Title: ADMX: The Axion Dark Matter Experiment

Date: Sep 30, 2014 01:00 PM

URL: http://pirsa.org/14090067

Abstract: Axions are an exceptionally well-motivated dark matter candidate in addition to being a consequence of the Peccei-Quinn solution to the strong CP problem. ADMX (Axion Dark Matter eXperiment) has recently been selected as the axion search for the US DOE Second-Generation Dark Matter Program. I will discuss the imminent upgrade of ADMX to a definitive search for micro-eV mass dark matter axions as well as the ongoing research and development of new technologies to expand the reach of ADMX to the entire plausible dark matter axion mass range.

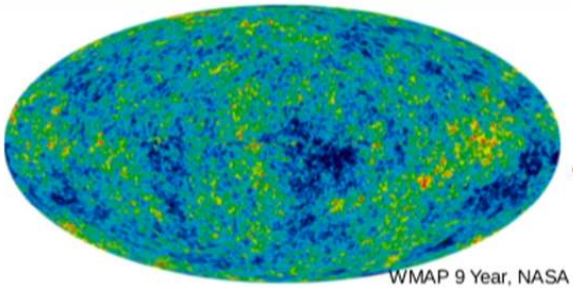
ADMX: The Axion Dark Matter Experiment

Science, Nov. 2013, 552 - 555

Gray Rybka
University of Washington

Perimeter Institute
October 2014

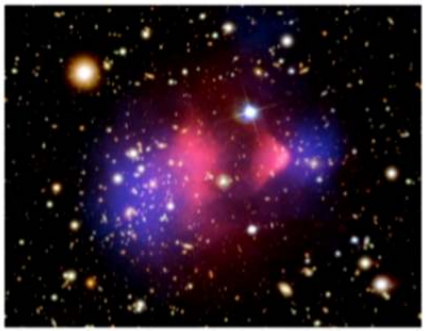
Dark Matter At All Scales



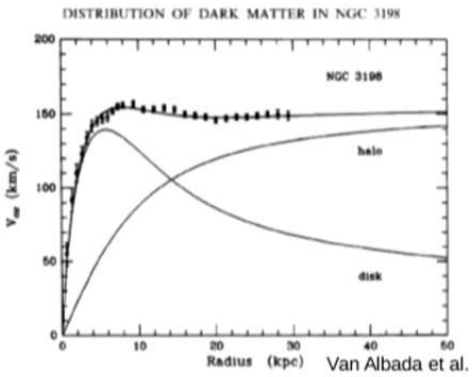
WMAP 9 Year, NASA

Our Hubble volume

Clusters of Galaxies



Composite: NASA, Markevitch etal., Clowe et al.



Van Albada et al.

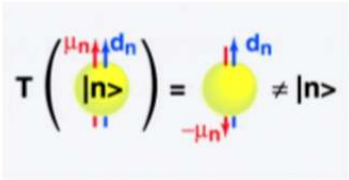
Individual Galaxies

In the laboratory?

QCD Axions

The Strong CP Problem

Lack of neutron electron dipole moment indicates strong force is CP invariant



edm<3·10^{-26} e-cm
Baker et al.
PRL 97 2006

How can the weak force be CP violating but the strong force remains CP invariant? O(10^{-10}) cancellation required

