The ADMX-HF Experiment

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Neutrinos and Dark Matter

2 June 2015

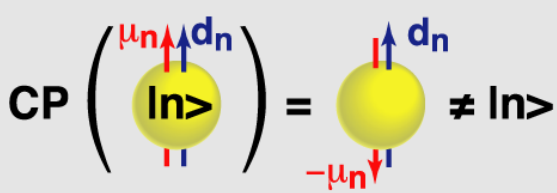
Outline

- Motivation for the axion as dark matter
- Microwave cavity axion searches
- The Axion Dark Matter Experiment at High-Frequencies.
- Innovations underway.

The Strong CP Problem

The Strong-CP Problem

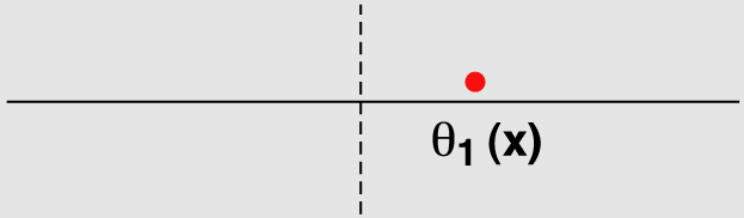
- $\mathcal{L}_{QCD} = \ldots + \frac{\theta}{32\pi^2} G\tilde{G}$
  - Explicitly CP-violating
- But neutron e.d.m. $|d_n| < 10^{-25}$ e · cm
  - $\bar{\theta} < 10^{-10}$
  - Strong-CP preserving



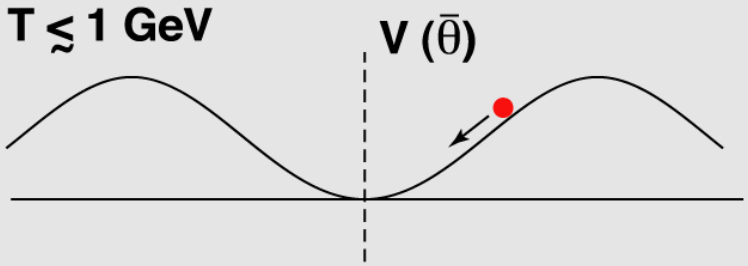
- Why?

