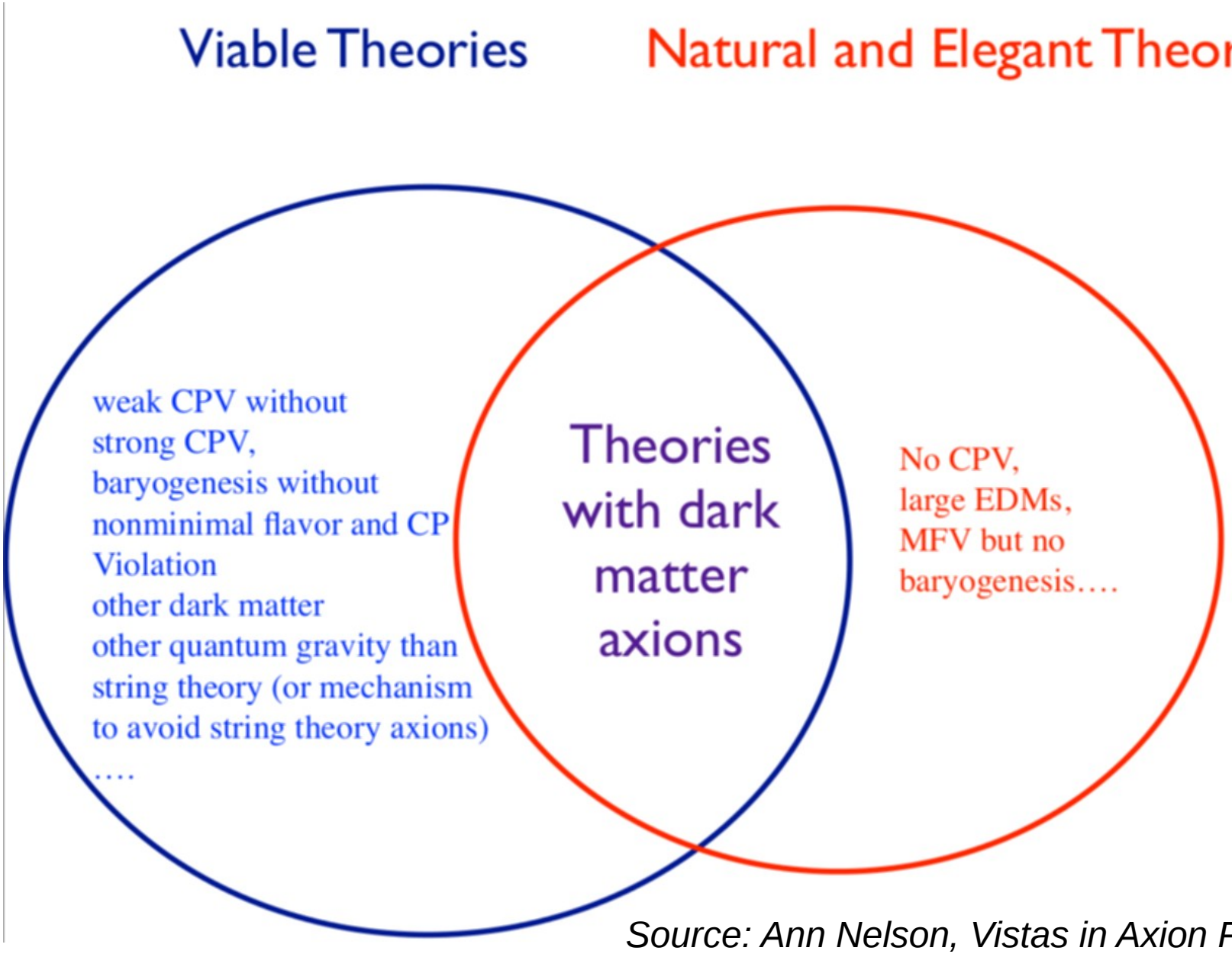
# The Axion Dark Matter eXperiment

*Science*, Nov. 2013, 552 - 555

Gray Rybka
University of Washington
on behalf of the ADMX Collaboration

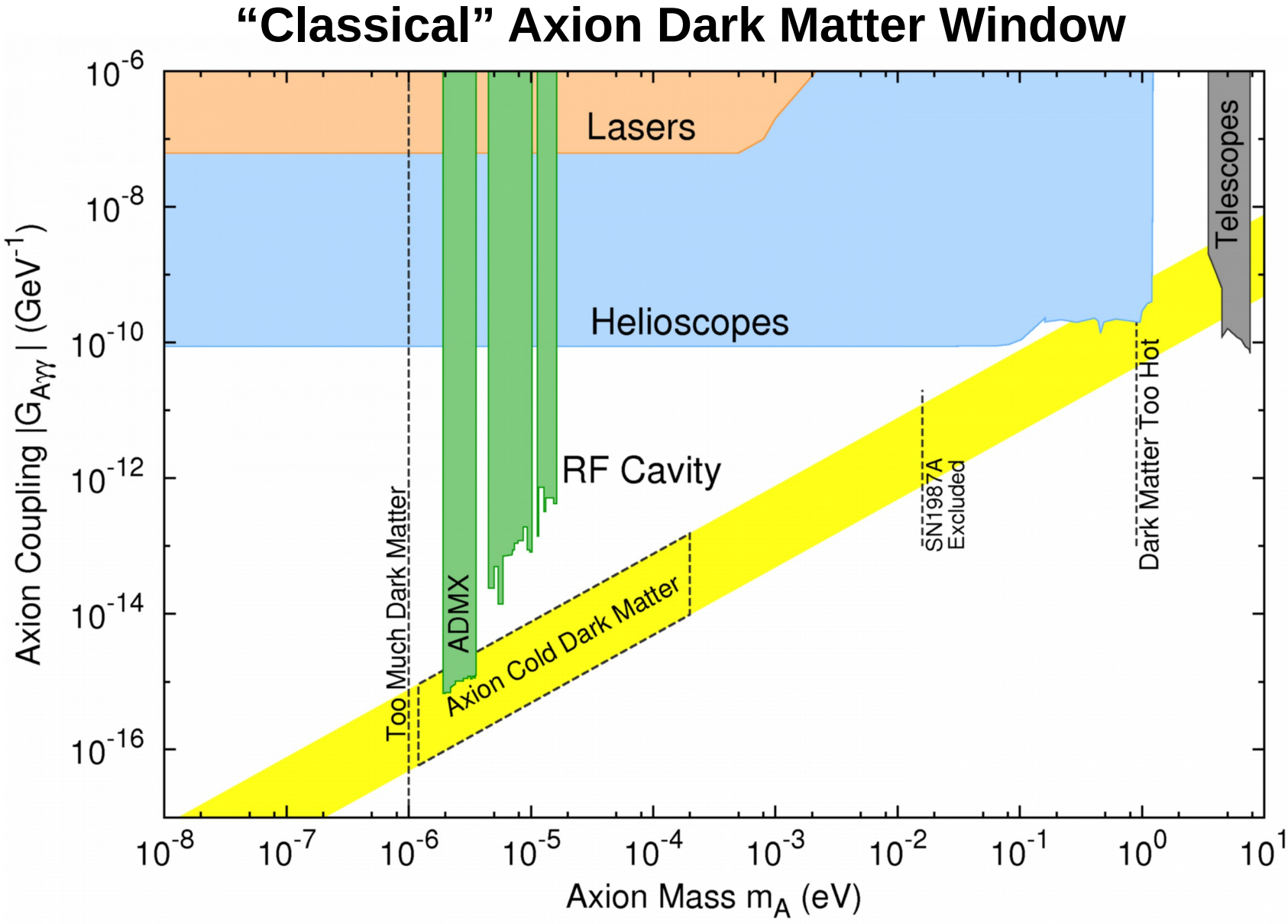
*Patras 2015*
Zaragoza, Spain
June 2015

# Axion Motivation

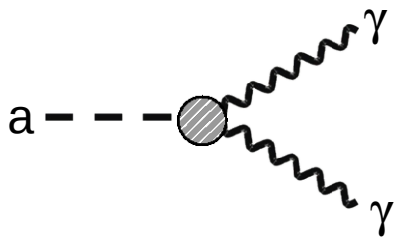



*Source: Ann Nelson, Vistas in Axion Physics 2012*

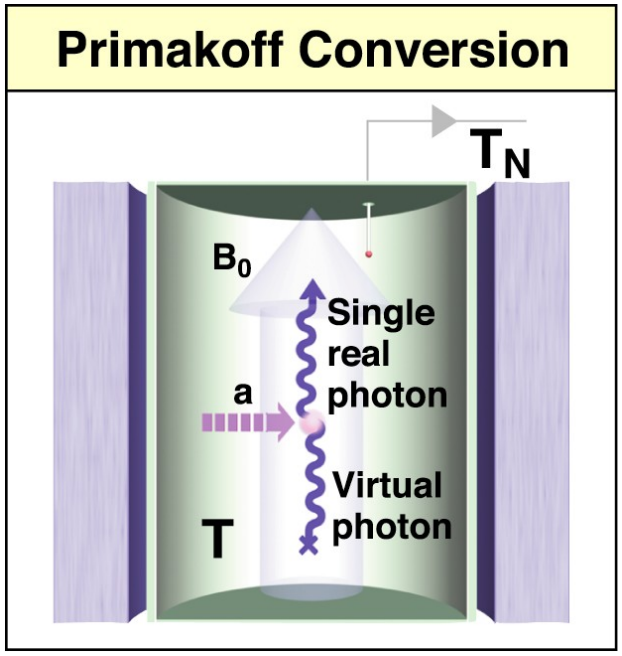
# Axion Parameter Space



# Axion Haloscope




$$\frac{\partial\left(\mathbf{E}^2/2\right)}{\partial t} - \mathbf{E}\cdot\left(\nabla\times\mathbf{B}\right) = g_{a\gamma}\dot{a}\left(\mathbf{E}\cdot\mathbf{B}\right)$$




Dark Matter Axions will convert to photons in a magnetic field.

The measurement is enhanced if the photon's frequency corresponds to the cavity's resonant frequency.

See: Sikivie, Phys. Rev. Lett. 1983

**You Want:**
-Large Cavity Volume
-High Magnetic Field
-High Cavity Q

**You Don't Want:**
-High Thermal Noise
-High Amplifier Noise

# ADMX: Axion Dark Matter eXperiment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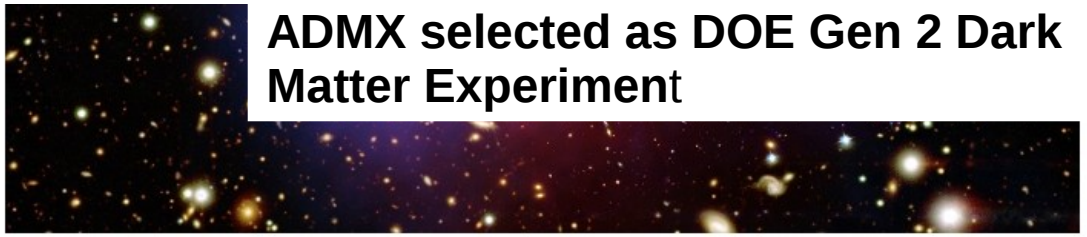


**ADMX selected as DOE Gen 2 Dark Matter Experiment**

Courtesy of NASA

breaking

July 11, 2014

## US reveals its next generation of dark matter experiments

Together, the three experiments will search for a variety of types of dark matter particles.

