# ABRACADABRA

## A Search for Low-Mass Axion Dark Matter

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**ABRACADABRA**, **A B**roadband/**R**esonant **A**pproach to **C**osmic **A**xion **D**etection with an **A**mplifying **B**-field **R**ing **A**pparatus, is an experiment that searches for ultra-light axion and axion-like dark matter in the mass range $10^{-14} - 10^{-6}$ eV. It uses a toroidal magnet to source an oscillating effective electric current from interactions with the axion field. This current is then detected and amplified with a SQUID magnetometer. Axions' tiny electromagnetic coupling means that the experiment must be highly sensitive and have minimal background noise. This poster presents the current status of the first generation of the experiment, ABRACADABRA-10cm.

## AXIONS

### Why axions?

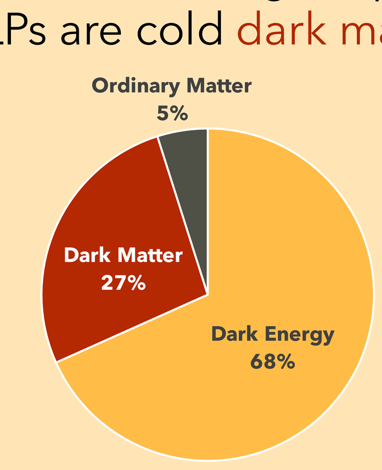
- QCD conserves CP symmetry:

$$\mathcal{L}_{QCD} \supset \bar{\theta}\frac{\alpha_s}{8\pi}G_{a\mu\nu}\tilde{G}^{\mu\nu}_a \qquad \bar{\theta} \lesssim 10^{-10}$$

- Why is $\bar{\theta} \in [0, 2\pi]$ so small? ⟶ strong CP problem
  - *Peccei and Quinn, 1977*: $\bar{\theta}$ is replaced to include a dynamical axion field,

$$\bar{\theta} \rightarrow \bar{\theta} + a/f_a$$

- Axion-like particles (ALPs) are also predicted by BSM theories including string theory, although they do not have to solve the strong CP problem
- Axions and ALPs are cold dark matter candidates

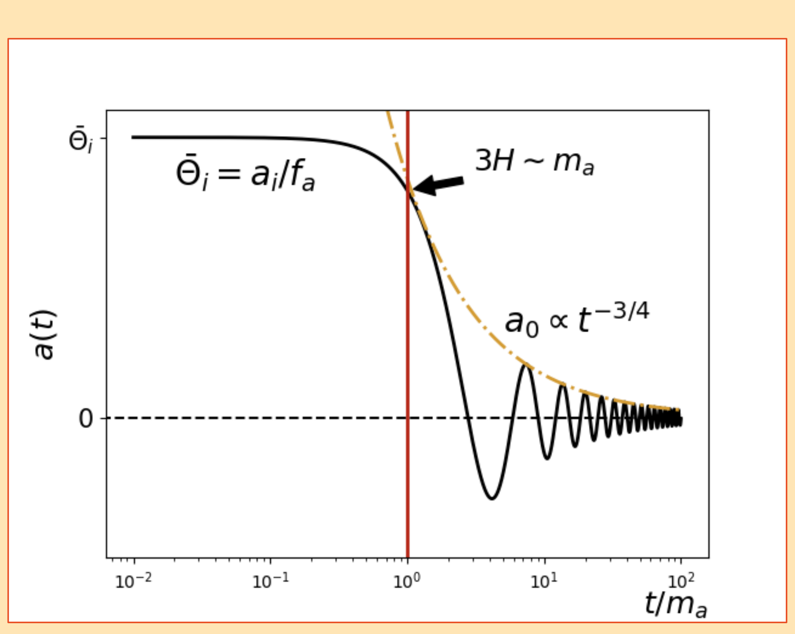



### Where do they come from?

- PQ symmetry breaking can happen before or after inflation at energy scale $f_a$
- Symmetry breaking before inflation can create axions via the misalignment mechanism:

$$\ddot{\theta} + 3H(T)\dot{\theta} - \frac{\nabla^2\theta}{a^2} = -\frac{1}{f_a^2}\frac{\partial}{\partial\theta}V(\theta, T)$$

$$V(\theta, T) \approx \frac{1}{2}m_a(T)^2 f_a^2\theta^2$$




### What do we look for?

- Model-dependent couplings
  - DFSZ and KSVZ models predict different strengths of coupling to photons, $g_{a\gamma\gamma}$
- The existence of axions modifies Ampere's Law:

$$\nabla \times \mathbf{B} = \frac{\partial \mathbf{E}}{\partial t} - g_{a\gamma\gamma}(\mathbf{E} \times \nabla a - \mathbf{B}\frac{\partial a}{\partial t})$$

- Mass not well-constrained, so must search across several orders of magnitude

$$m_a \propto 1/f_a \qquad 10^{-12} \lesssim m_a \lesssim 10^{-2}\,\text{eV}$$

## DETECTION METHOD

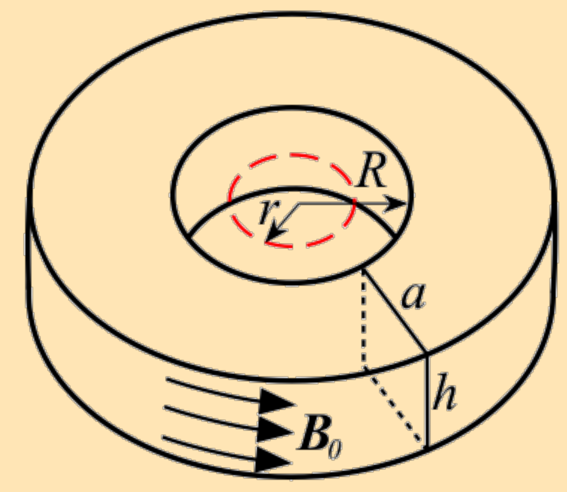
- Ultralight axion dark matter can be treated as a coherent classical field,

$$a(t) = \frac{\sqrt{2\rho_{DM}}}{m_a}\sin(m_a t)$$

- Toroidal magnet sources an oscillating, parallel effective electric current from the axion field:

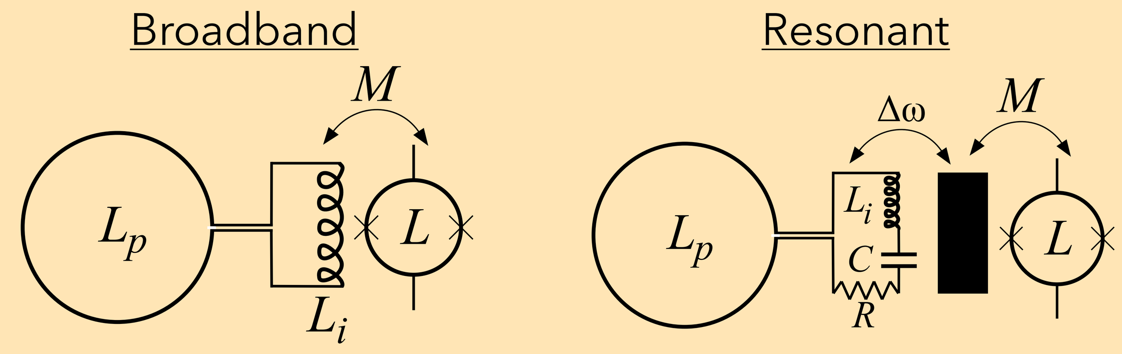
$$\mathbf{J_{eff}} = g_{a\gamma\gamma}\sqrt{2\rho_{DM}}\cos(m_a t)\mathbf{B_0}$$

- This in turn sources an oscillating B-field through the center of the toroid
- Changing magnetic flux detected with a pickup loop connected to a SQUID magnetometer
  - Highly sensitive–can detect fractions of a flux quantum

