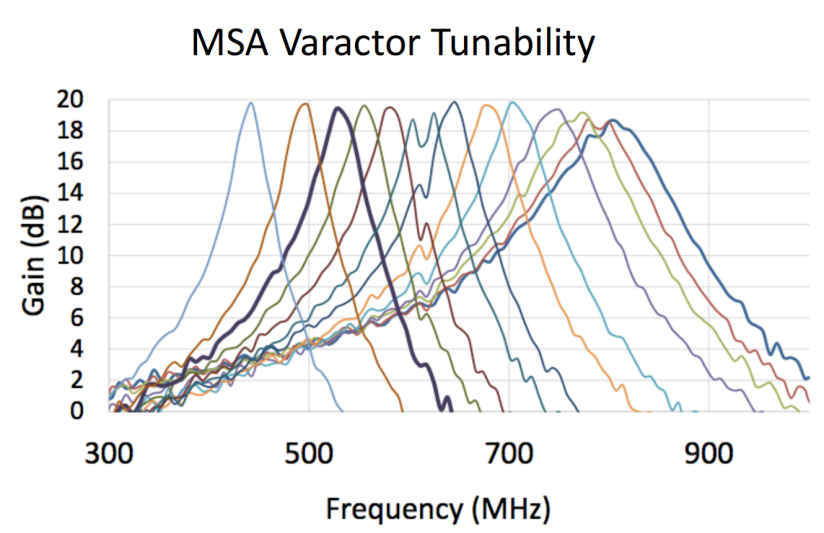
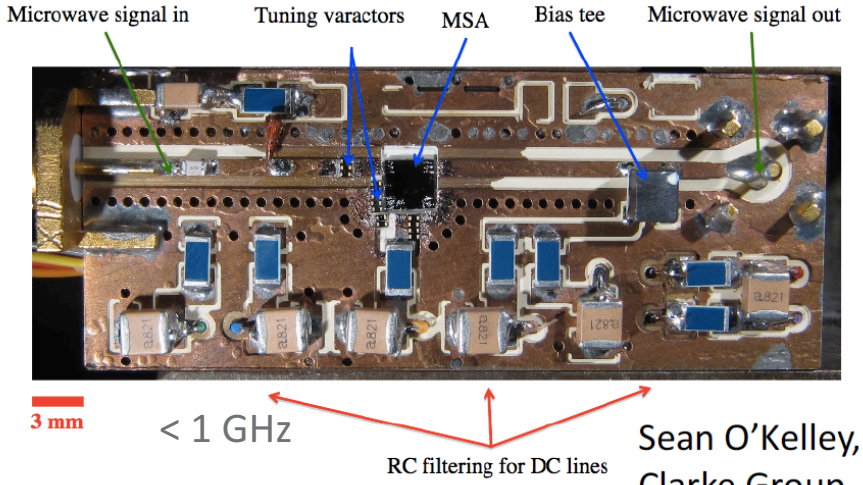