By Kathryn Jepsen

Two US federal funding they will support in the r

*- Symmetry Maganzine*

Collaboration:

- *University of Washington*
- *LLNL*
- *University of Florida*
- *Yale*
- *UC Berkeley*
- *NRAO*
- *FNAL*

# ADMX Design

Field Cancellation Coil

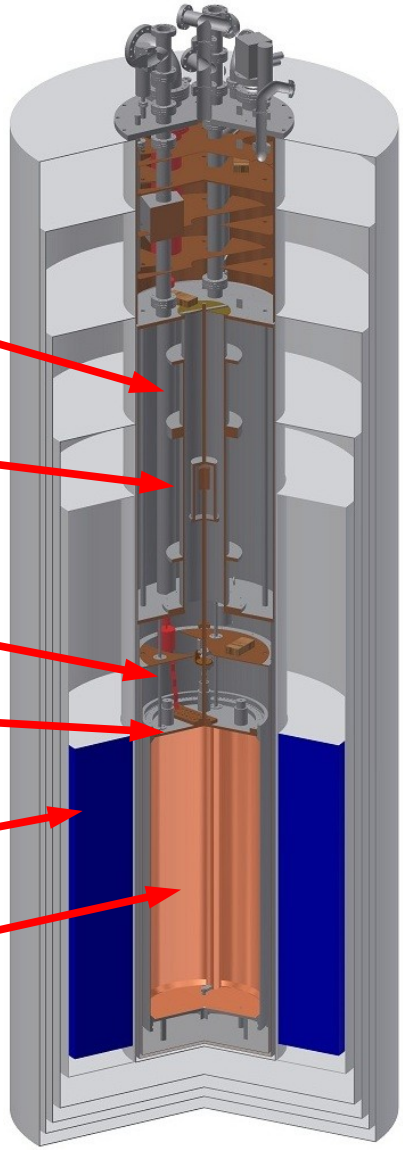
SQUID Amplifier package

Refrigeration

Antennas

8 Tesla Magnet

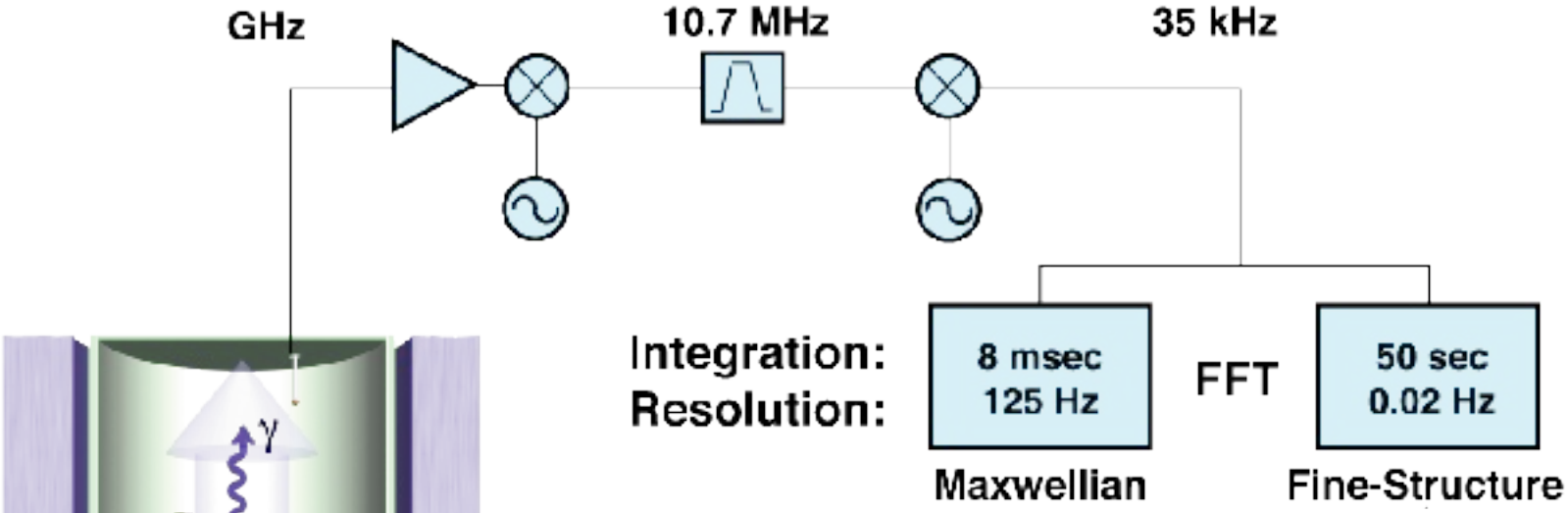
Microwave cavity



Insert + Magnet Schematic

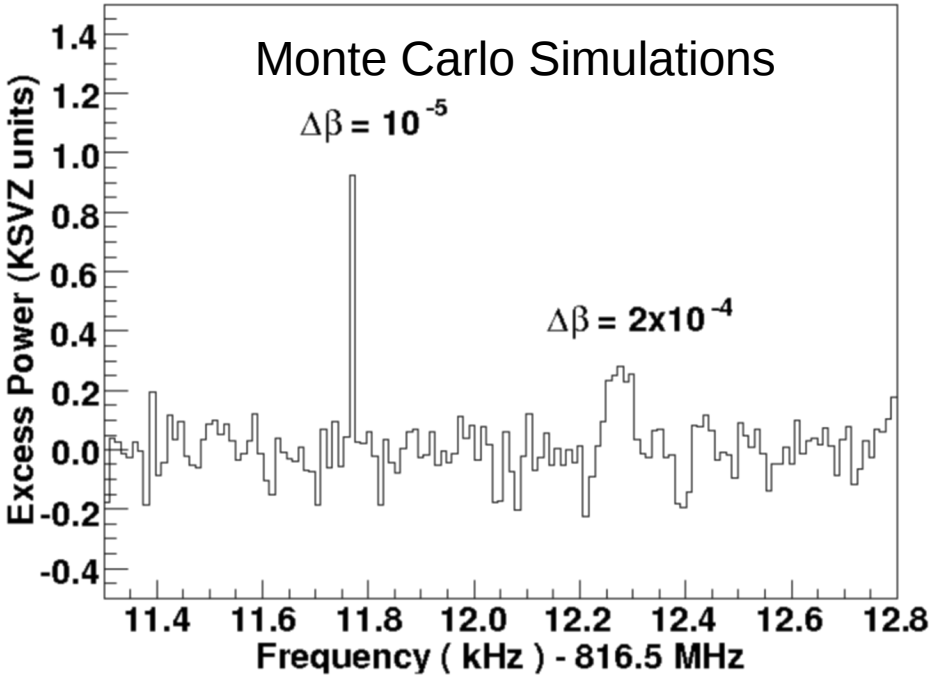
Insert extraction from magnet

# ADMX Receiver

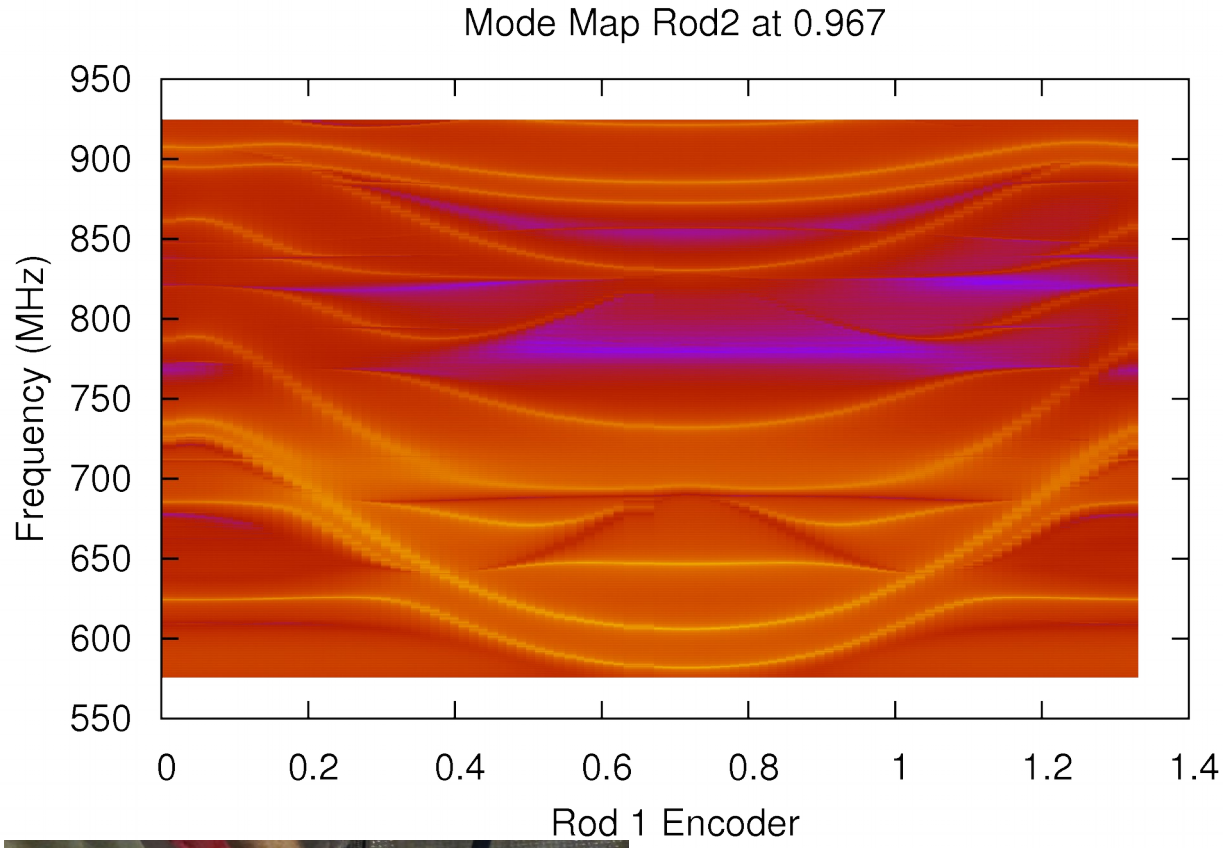


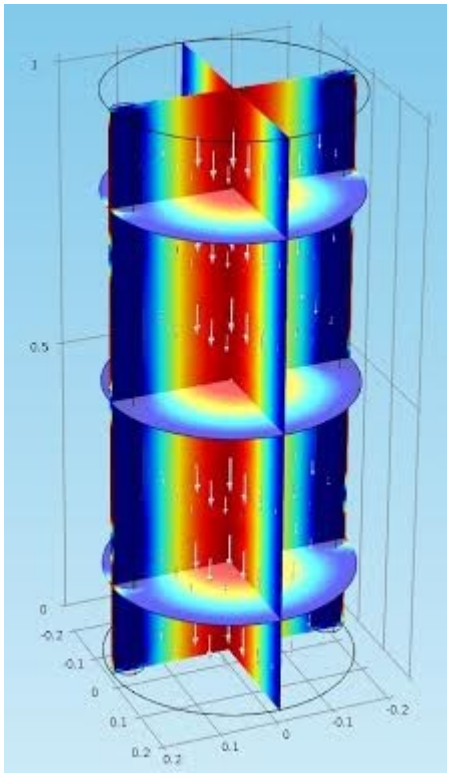

B=8 Tesla

Axions, stimulated by a magnetic field, decay into microwave photons which resonate in the cooled cavity and are amplified and read out