Peccei-Quinn / Weinberg-Wilczek

- θ a dynamical variable
- $T = f_a$ spontaneous symmetry breaking

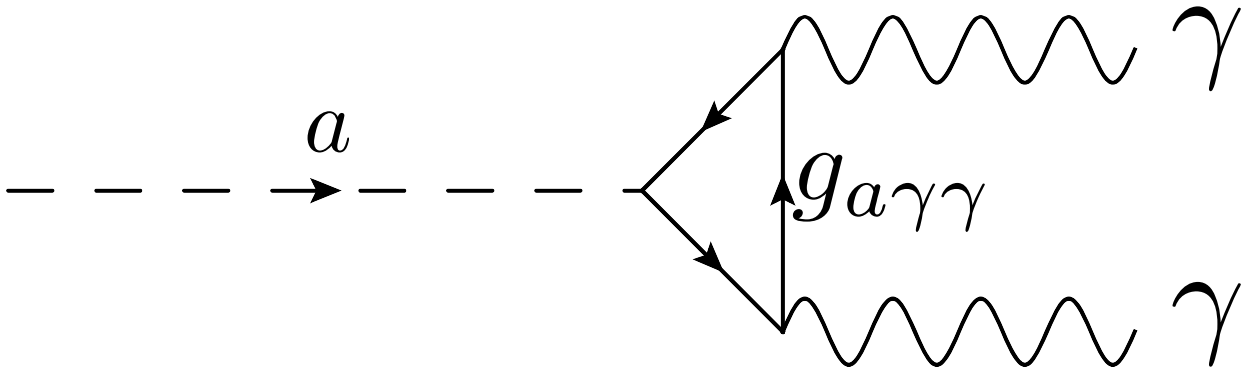


- $T \lesssim 1$ GeV



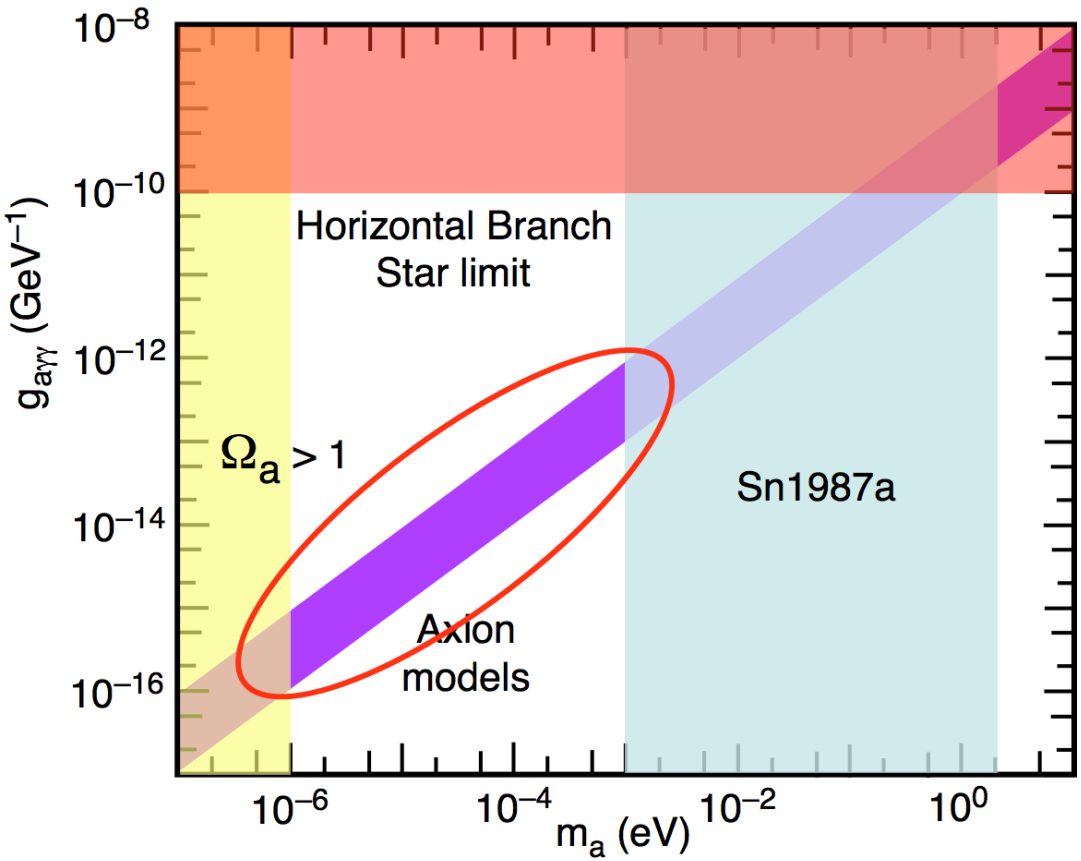
  - $\bar{\theta}$ dynamically $\rightarrow 0$
  - Remnant oscillation = Axion

Axion Coupling



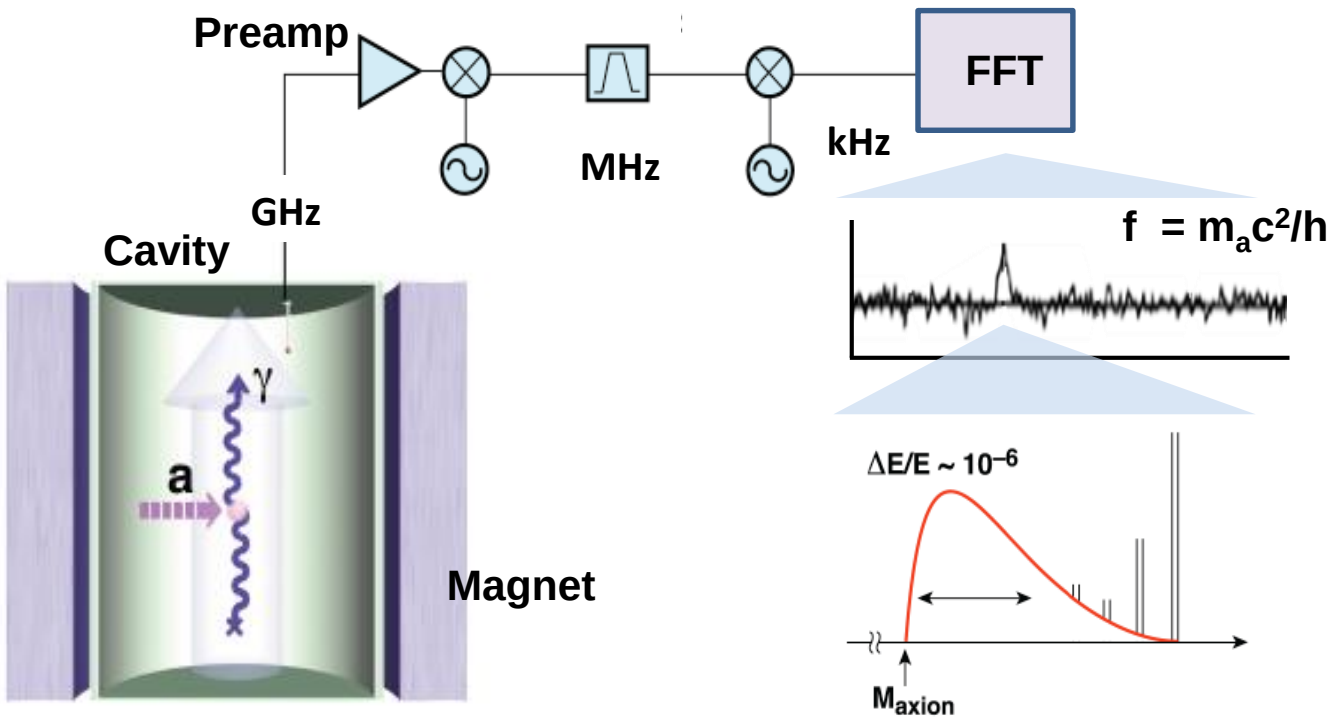
The axion predicted by the Peccie-Quinn Mechanism, a light cousin of the π°, couples to two photons. This coupling is of particular interest in microwave cavity searches.

The Axion and Dark Matter



Given constraints form Sn1987a and from the cosmology, and axion in the μeV range is a good candidate for dark matter.