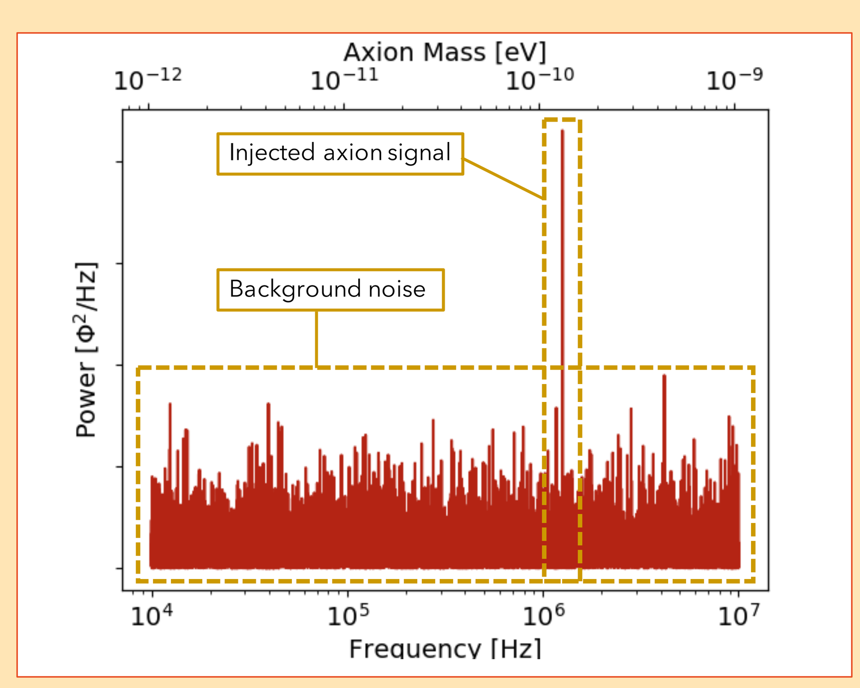



- Two methods of readout:

Broadband    Resonant

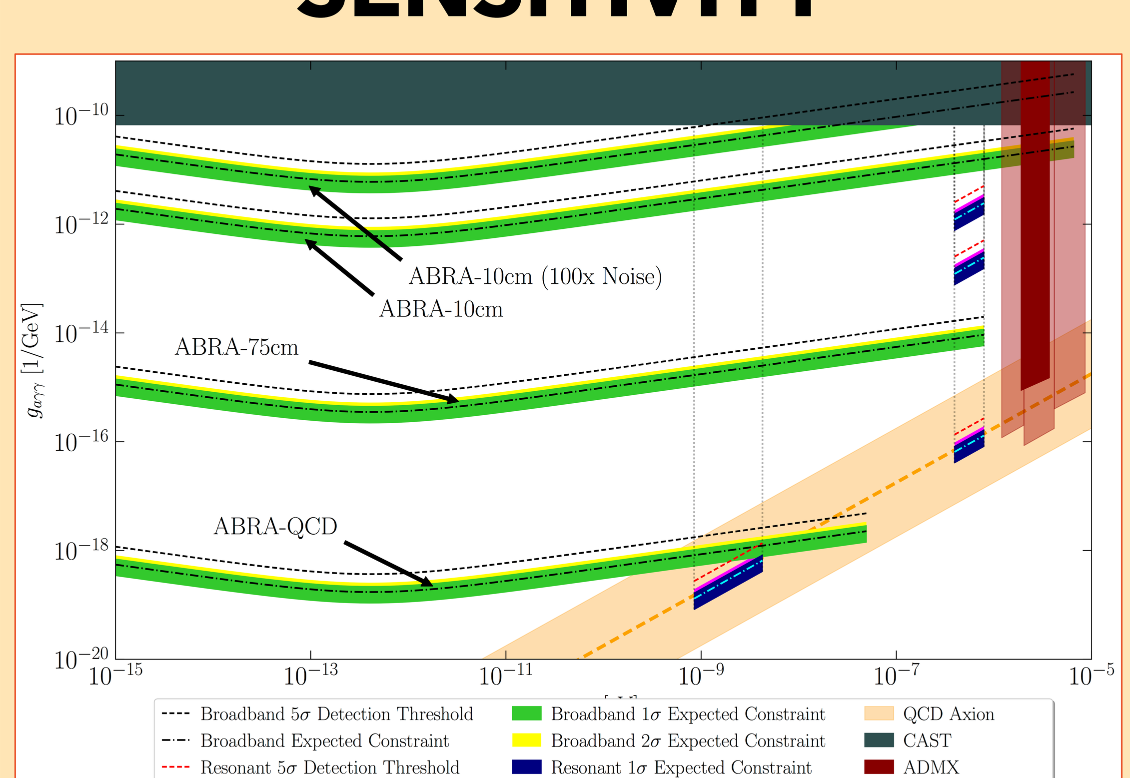



- Take time series data and then Fourier transform
  - An axion signal appears as a peak in frequency space (fake data):




- Method proposed in *Kahn, Safdi, and Thaler, 2016*
- Main challenge is noise reduction