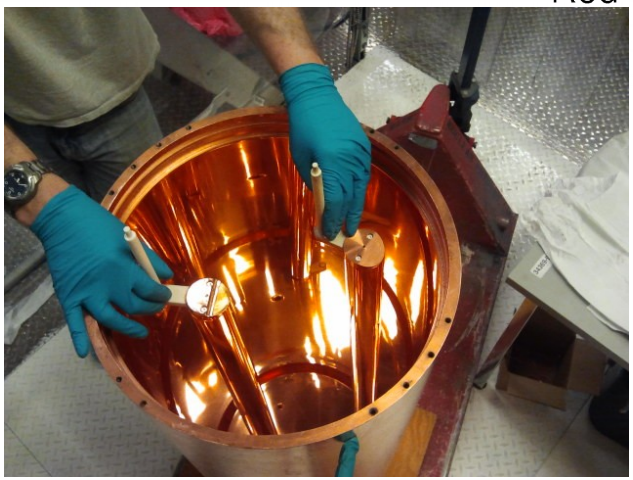


# Tuning



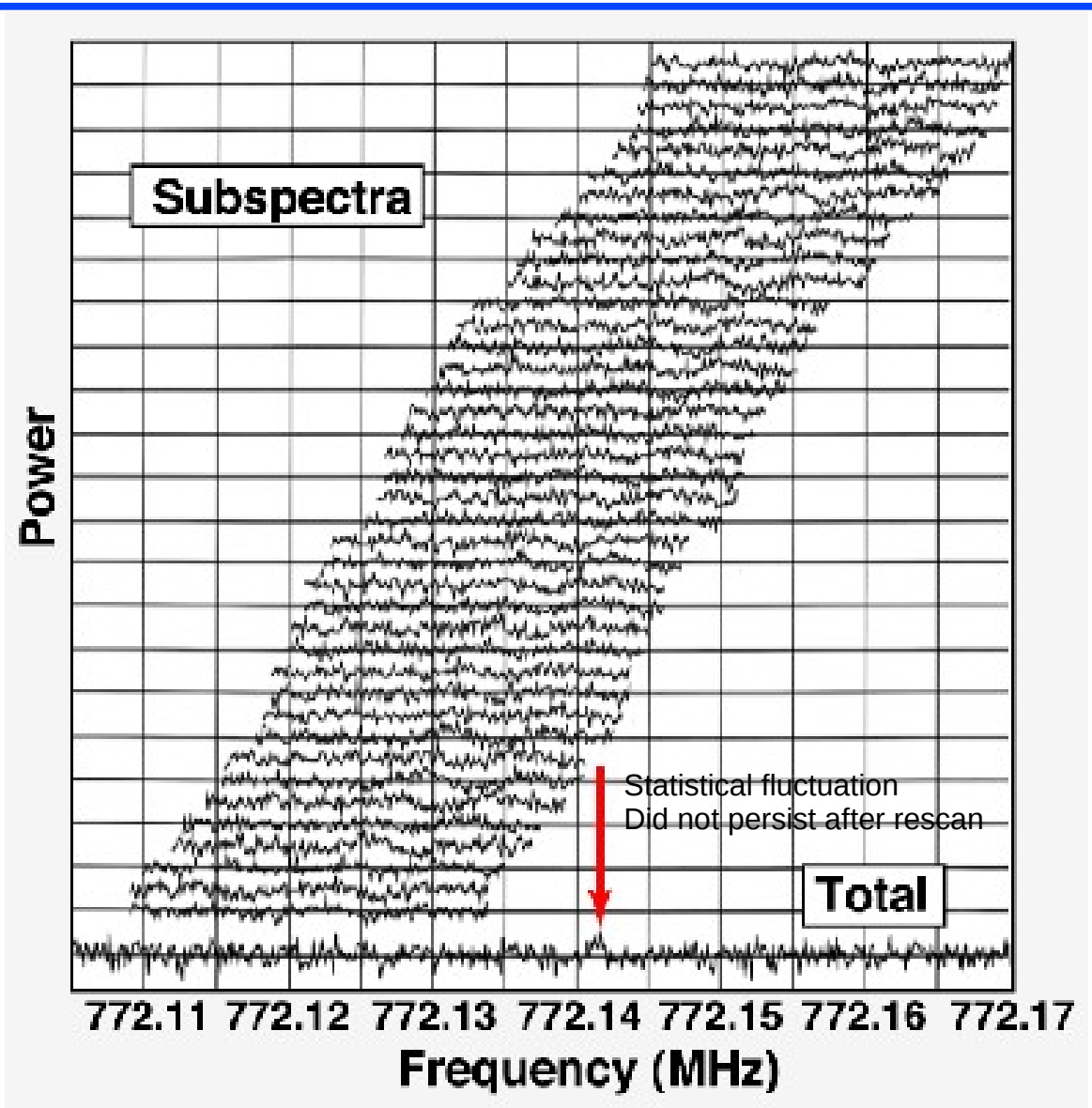



Field simulation of TM010 mode, no rods



Cavity with lid off, showing tuning rods

# Axion Search Cadence



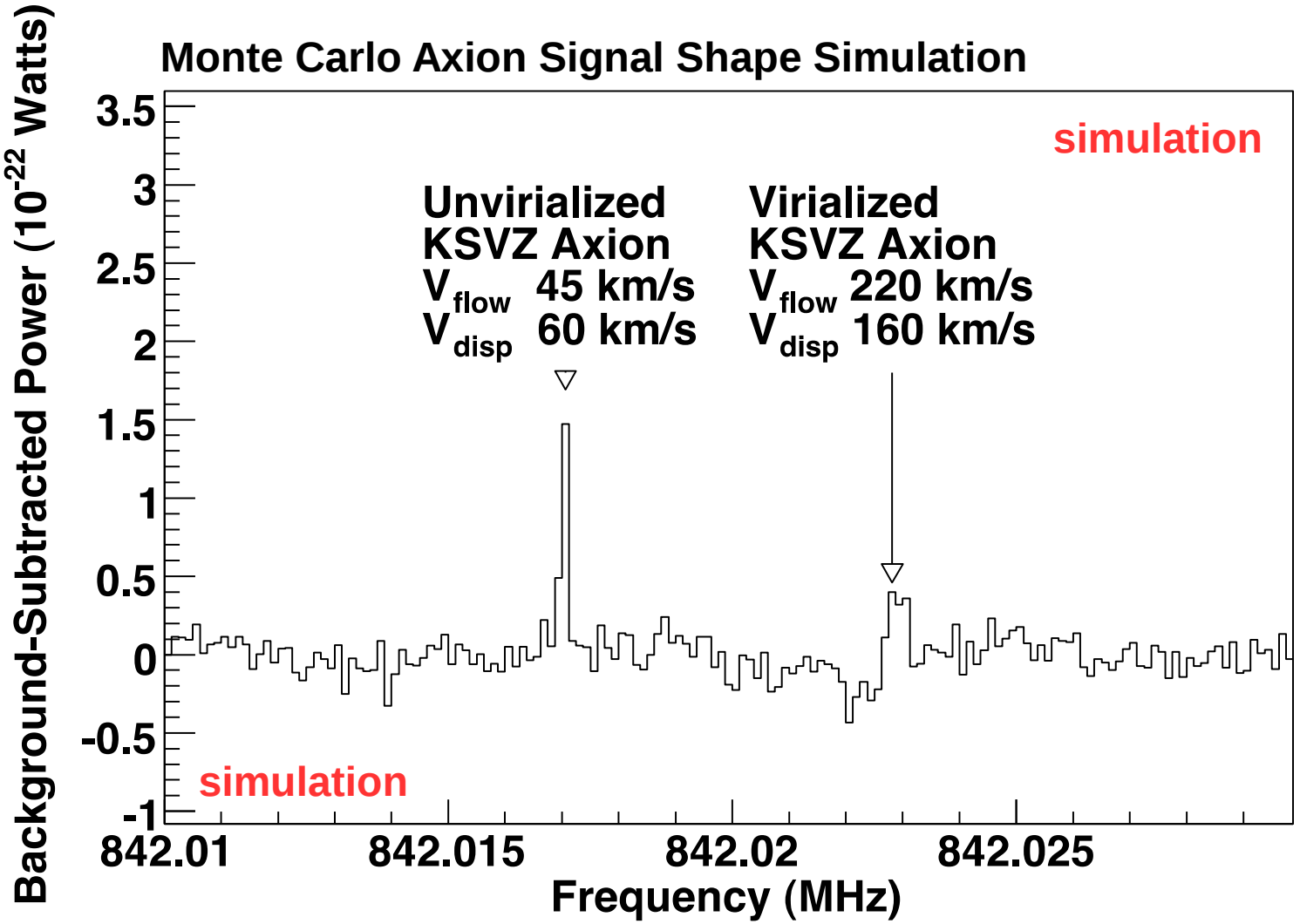

Cavity resonant frequency is tuned by two movable rods

Power spectra are measured at each rod position

Axion signal would appear as a constant power excess

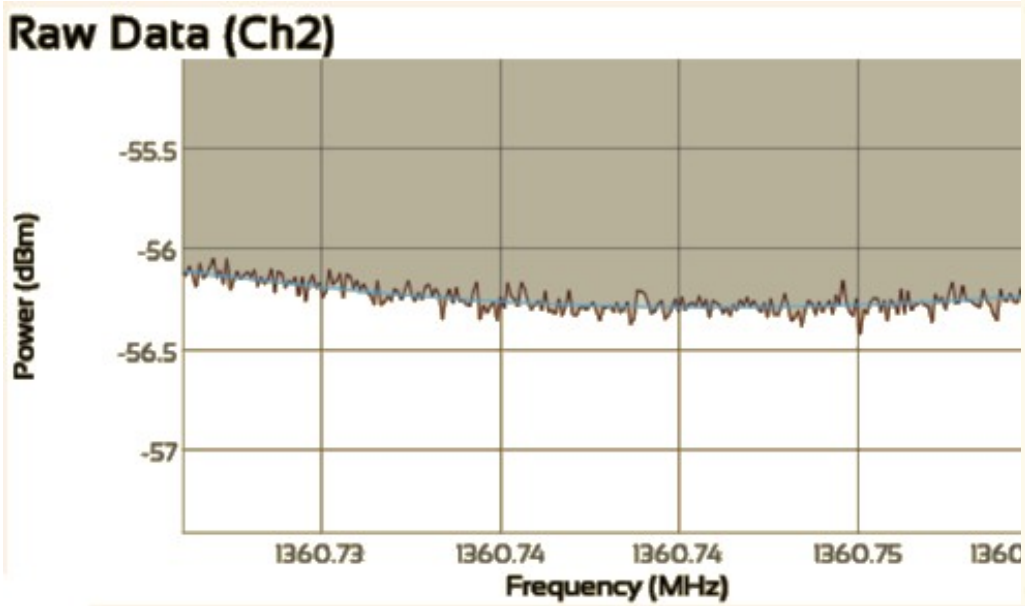
Most backgrounds do not persist

# ADMX Expected Signal

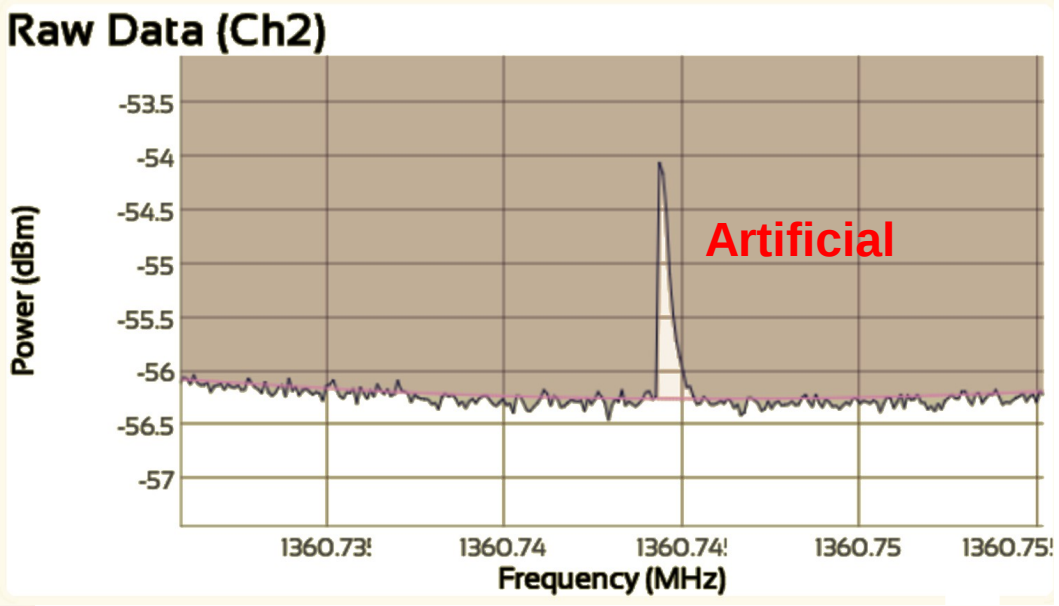


# Axion-Like Signal Calibration

**Single Raw Power Spectrum (100 second integration)**

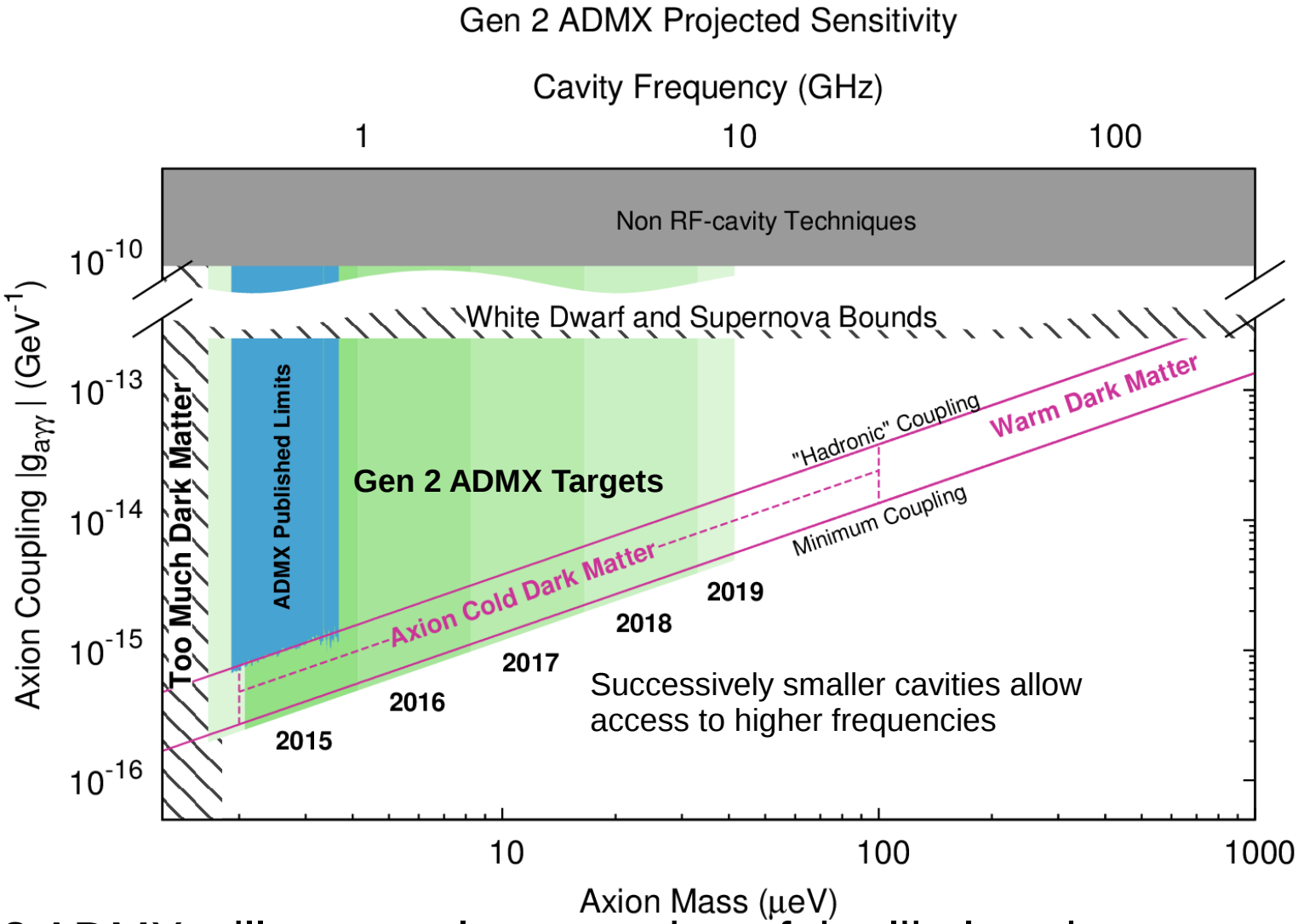