ADMX Tunable MSA



< 1 GHz

Sean O'Kelley, Clarke Group, UC Berkeley

ADMX JPA

> 1 GHz

Yanjie Qiu, Siddiqi Group, UC Berkeley

Figures from 2nd Workshop of Microwave Cavities and Detectors for Axion Research

Determining the System Noise

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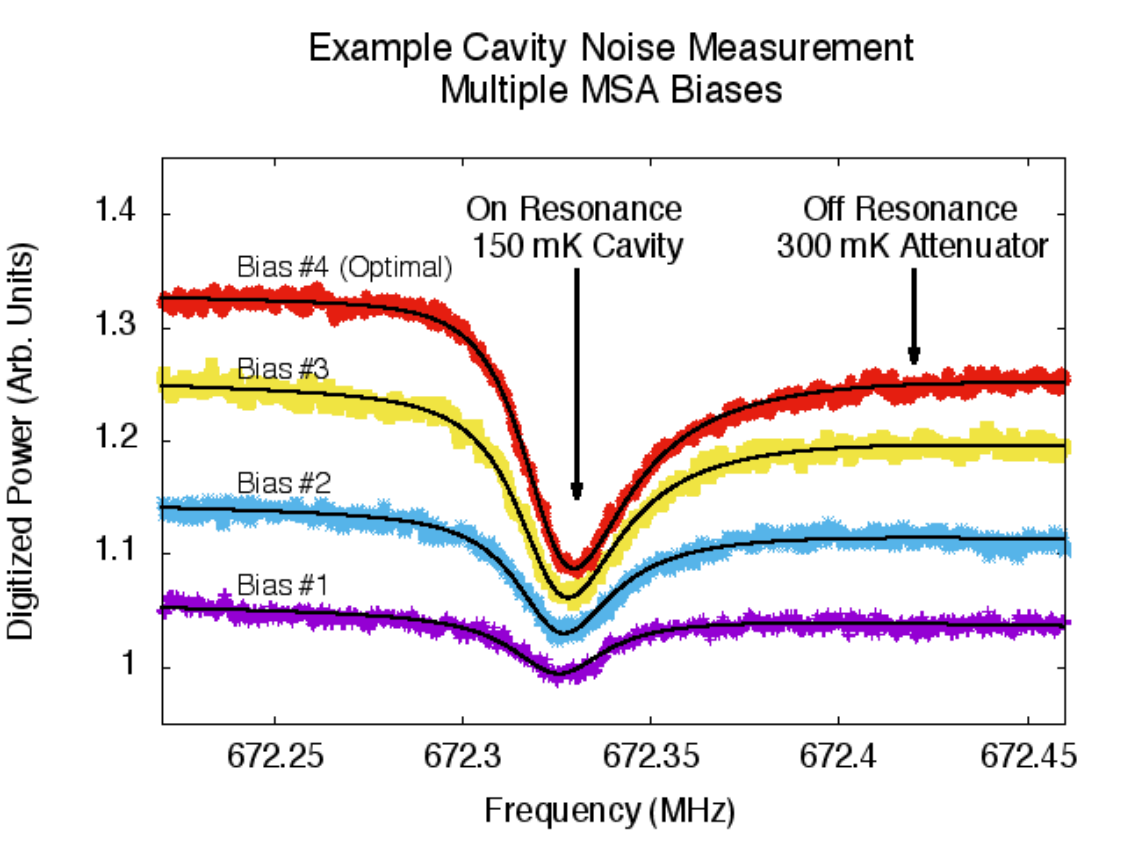
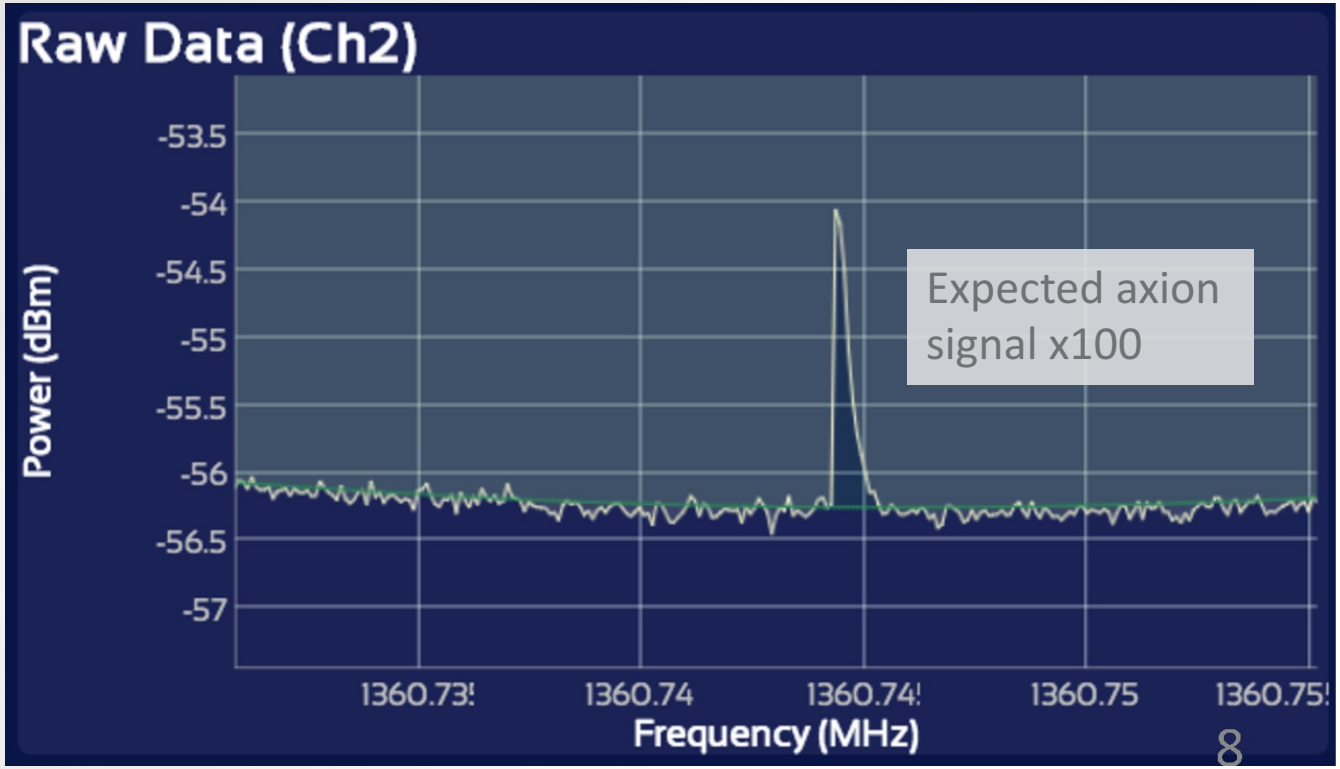
- Need to understand the system noise temperature to accurately assess sensitivity
- Perform a Y-factor measurement using two known physical temperatures
- System noise determined to be ~0.5K