Experimental Detection Techniques



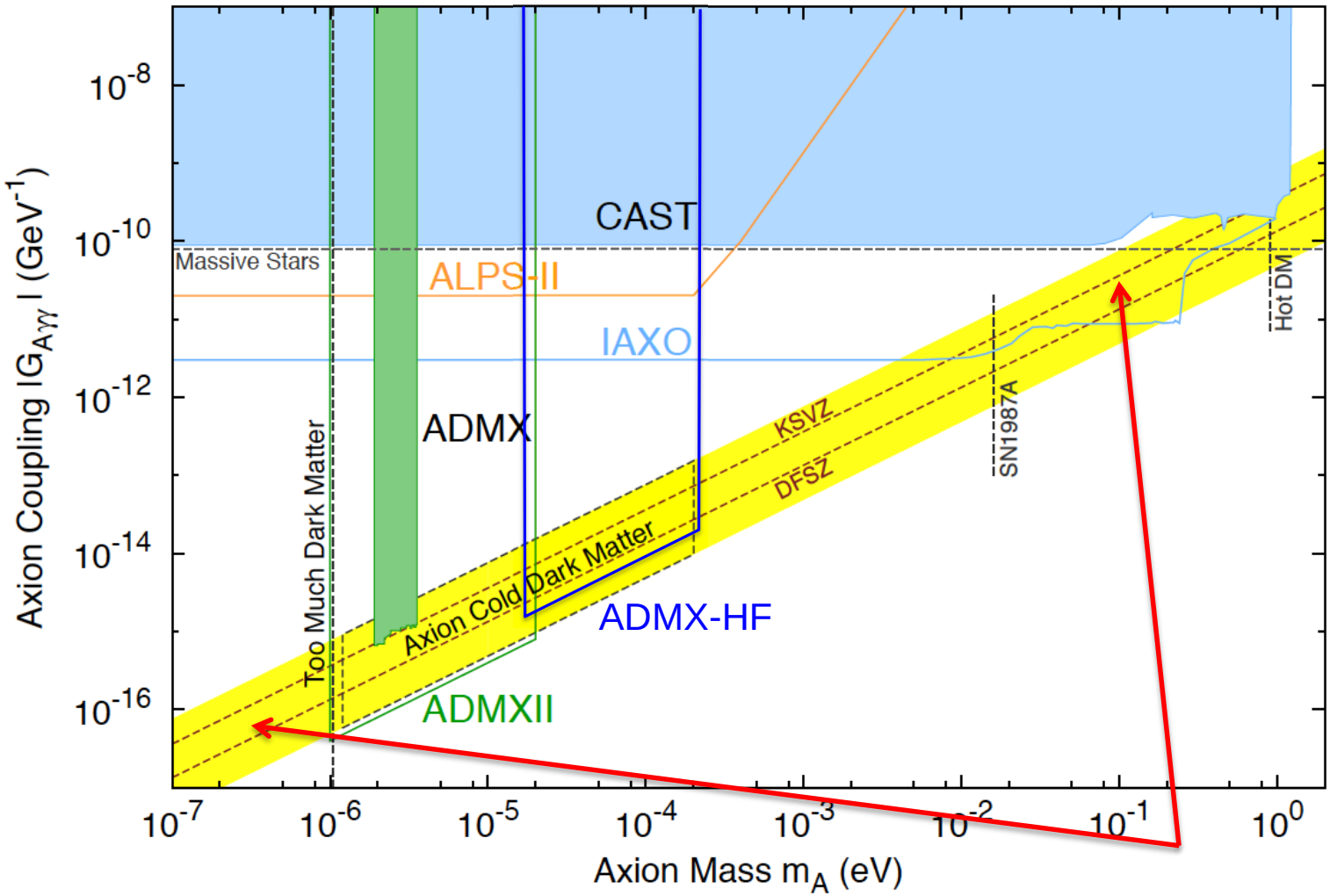
Sikivie outlined a technique that would use the Primakoff effect to couple virtual photons from a magnetic field with axions to produce an outgoing photon.

$$P_{sig} \propto (B^2 V Q_{cav})(g^2 m_a \rho_a)$$

$$P_{sig} \sim 10^{-23}\mathrm{W}$$

$$\frac{s}{n} = \frac{P_{sig}}{kT_{sys}}\sqrt{\frac{t}{\Delta\nu}}$$

Axion Experiments



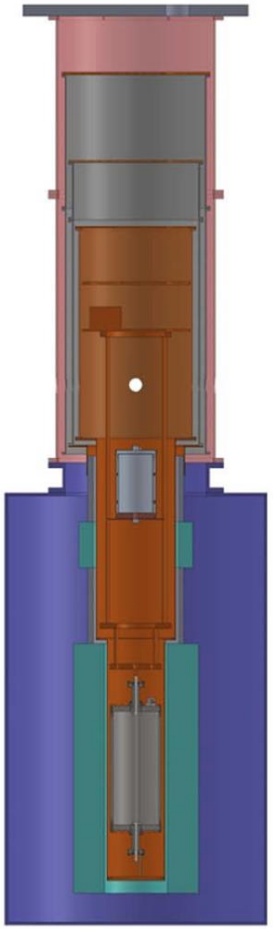
Expected axion model regions

ADMX

- Large Scale Experiment running 1995-present.
- Excluded KSVZ axions with mass 1.9-3.6 μeV (460-860 MHz).
- Uses DC SQUID amplifiers.
- Currently commissioning dilution refrigerator upgrade.
- Present search region is 3.6-10 μeV.