**Raw Spectrum with Artificially Generated Axion-Like Signal**




Injection of Axion-Like signals into cavity allow us to calibrate our analysis

# Gen 2 ADMX Program




Gen 2 ADMX will cover a large portion of the likely axion mass range at minimal couplings. We have a good chance at finding the axion.

# Key Technology: Sub-Kelvin Cooling

Time to scan axion mass range a 2010 speed: ~100 years

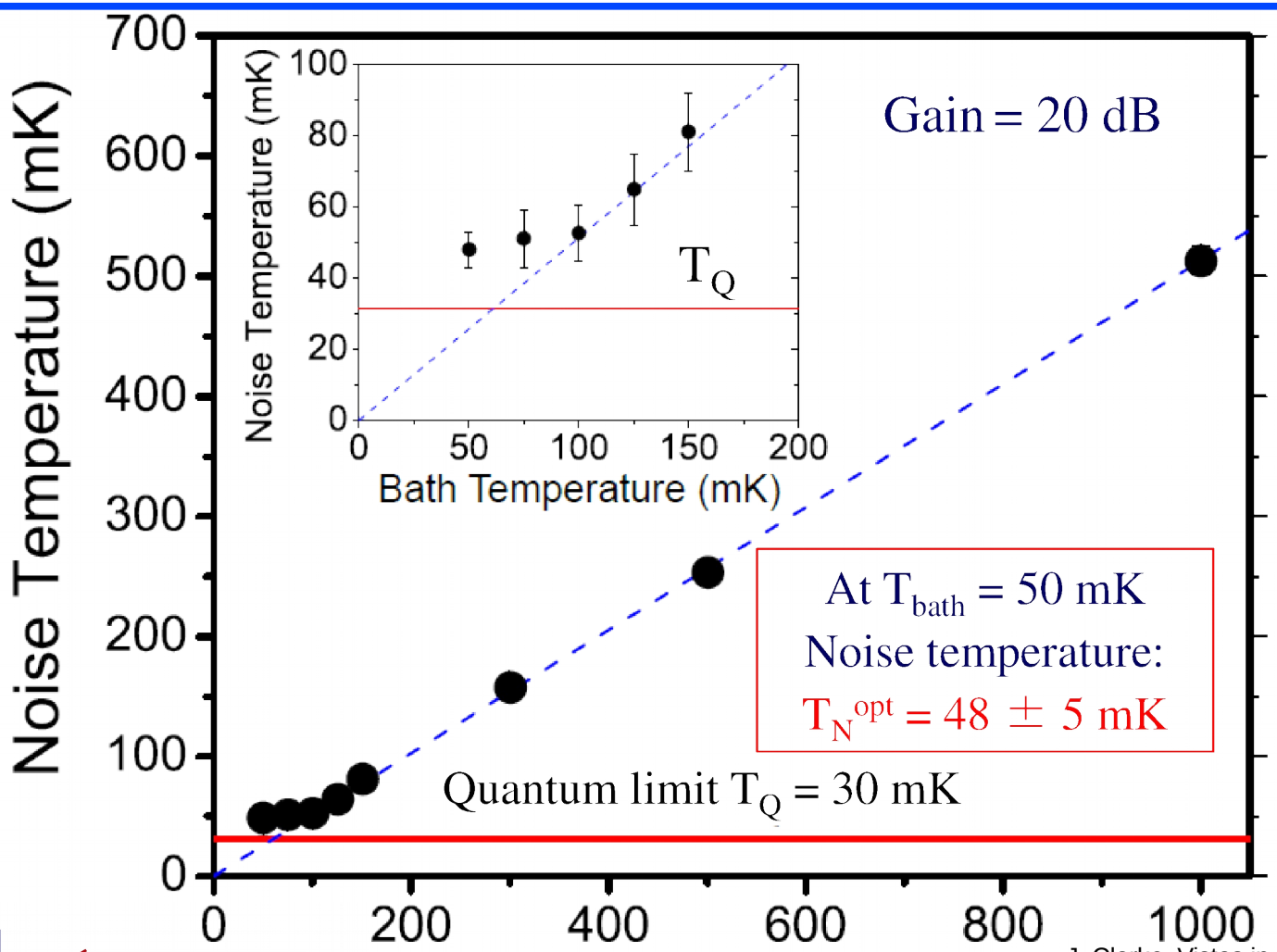
Scan Speed $\frac{df}{dt} \propto \frac{1}{T_{noise}^2}$

Want to run faster? **Run colder!**

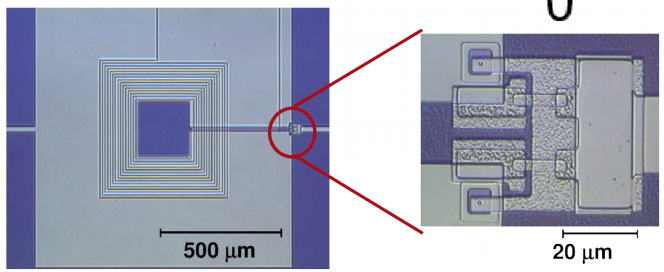
Noise comes from amplifiers and physical temperature