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



Operating ADMX

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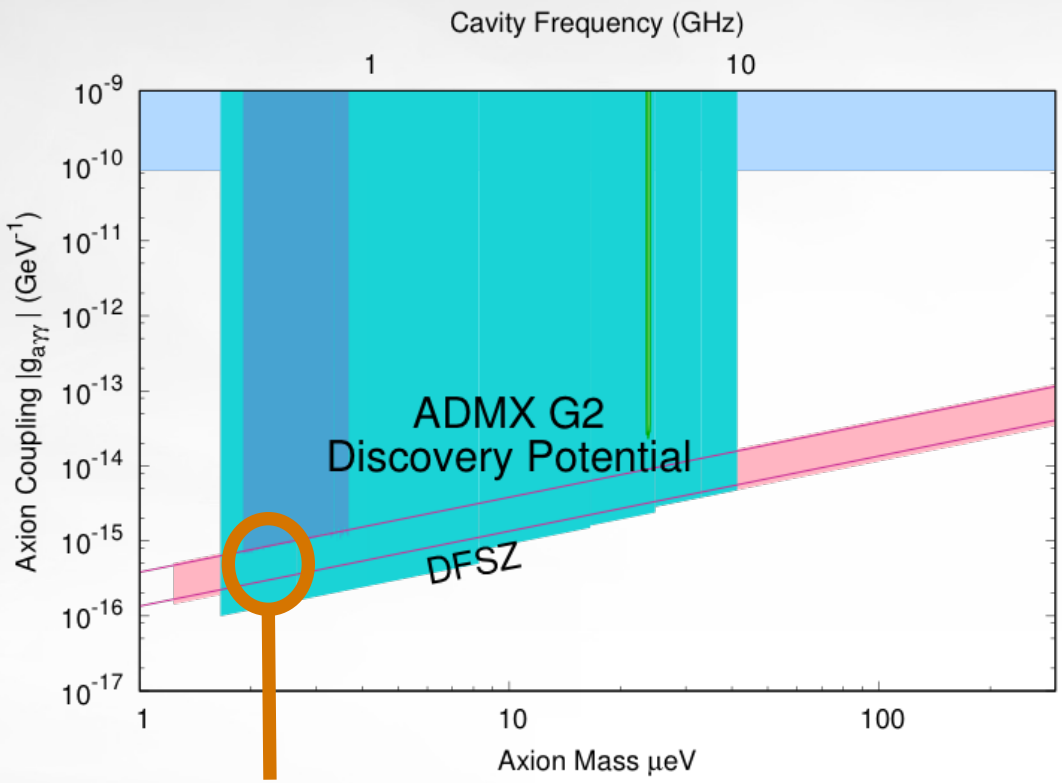
- Live analysis
  - Cavity frequency scanned until a desired signal-to-noise level is reached
  - Regions with power above trigger threshold are flagged as potential candidates
    - Could be statistical anomalies, external RF leakage, synthetic injected axions, or real detected axions
  - Candidates 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