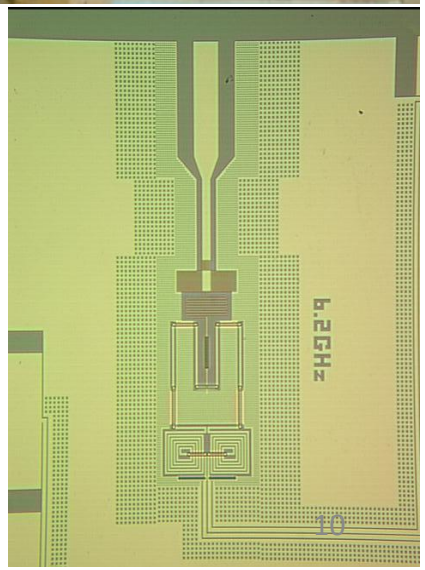
ADMX-HF

- Smaller Experiment in the few GHz range.
- Pathfinder: first look at data in this range.
- Innovation Testbed: develop new technologies.

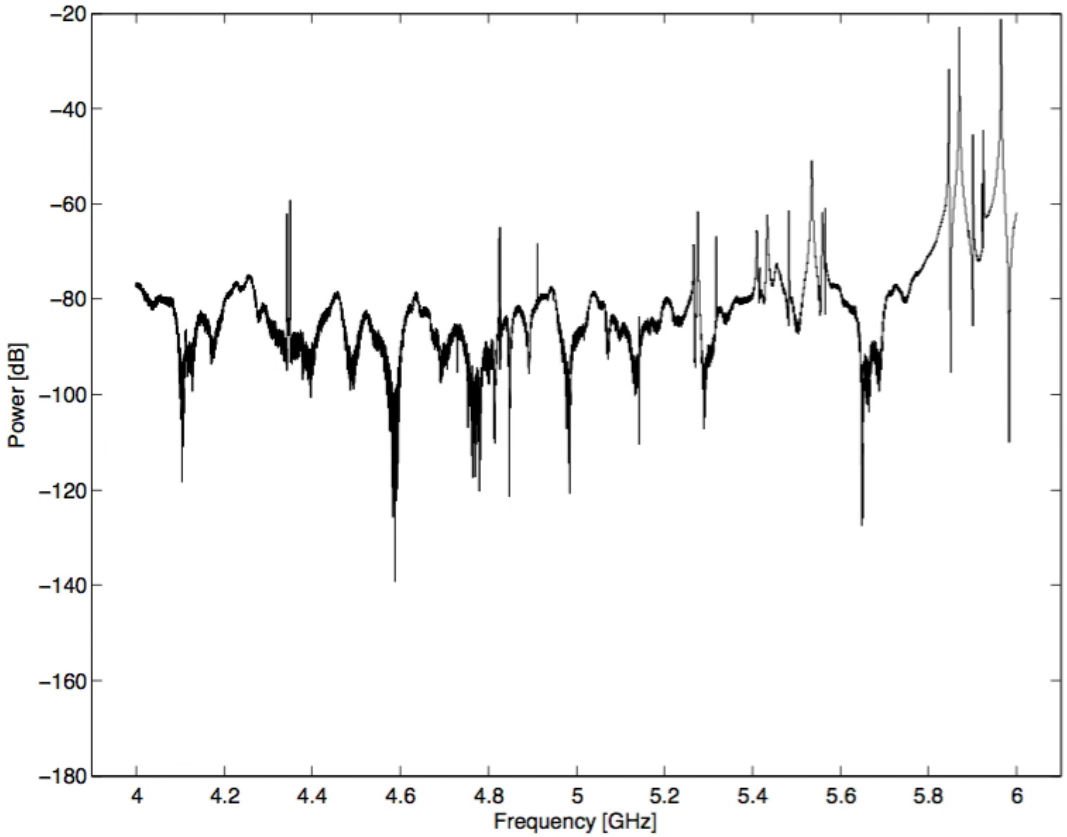


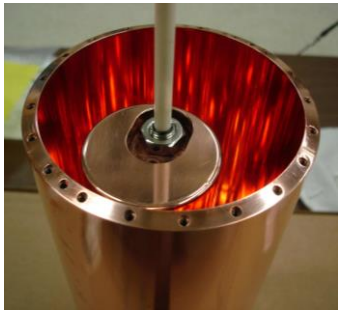
ADMX-HF

- Probes the 5-25 GHz (20-100 μeV) axion mass region.
- Uses a 25 mK dilution refrigerator.
- Uses a highly uniform 9 T magnet.
- Uses Josephson Parametric Amplifiers (JPAs)