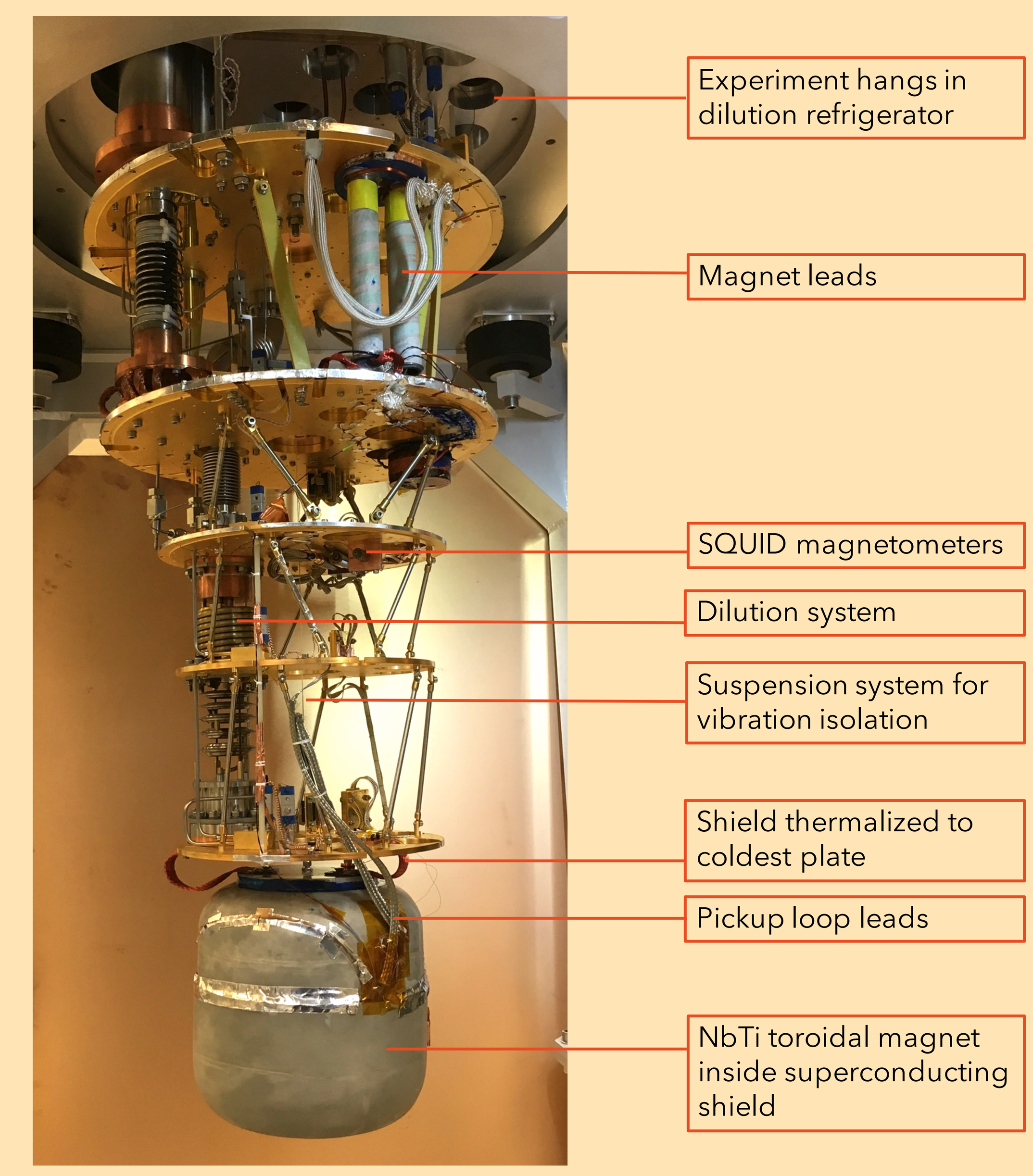
## SENSITIVITY



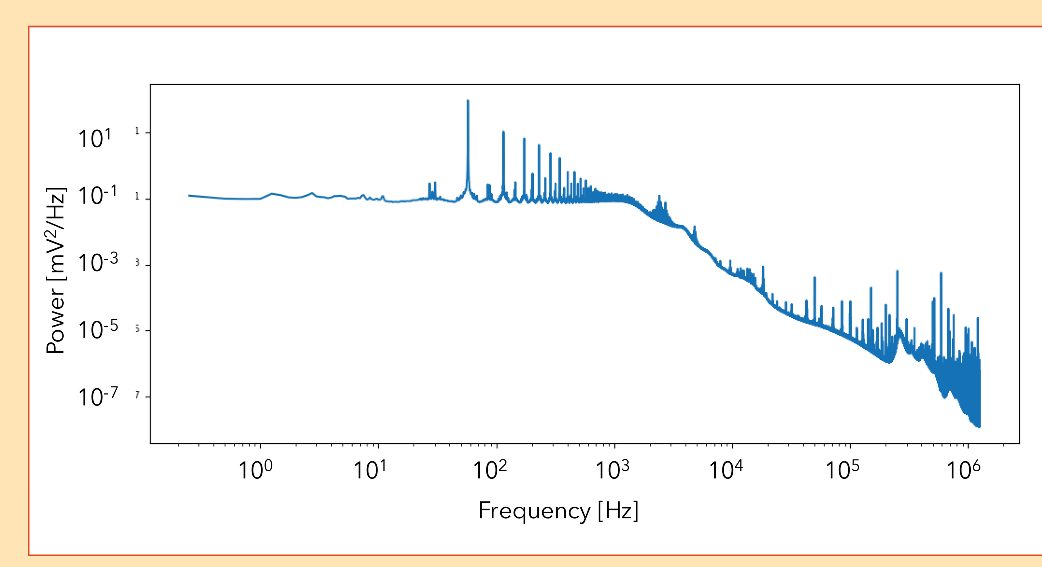

- Resonant curves shown above are with a pessimistic scan strategy
- ABRACADABRA is a complementary experiment to higher-mass searches such as ADMX
- ABRACADABRA-10cm will set world-leading limits with its first run

## ABRACADABRA-10CM

### The Detector




### Current Status




- Currently commissioning the system and reducing background noise

### Next Steps

- Improve vibration isolation
- Identify and eliminate ground loops
- Take data!

## ABRACADABRA-75CM

- Plan to take a staged approach to increase sensitivity:

ABRACADABRA-10cm
↓
ABRACADABRA-75cm
↓
ABRACADABRA-QCD

- ABRACADABRA-75cm will be able to begin probing well into the favored QCD axion space
  - Meter-scale experiment
- May lead into larger ABRACADABRA-QCD
  - CMS-scale experiment

## ACKNOWLEDGEMENTS

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