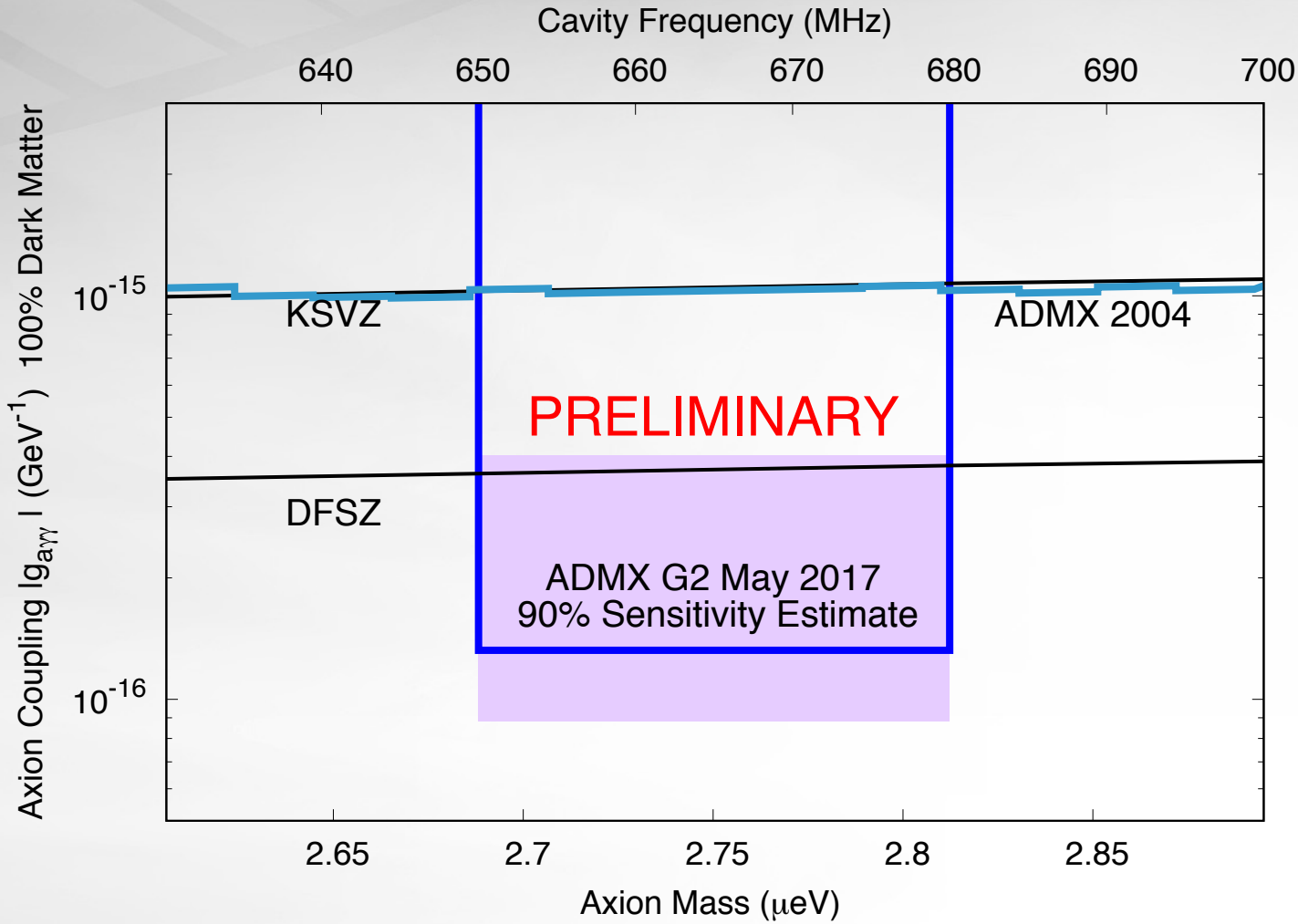
Current Status

- 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



Spring 2017 ADMX G2 Operations

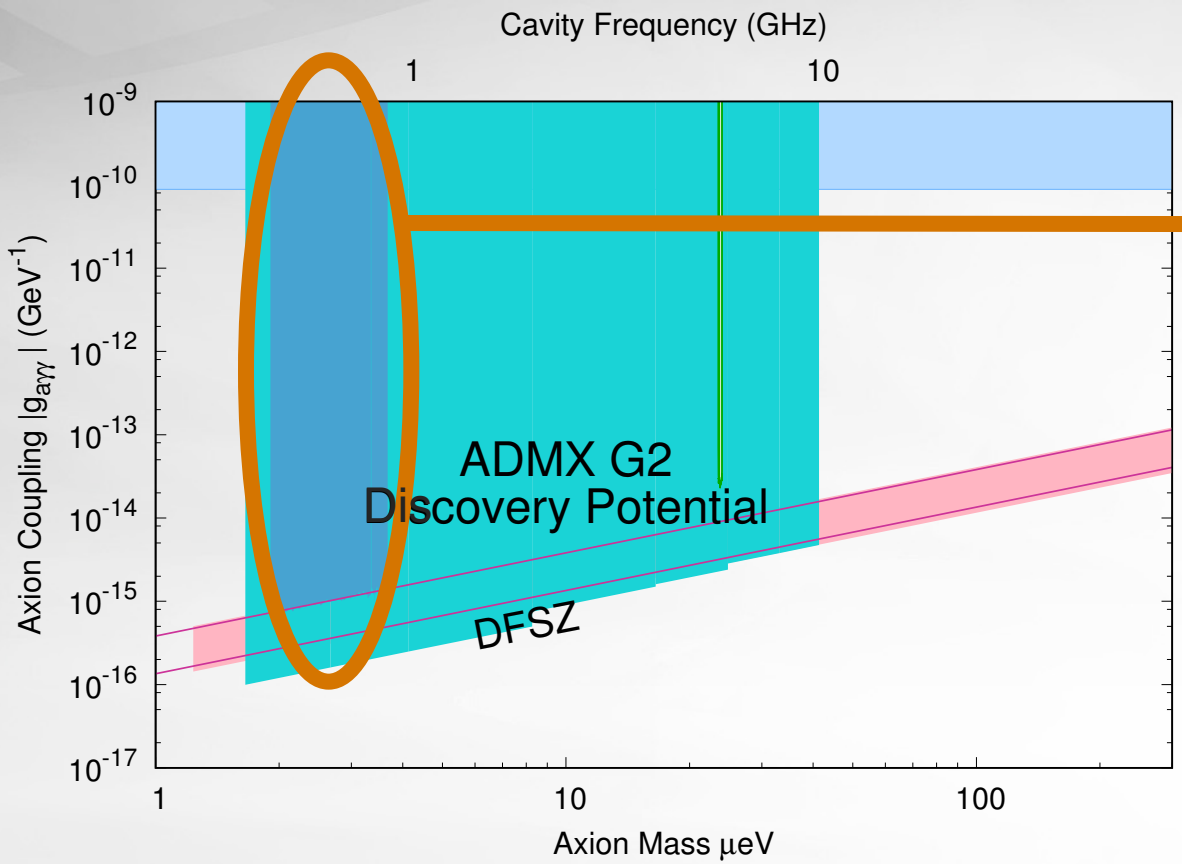
First Axion Search at DFSZ Sensitivity

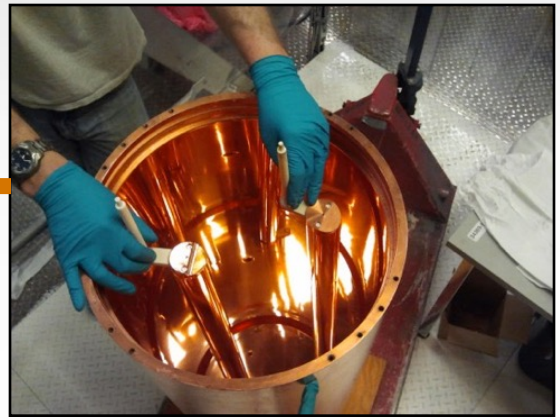