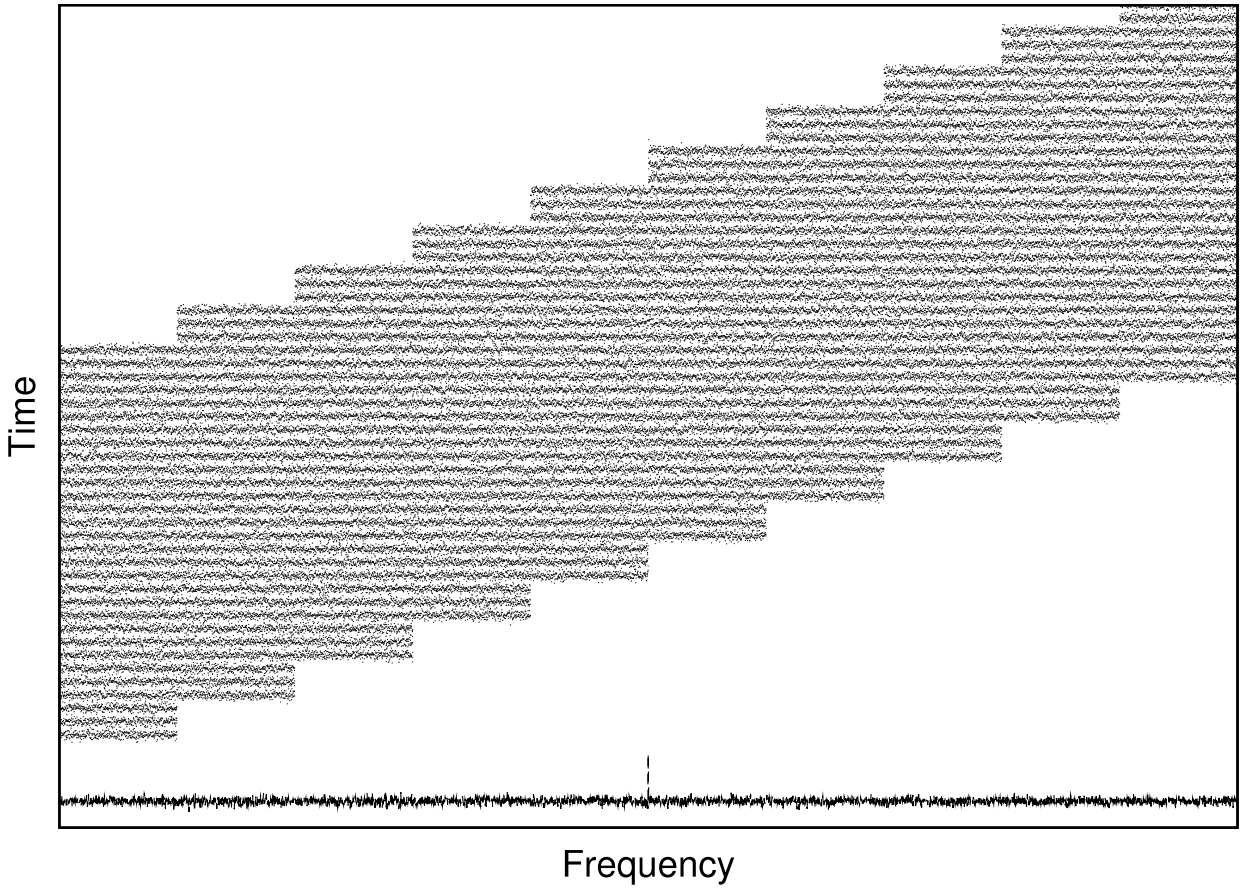
ADMX-HF Cavity Tuning





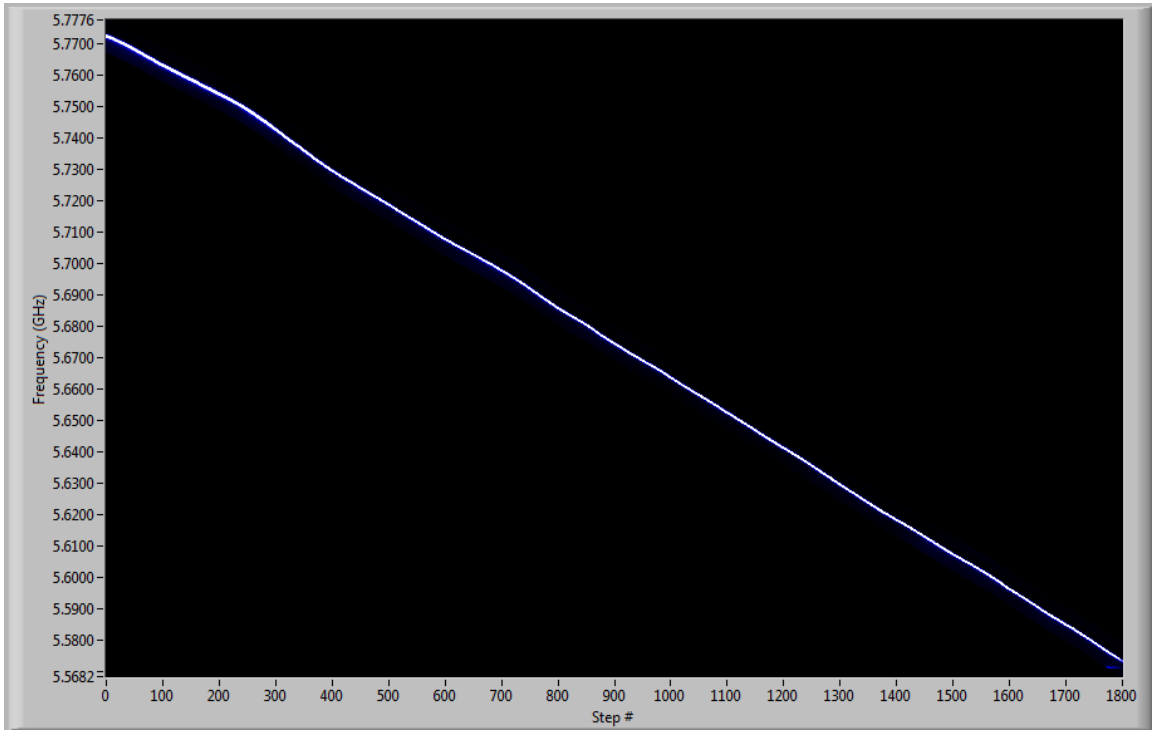
Tunable Cavity

Data Analysis



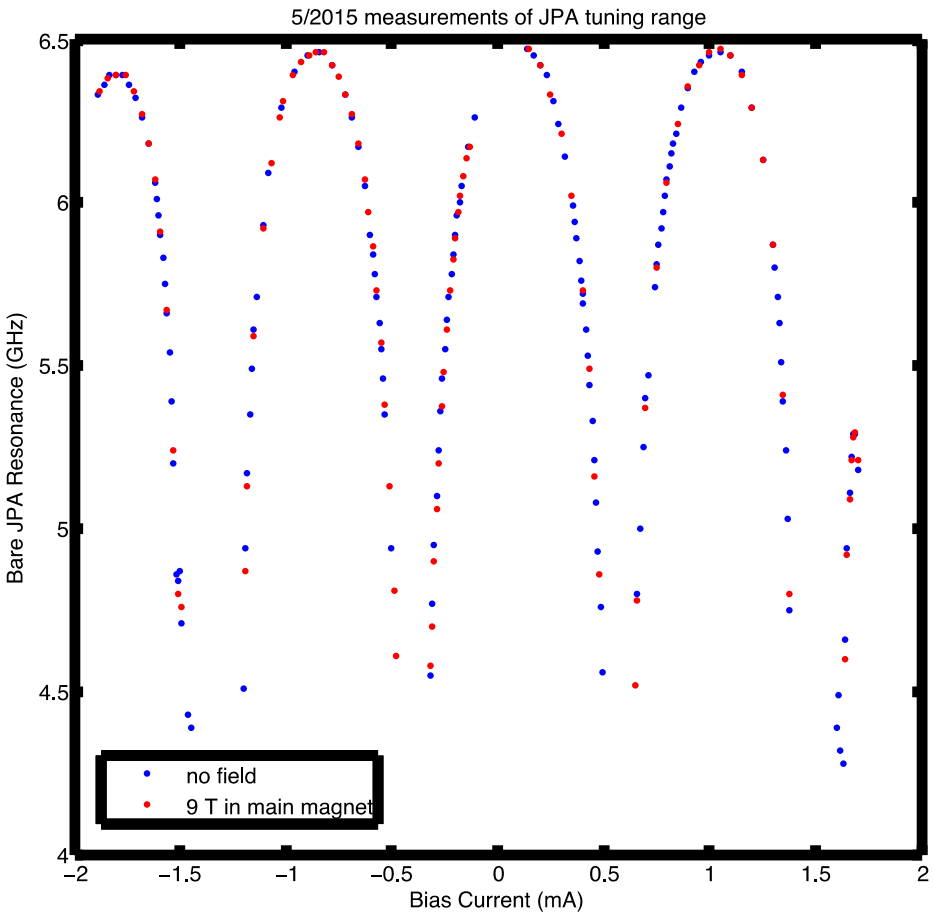
ADMX-HF Current Status

- Commissioning since last Summer
  - Cold Cavity Tuning



ADMX-HF Current Status

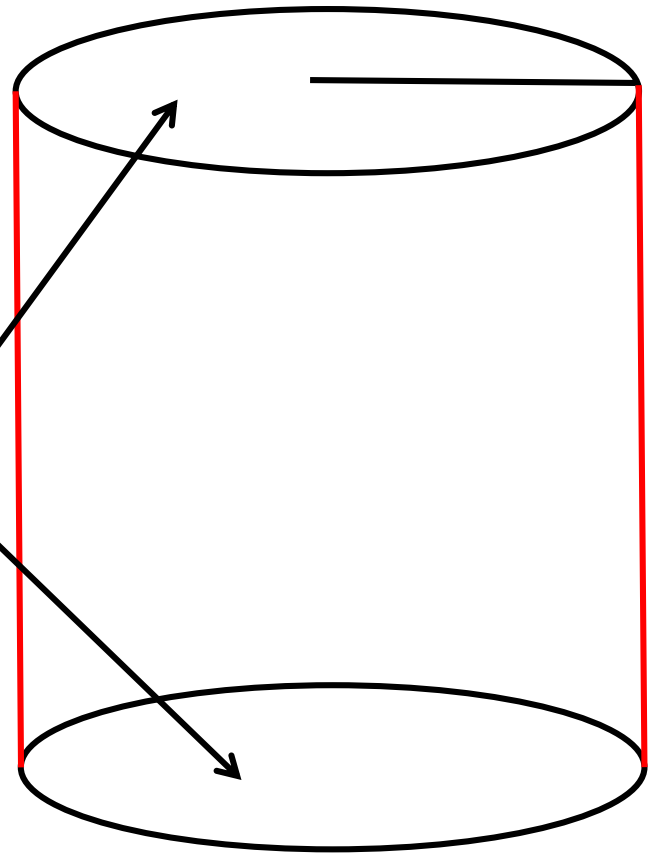
- Commissioning since last Summer
  - Cold Cavity Tuning
  - JPA Tuning
  - Magnetic ramp up to 9T



Innovations Underway

- Superconducting cavities to increase Q.
- Development of lower noise, squeezed state amplifiers.
- Work on piezoelectric tuning to decrease system noise.
- New cavity designs that push the cavity frequencies into the 10’s of GHz range.