$T_{noise} = T_{amplifier} + T_{physical}$

# Key Technology: Quantum-limited Amplifiers

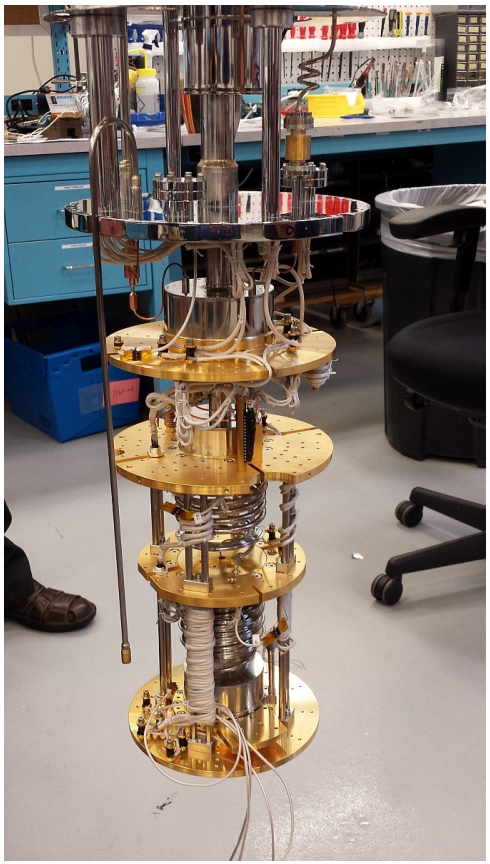



J. Clarke, Vistas in Axion Physics, 2012

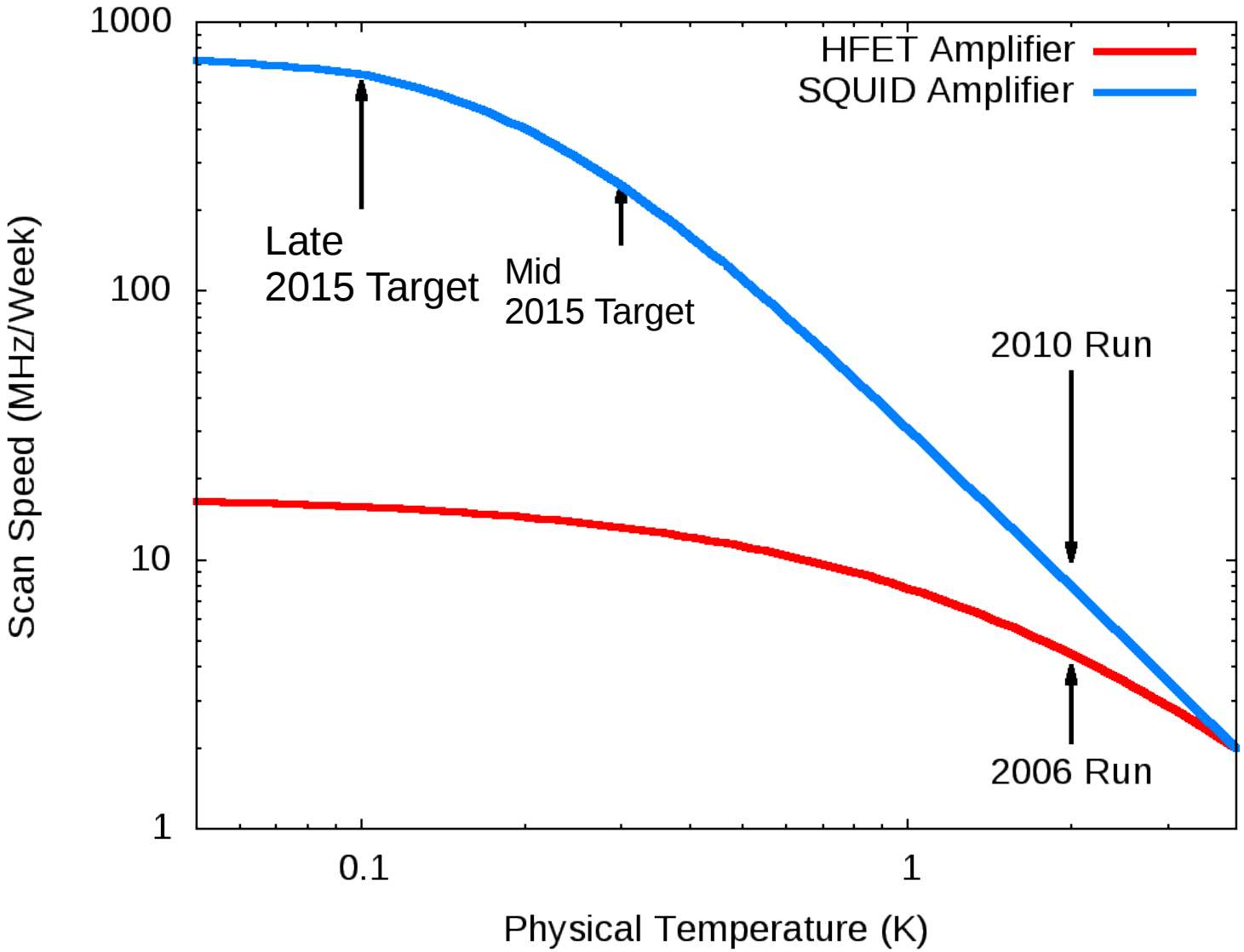



Below 1 GHz: SQUIDs
Above 1 GHz: JPAs

# ADMX Gen 2 Key technologies improve scan speed immensely

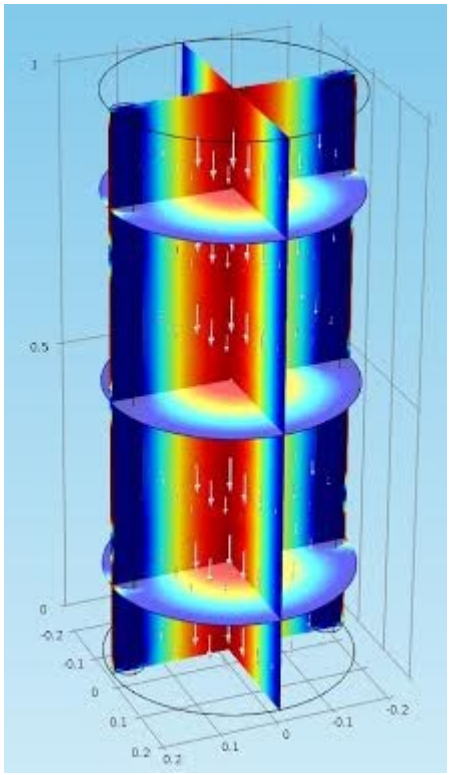


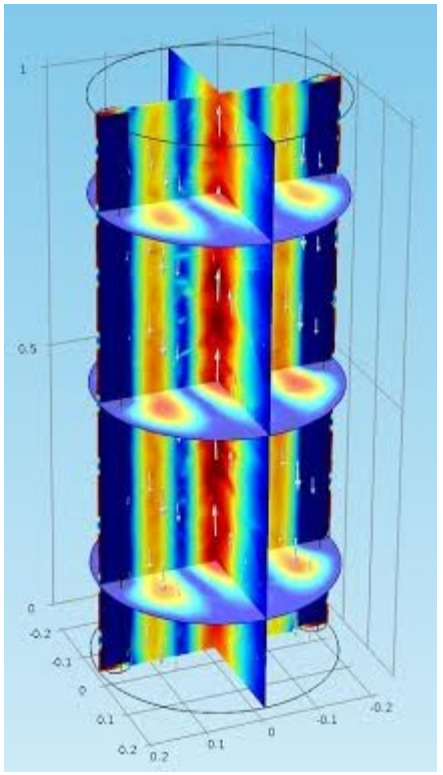
Dilution refrigerator under test. Currently being packed for shipment to to UW.



# Another Gen 2 Improvement: Multimode Data Taking

$$Sensitivity \propto E_z \cdot B_z$$





$TM_{010}$

Tuning Range 400-900 MHz

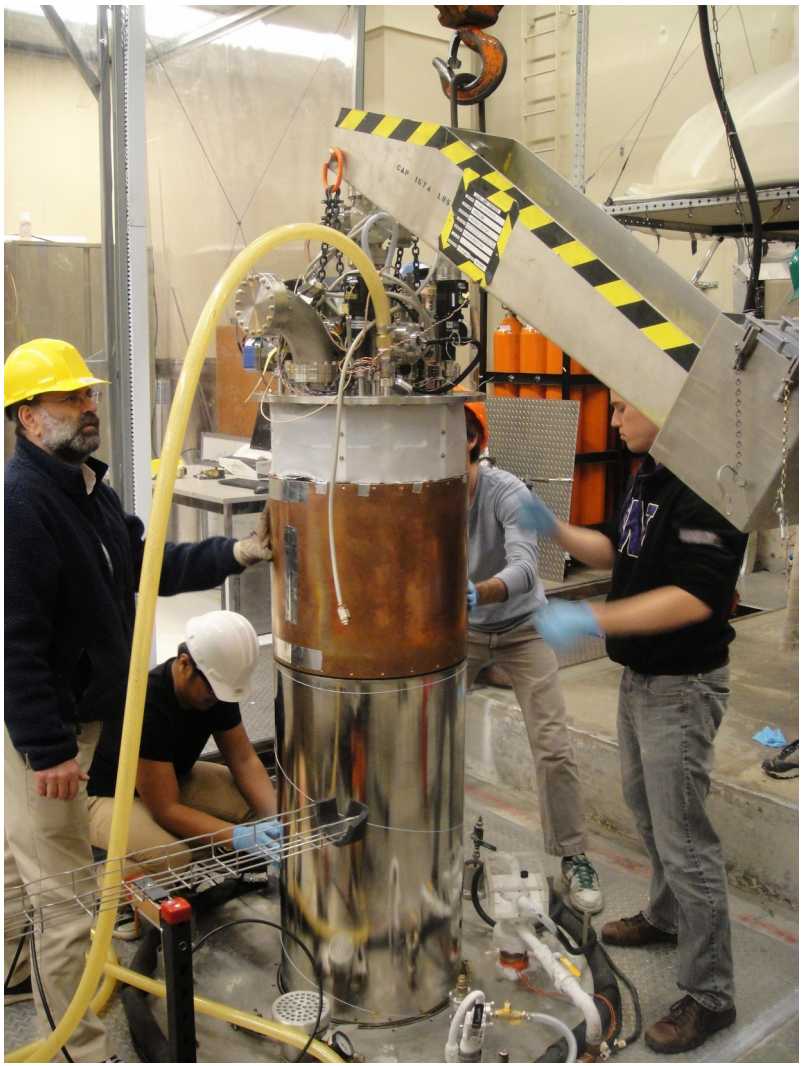
Relative Power 1.0

$TM_{020}$

Tuning Range 920-2,100 MHz

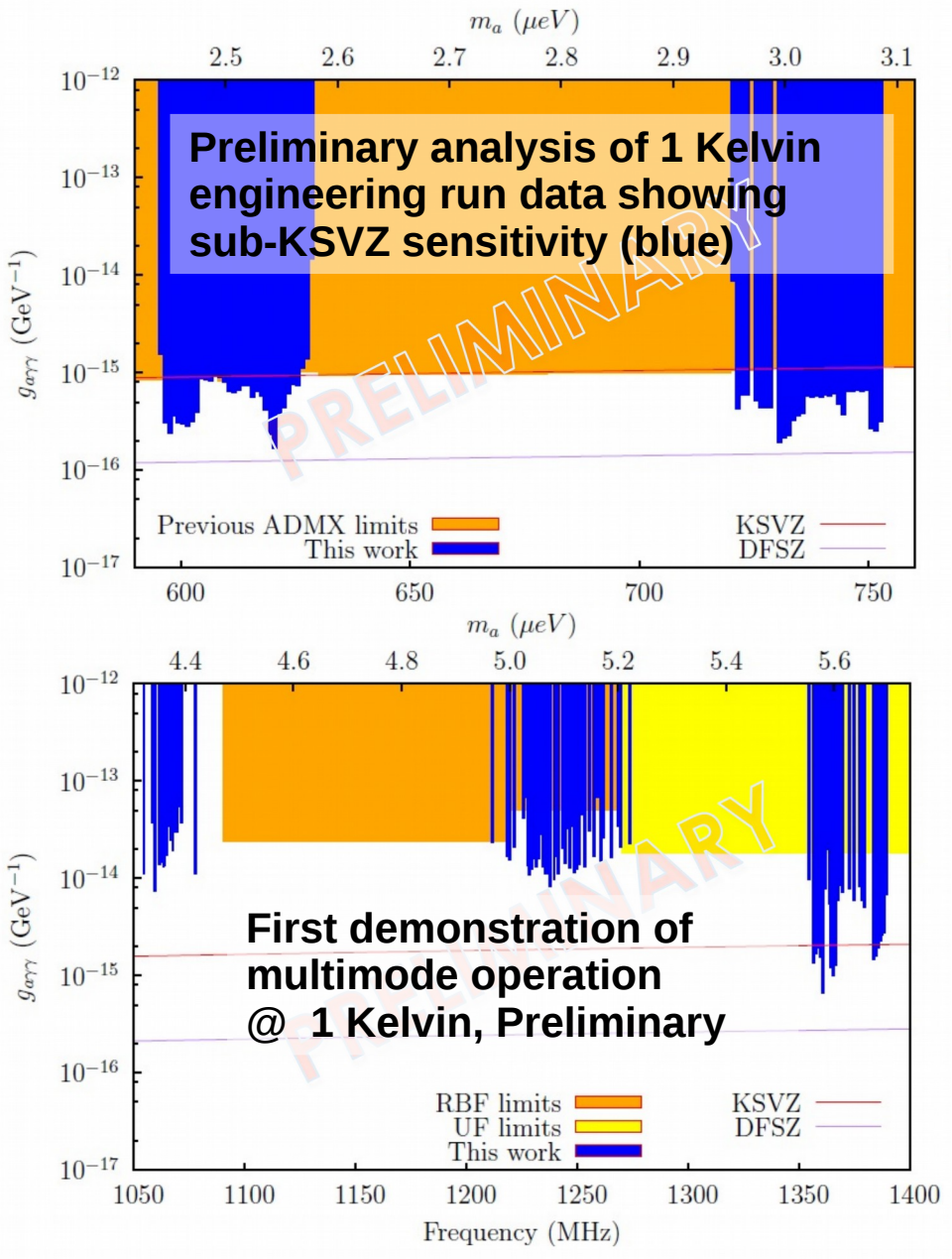
Relative Power 0.41

# ADMX Recent Engineering Run



System exercised Summer/Fall 2014

# ADMX Recent Engineering Run




Summer/Fall 2015 Engineering Run @ 1K:

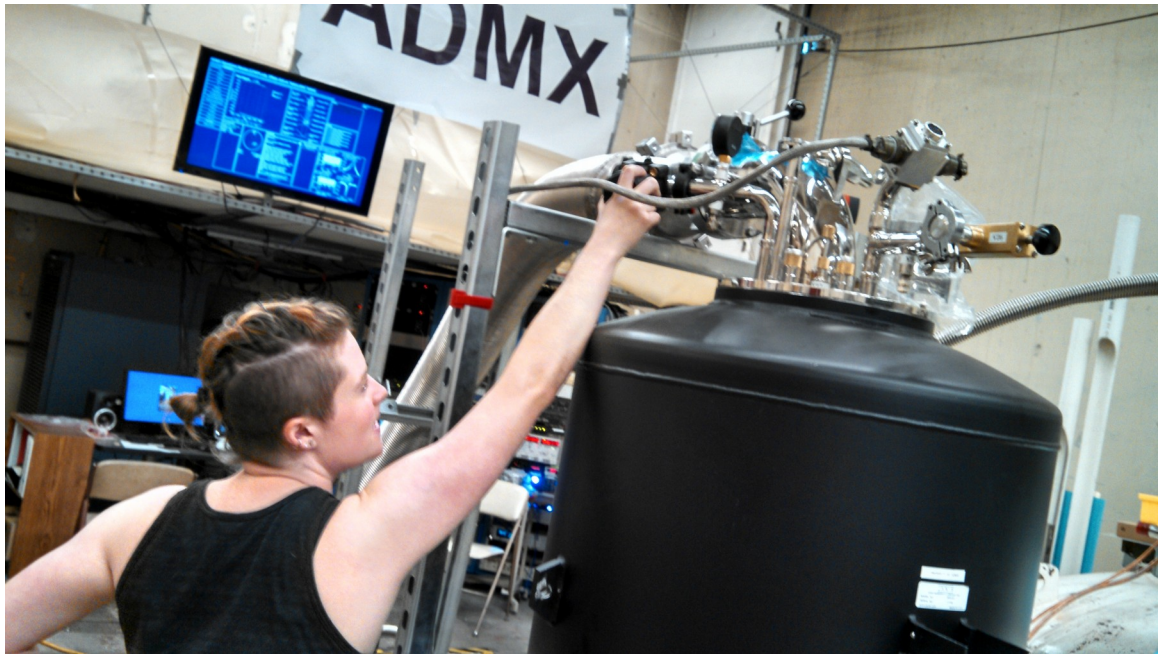
- Verified magnet functionality after move to Seattle
- Verified functionality of rebuilt experimental insert/cavity system
- Tested thermal performance of redesigned cryogenic system at 1K
- Tested in-situ noise measurement of SQUID amplifier

Same data taken used for graduate thesis (Lyapustin, 2015): Study of multimode tuning and sensitivity of new system

# ADMX Gen 2 Status

Dilution Refrigerator
Commissioning in progress at the University of Washington

All other subsystems are ready to go.

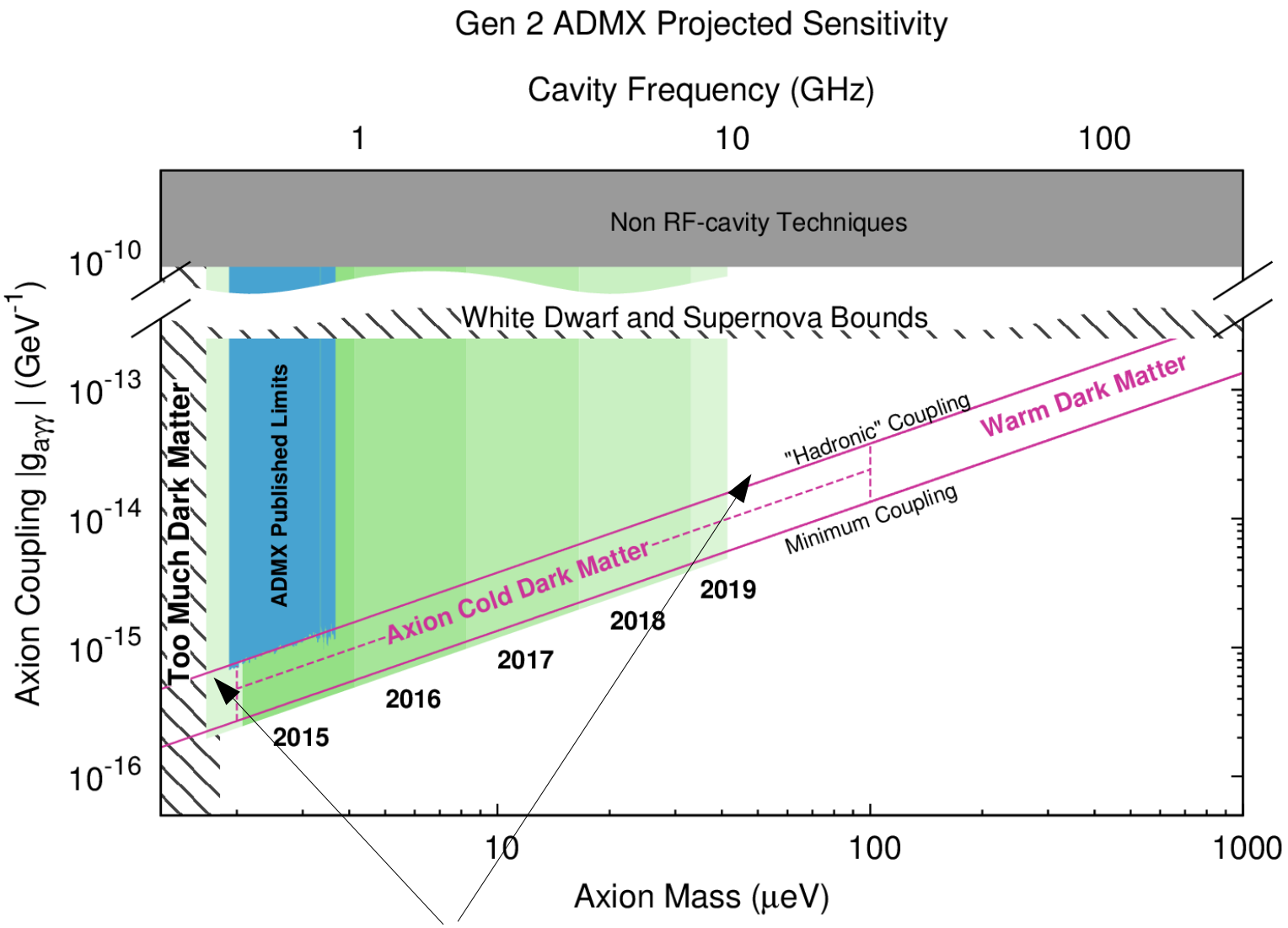


# ADMX Gen 2 Near Term Schedule

*Summer/Fall 2015*: Dilution Refrigerator Commissioning

*Fall/Winter 2015*: Data Taking Begins

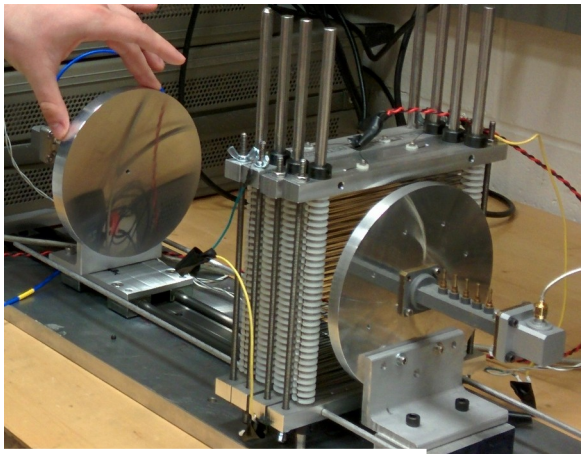
# Expanding ADMX's Mass Range



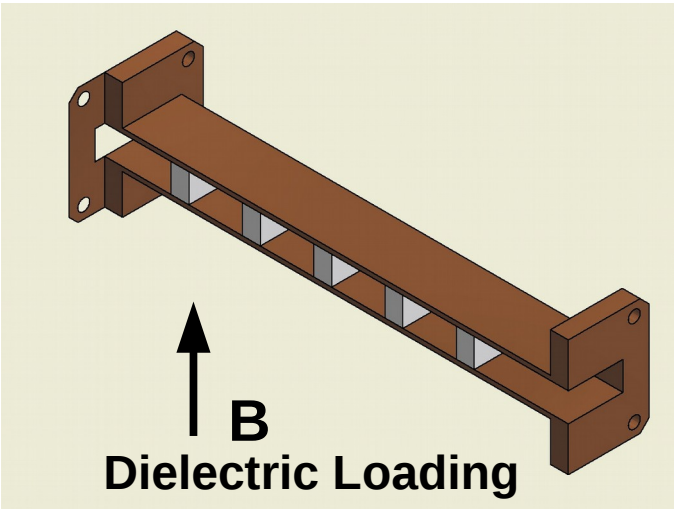

How do we reach here?