The Peccei-Quinn Solution

Add a dynamic field, spontaneously broken, which cancels any strong CP violation

This results in a new pseudoscalar particle, the Axion

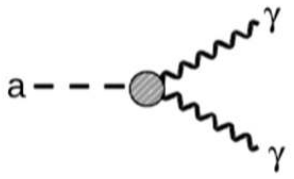
-Weinberg, Wilczek

Axions as Dark Matter

For the right mass range, axions are a good dark matter candidate

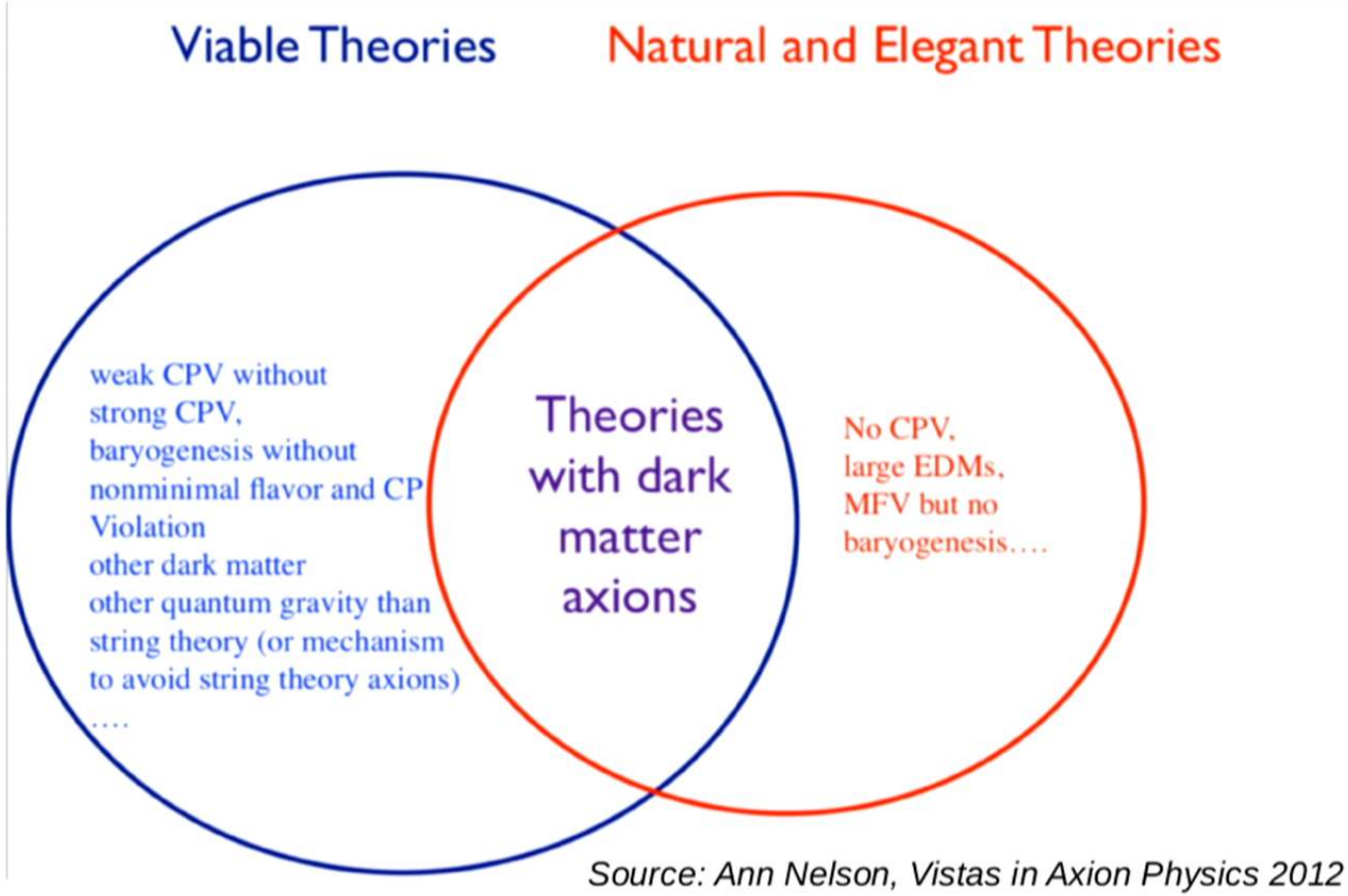
Classical window: 1 μeV to 1 meV
Axion interaction is extremely weak
Enough produced to be all of dark matter
Cold enough to be dark matter