Superconducting Cavities



Thin film superconducting barrel.

Copper end caps

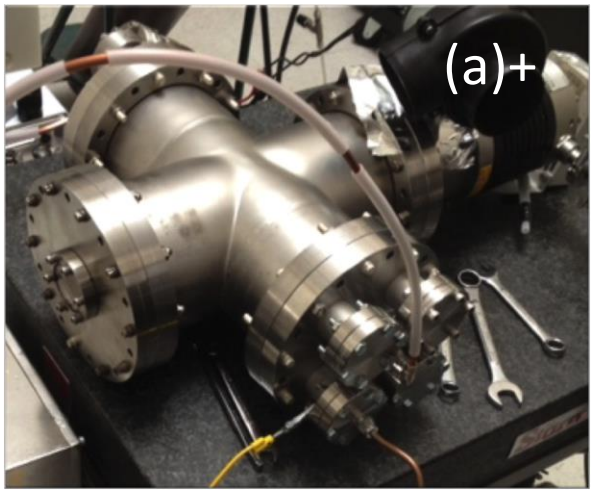
$$Q_L = \frac{L/R}{1 + \cancel{L/R}} \cdot \frac{R}{\delta}$$

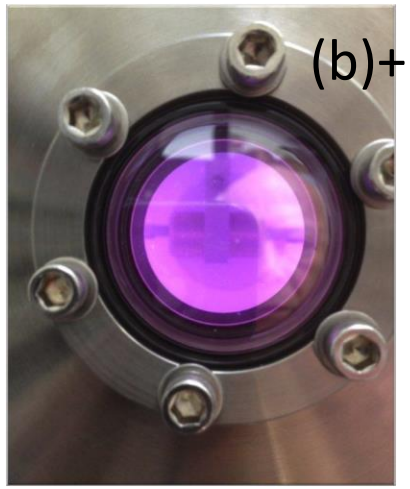
Skin Depth of copper.

$$Q_{hybrid} = (1+L/R) \cdot Q_{Cu}$$

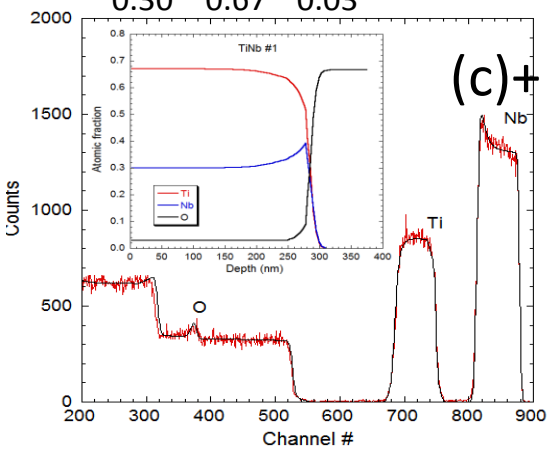
Typical enhancement for an ADMX cavity is 6.