# ADMX Higher Frequency Projects Underway

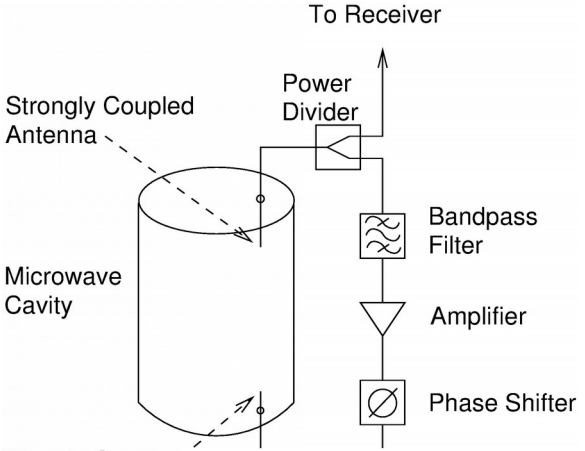
***A subset of ideas being explored...***



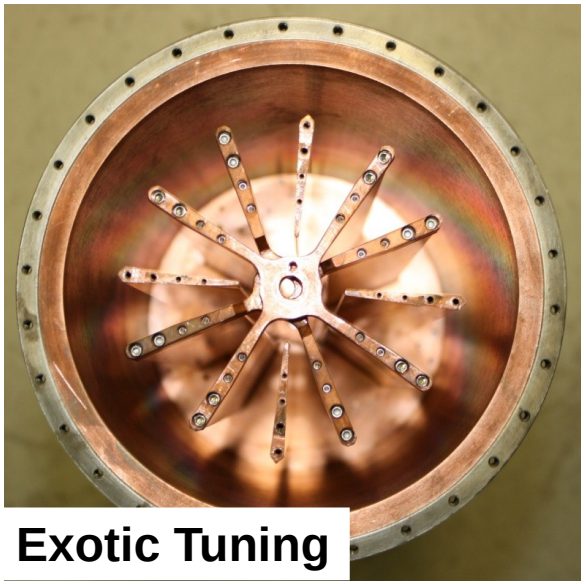
**Open Resonators**



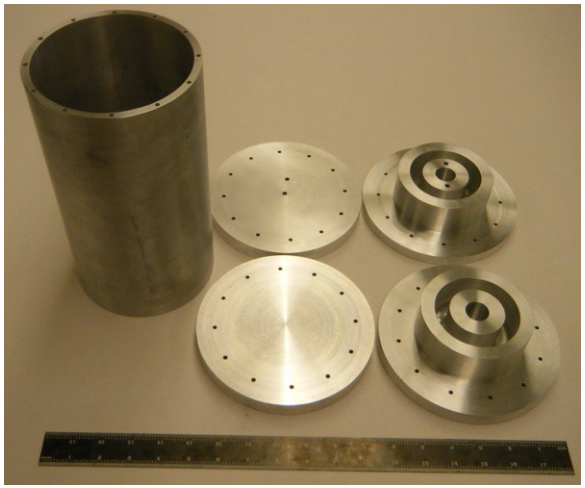

**Dielectric Loading**



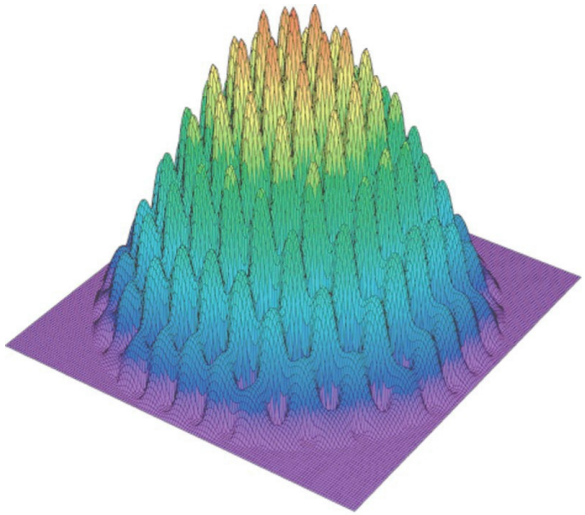

**Active Resonators**



**Exotic Tuning**



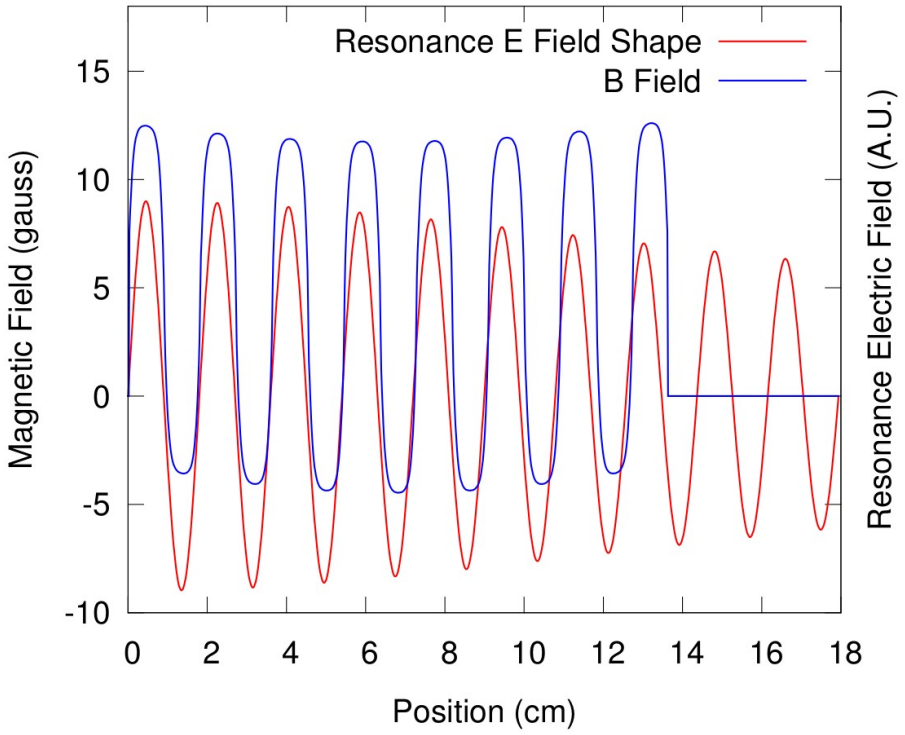
**Re-entrant Cavities**

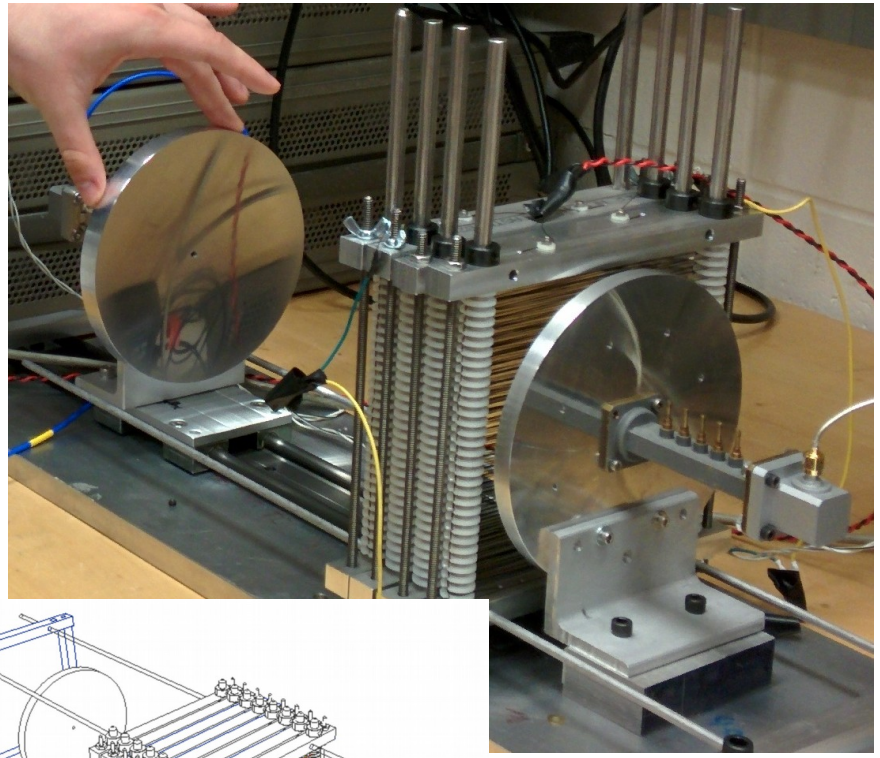


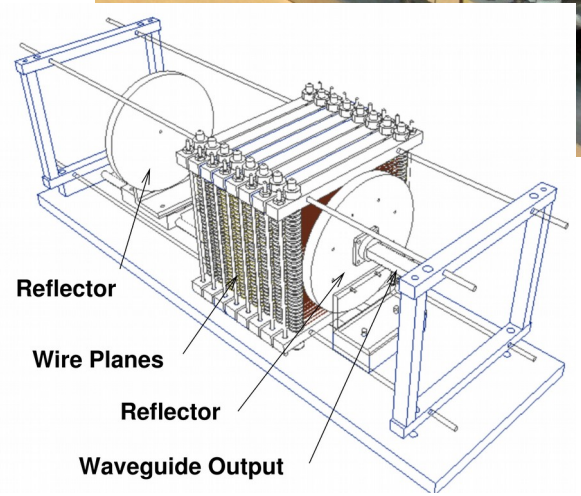
**Photonic Bandgap Cavities**

# Open Resonators

Open resonators with spatially varying magnetic fields or resonances distorted by dielectrics allow for coherent dark matter axion conversion over volumes larger than traditional resonators



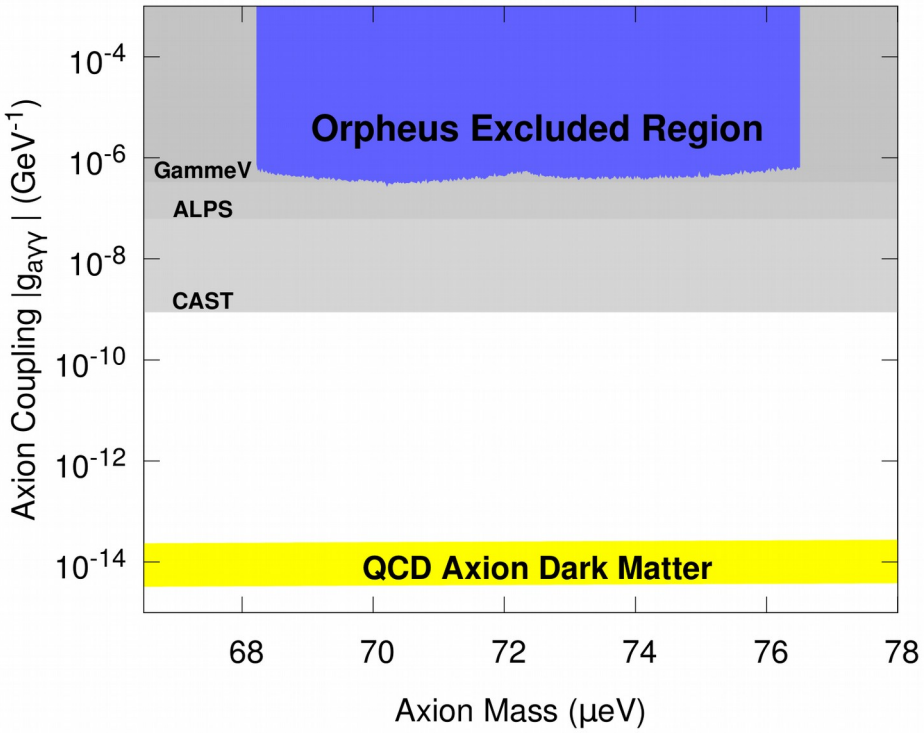


# Open Resonators

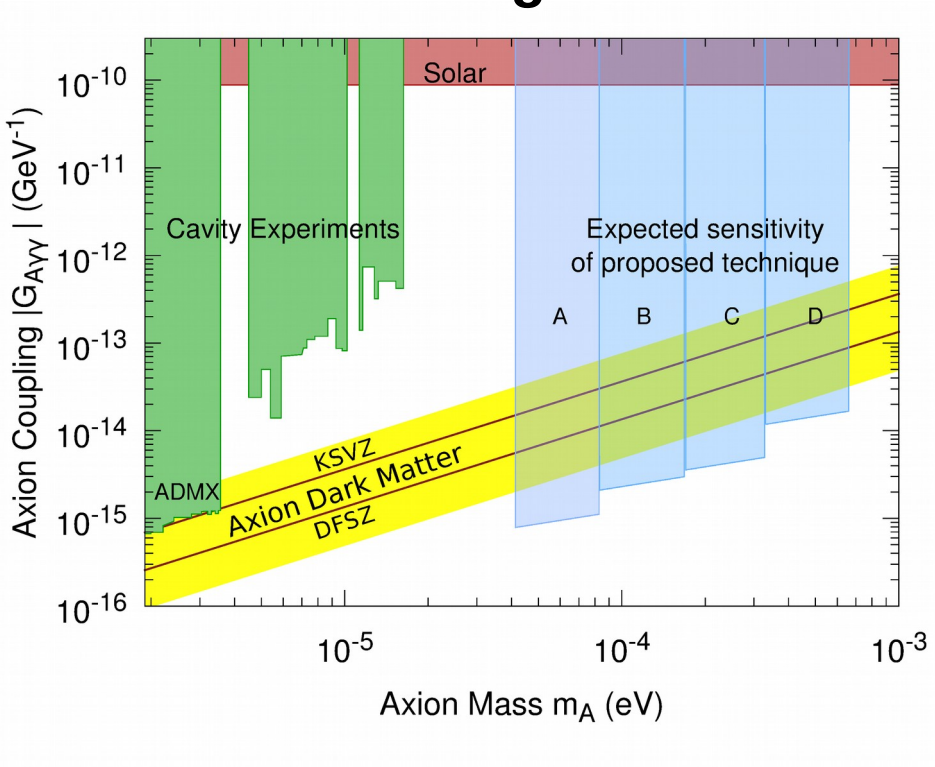
Benchtop prototype results have been promising