Moving to Higher Frequencies

- 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

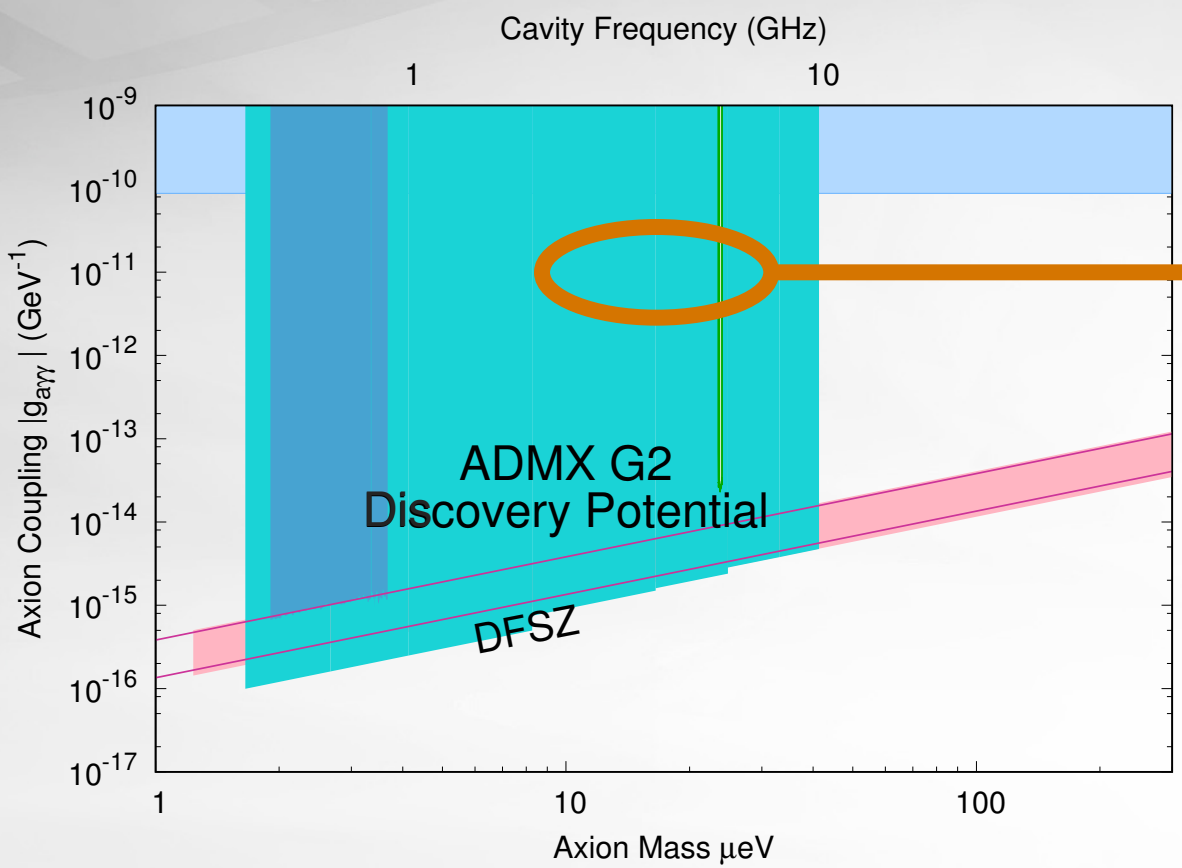


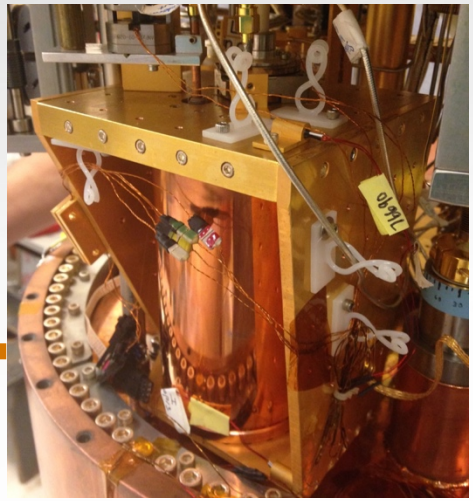


Frequency range:
500 MHz – 1 GHz

Operating at DFSZ sensitivity now!