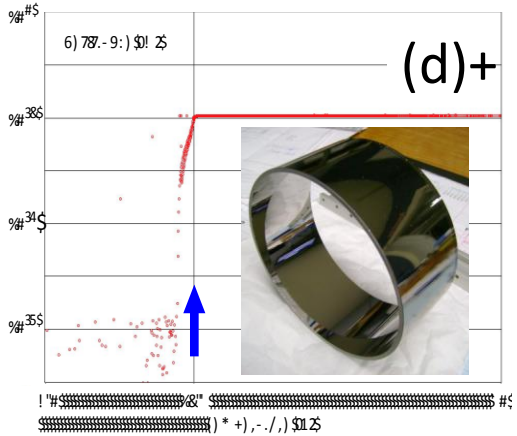
Superconducting Cavities





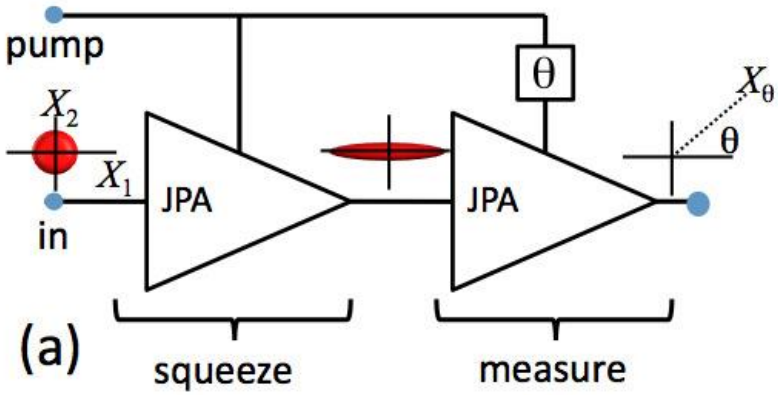
$Nb_{0.30}Ti_{0.67}O_{0.03}$ ~280 nm

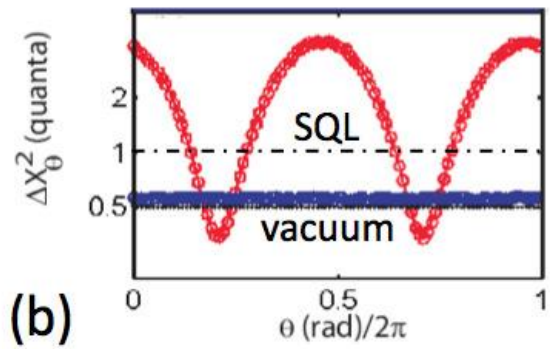


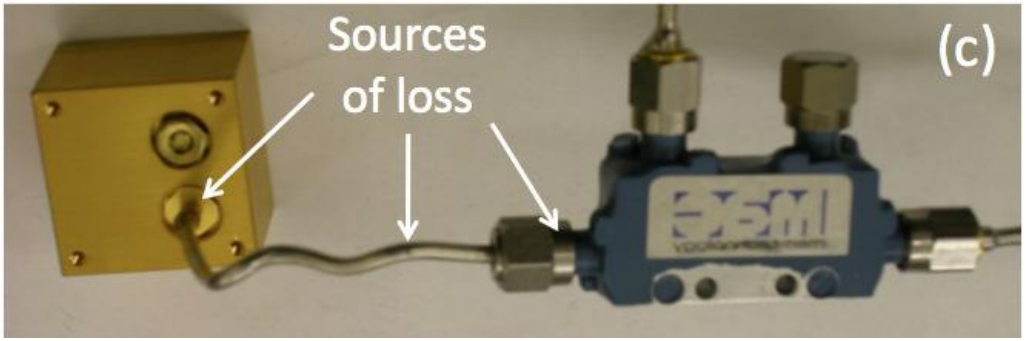


- R&D UCB to produce cavities coated with Type II thin film superconductors.
- We've just installed an RF plasma deposition system to coat cavities, and have installed infrastructure to test the Q's of these cavities above and below the transition temperature.

Squeezed-Vacuum State Amplifiers

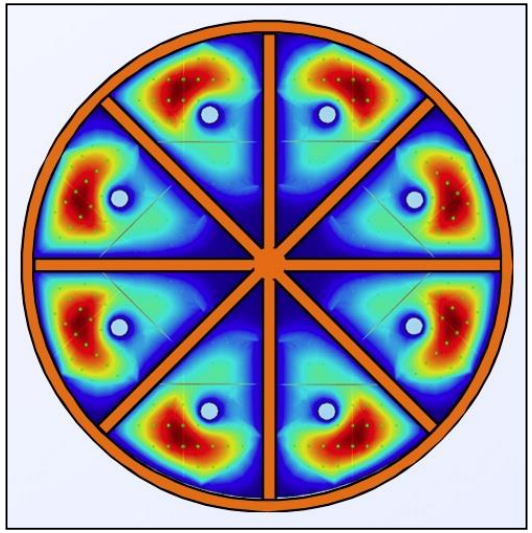


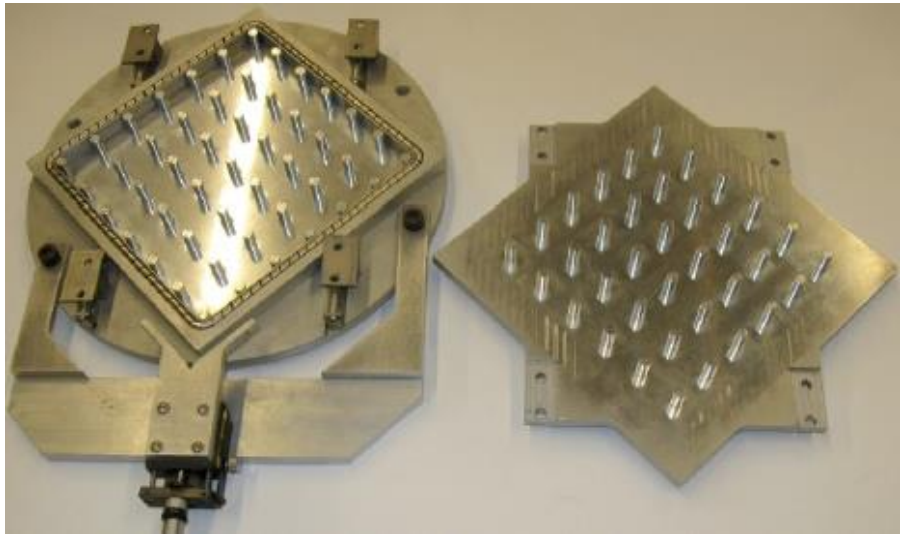




Work of K. Lehnart of University of Colorado

High Frequency Cavity Designs





Timeline

- Construction: 2011-14
- Commissioning: 2014-15
- Long data run: Summer 2015
- Current: R&D

Conclusion

- Axions are highly motivated as a solution to the Strong CP.
- Axions are a very compelling dark matter candidate.
- ADMX and ADMX-HF are capable of searching for dark matter axions in 250 MHz to 10 GHz region.

Thank You!

Lawrence Livermore National Laboratory – ADMX began here in the mid-1990s.
Gianpaolo Carosi, Darrell Carter, Jaime Ruz Armendariz
University of Washington – main experiment moved here in 2010.
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University of Florida
David Tanner, Pierre Sikivie, Neil Sullivan, Jeff Hoskins, Jungseek Hwang,
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