Rybka et al. Phys. Rev. D 91, 011701(R) (2015)

**Limits from Benchtop Prototype**

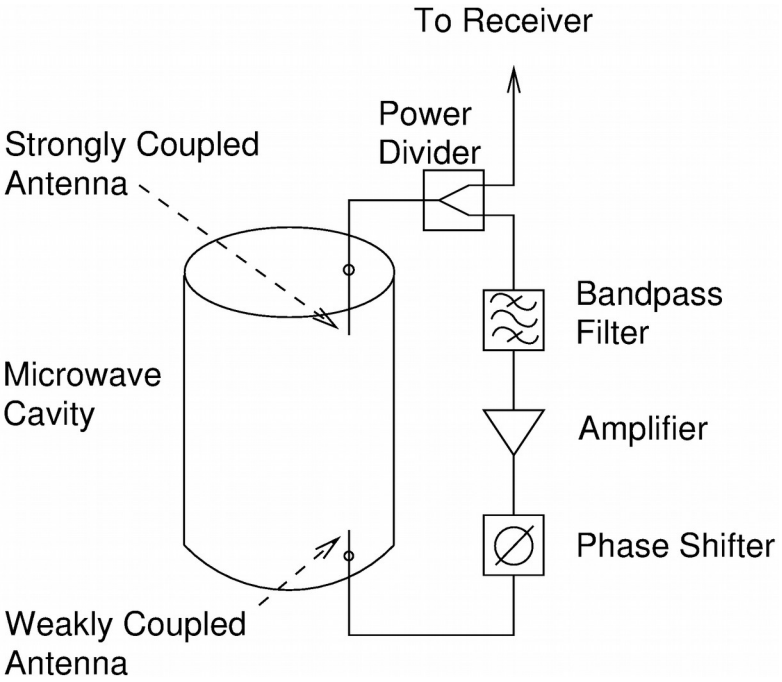



**Projected sensitivity at technological limit**




Larger, cryogenic prototype design in progress

# Active Resonators

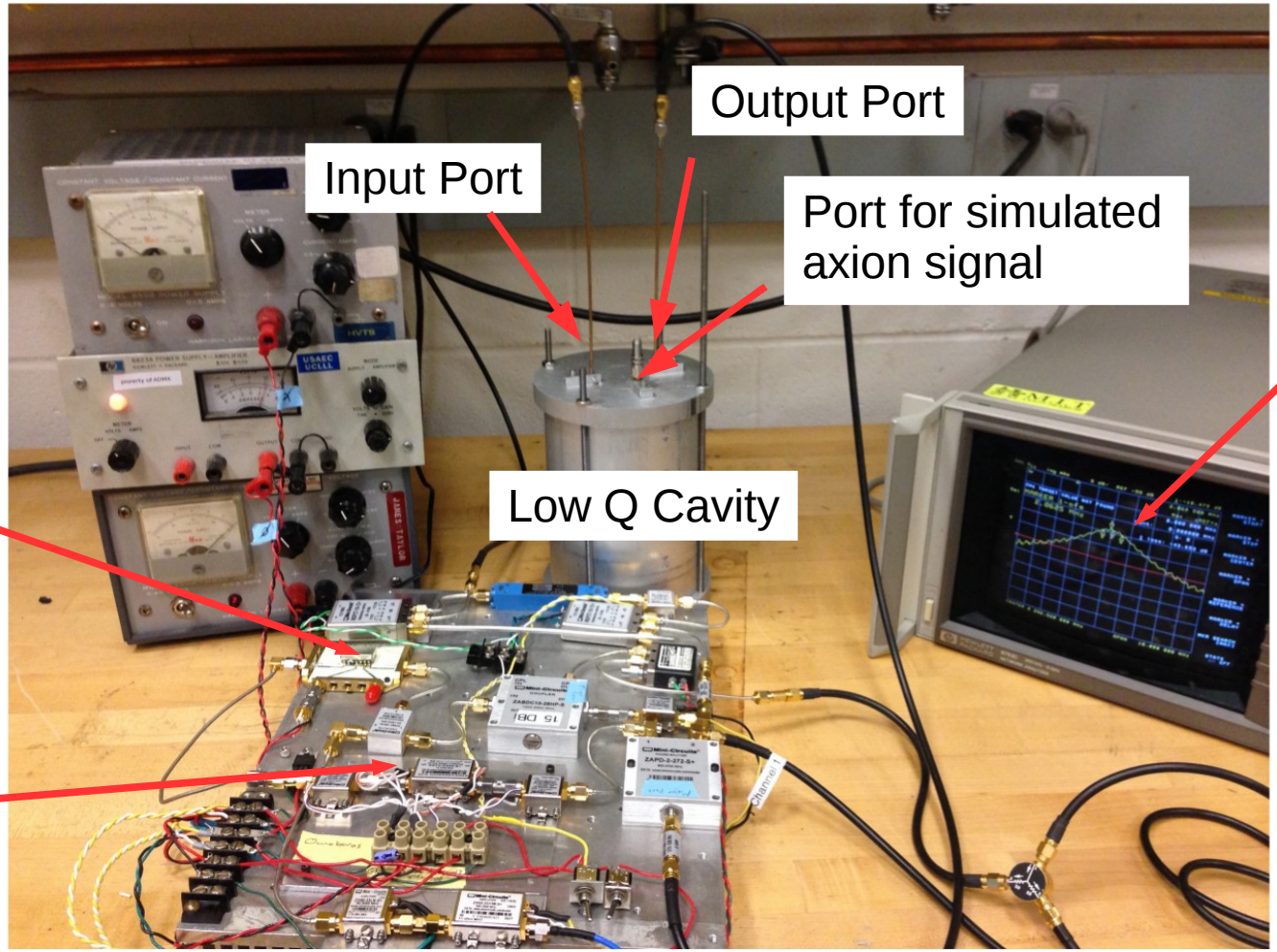



- Axion field acts as a source term in Maxwell's equations, just like a current.
- In this view, weak axion to cavity coupling is an impedance mismatch issue.
- Feedback circuits are commonly used to actively match impedances .
- This effectively increases the Q of the resonator.

Study on implementing for ADMX underway.

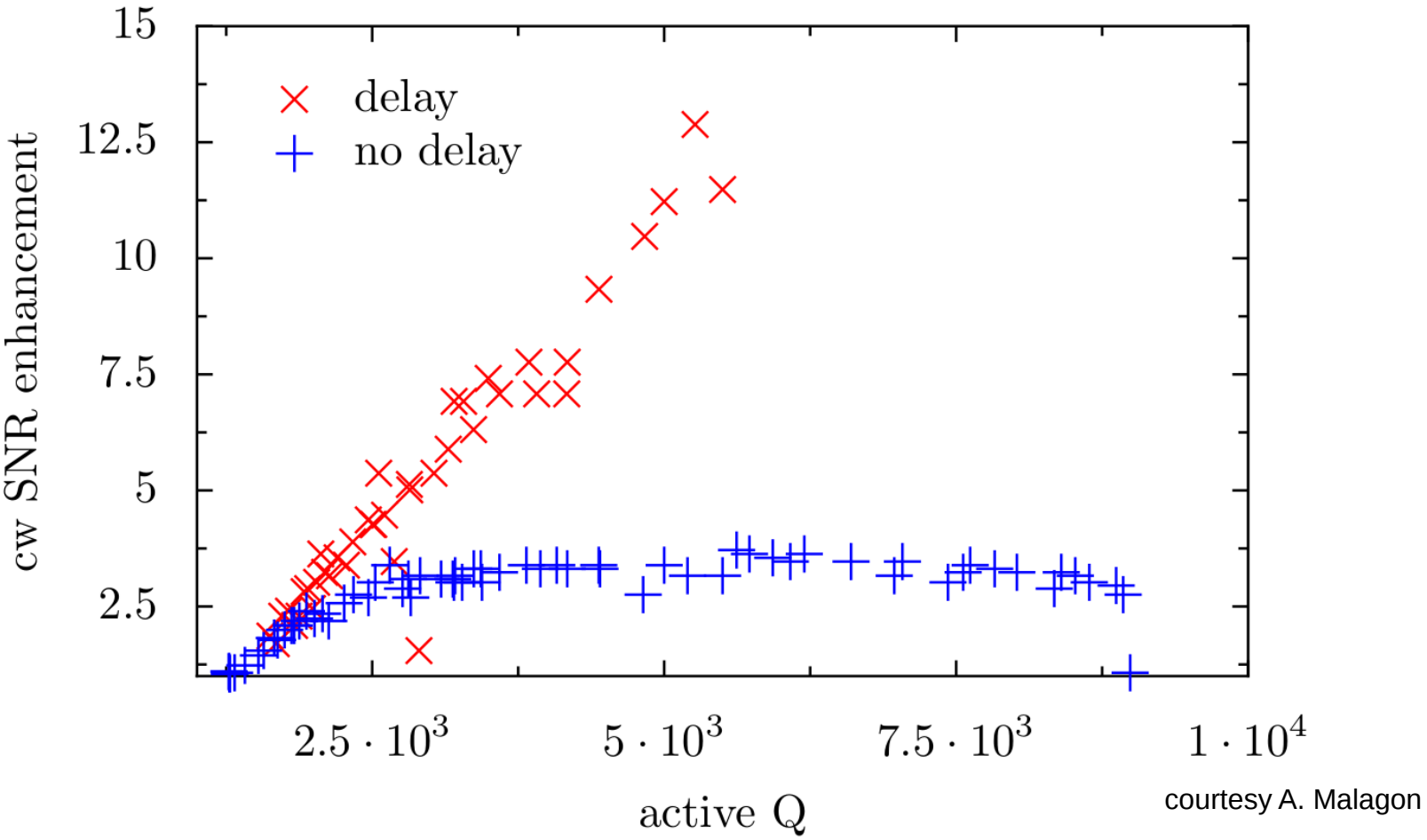
# Active Resonators

System can be demonstrated using weakly coupled antenna to simulate axion coupling



# Active Resonators

SNR Enhancement with synthetically generated axion-like RF signal




courtesy A. Malagon

# Conclusions

*Science*, Nov. 2013, 552 - 555

**Gen 2 ADMX is poised**

*to explore the classical dark matter axion window, starting this year.*

**ADMX will be definitive**

*if dark matter is made of QCD axions when we test a mass range we will see it, even at pessimistic couplings.*

**We are expanding our mass coverage**

*with the goal of exploring highest possible masses.*

**We are going to find axion dark matter**

*if it is out there.*