Prototype for Higher Frequency Systems

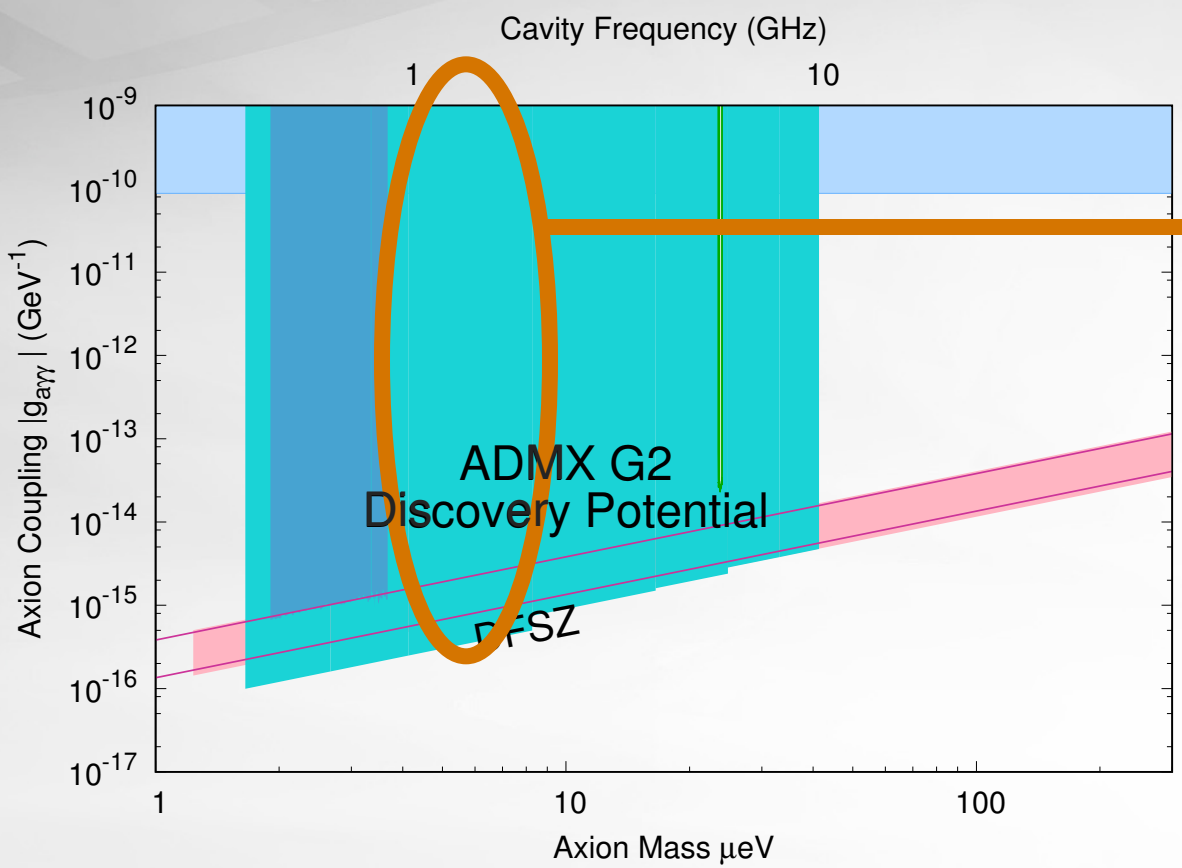


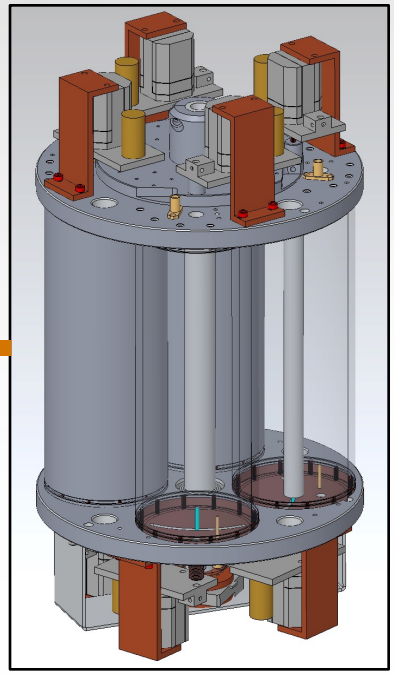


Data-taking for the 5-7 GHz range is complete

Prototype for using piezoelectric controls, and data-taking at higher frequencies

1-2 GHz: Four-Cavity Array

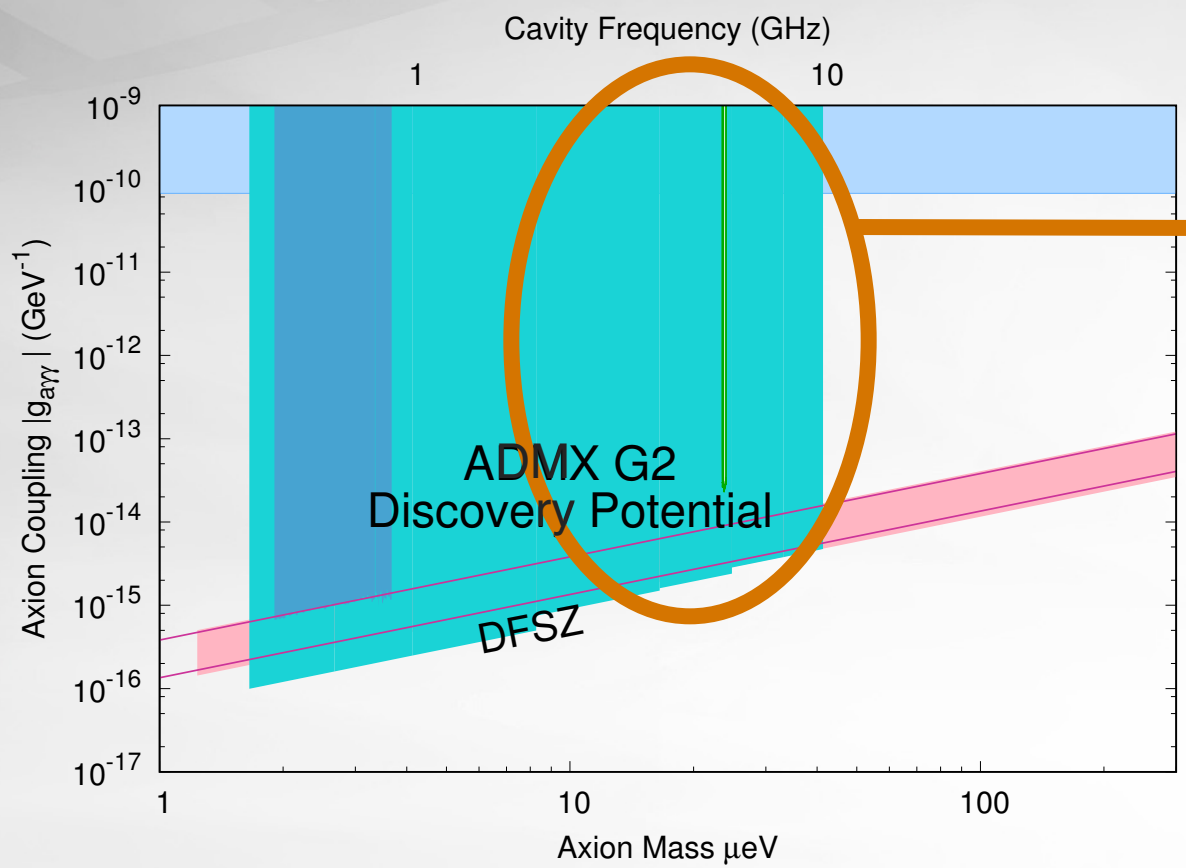


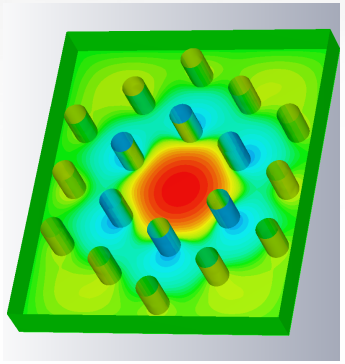


Frequency range:
1-2 GHz

Prototype being fabricated now

2+ GHz: Cavity Arrays and Other Designs





Cylindrical cavities from 2-6 GHz

Other resonator designs for 6-10 GHz

Beyond ADMX G2: 10+ GHz

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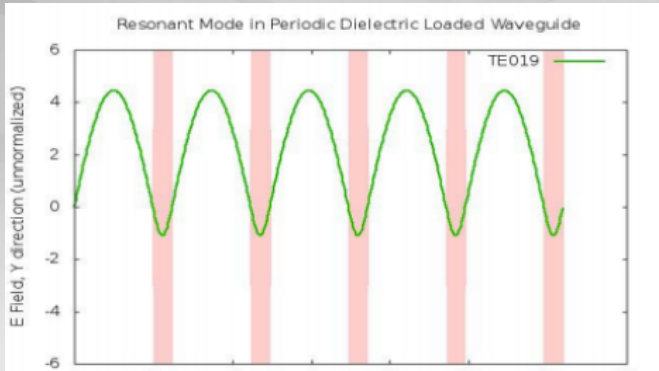
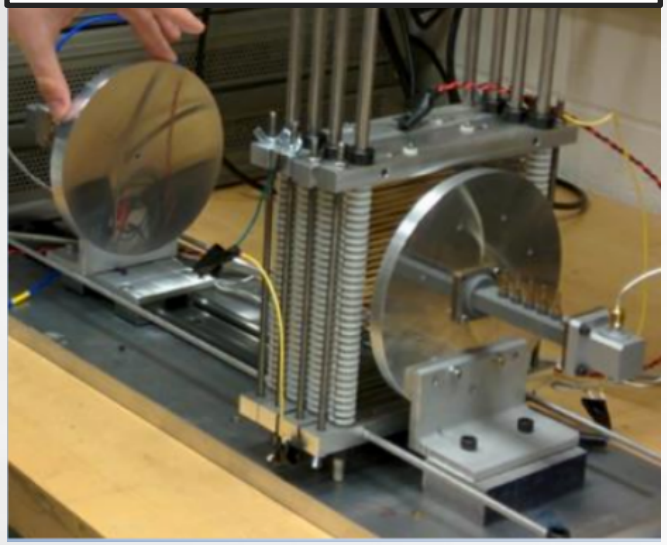
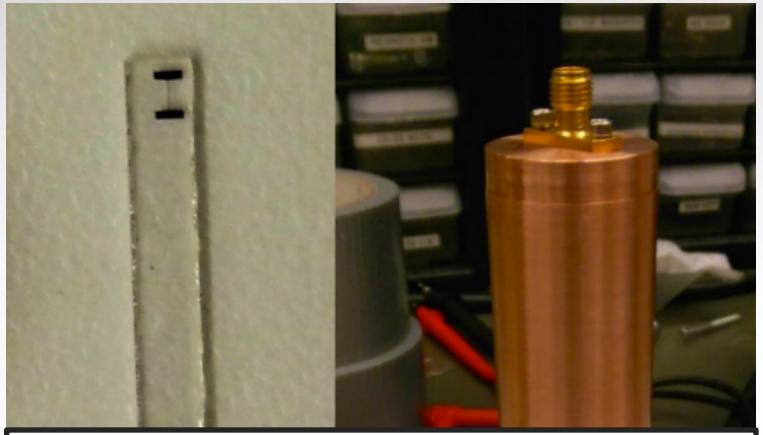
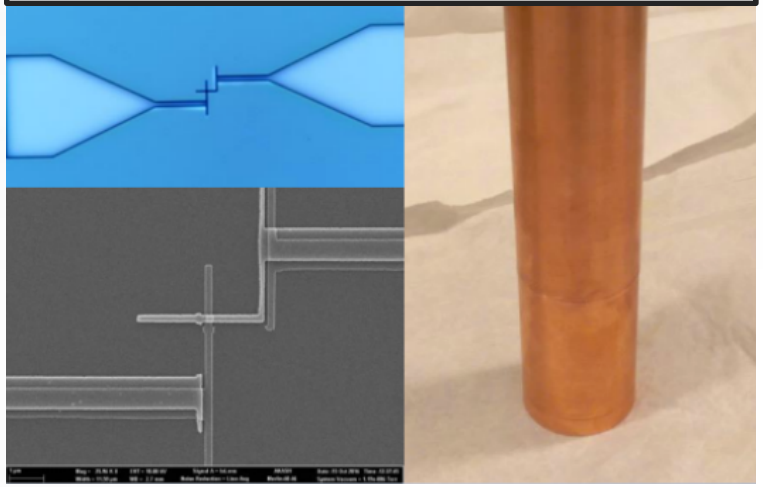


Periodic Dielectric Resonator





Superconducting Qubit Detector



Summary

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- 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

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University of Washington

University of Florida

Lawrence Livermore National Laboratory

Fermilab

University of California, Berkeley

Pacific Northwest National Laboratory

Los Alamos National Laboratory

National Radio Astronomy Observatory

Washington University

Sheffield University

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