Two photon coupling is the relevant interaction



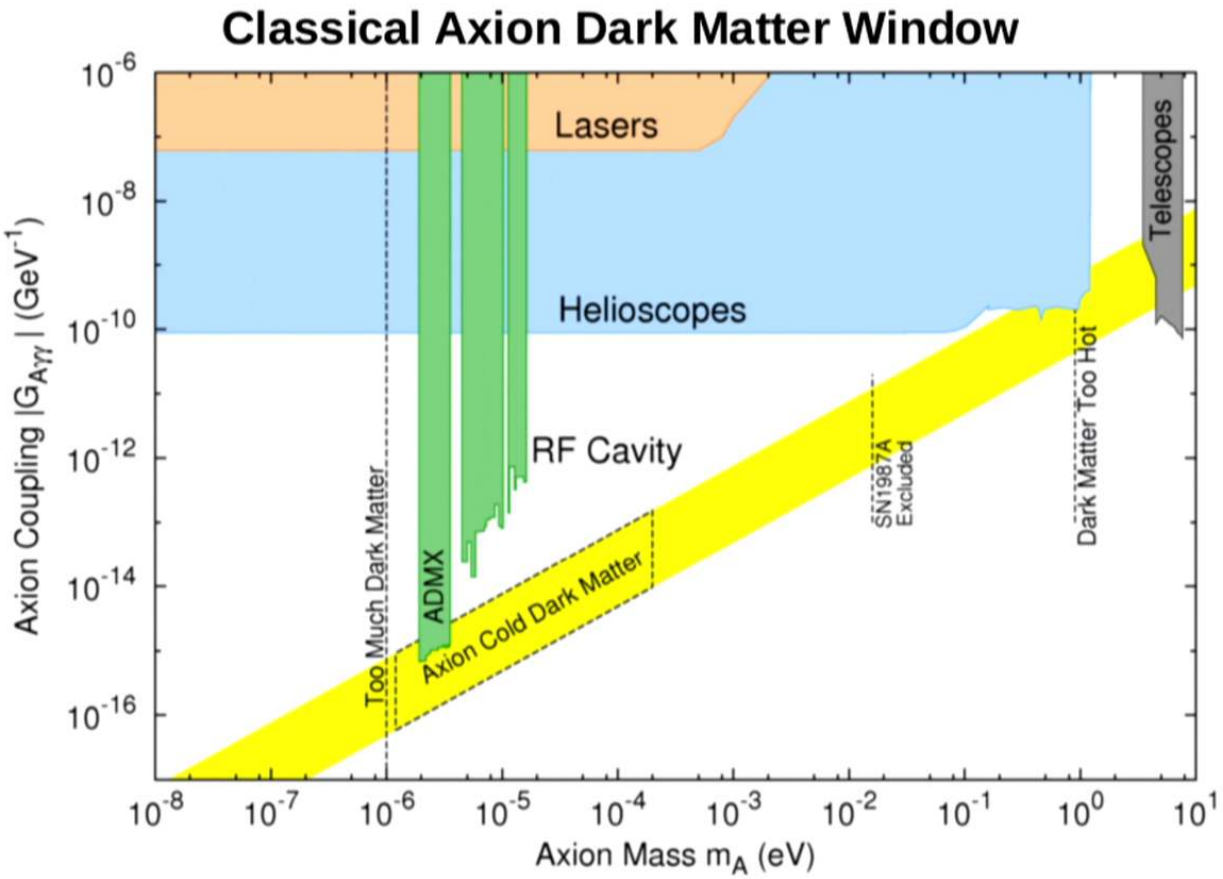
There are other windows (e.g. Anthropic window), that may or may not be affected by an observation of the scale of inflation, but this talk focuses on the classical window

Axion Motivation



Source: Ann Nelson, Vistas in Axion Physics 2012

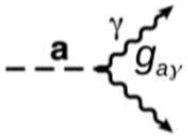
Axion Experiments



Detecting Axions

At these masses axion dark matter is best treated as a classical field

The axion-photon coupling…

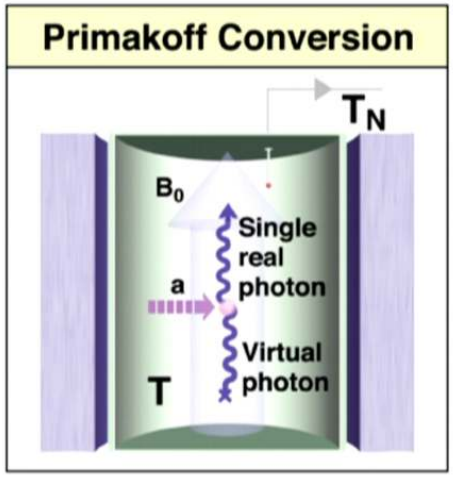


…is a source term in Maxwell's Equations

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

So, e.g., imposing a strong external magnetic field B transfers dark matter axion field energy into electromagnetic energy.

Axion Haloscope



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

University of Washington

LLNL

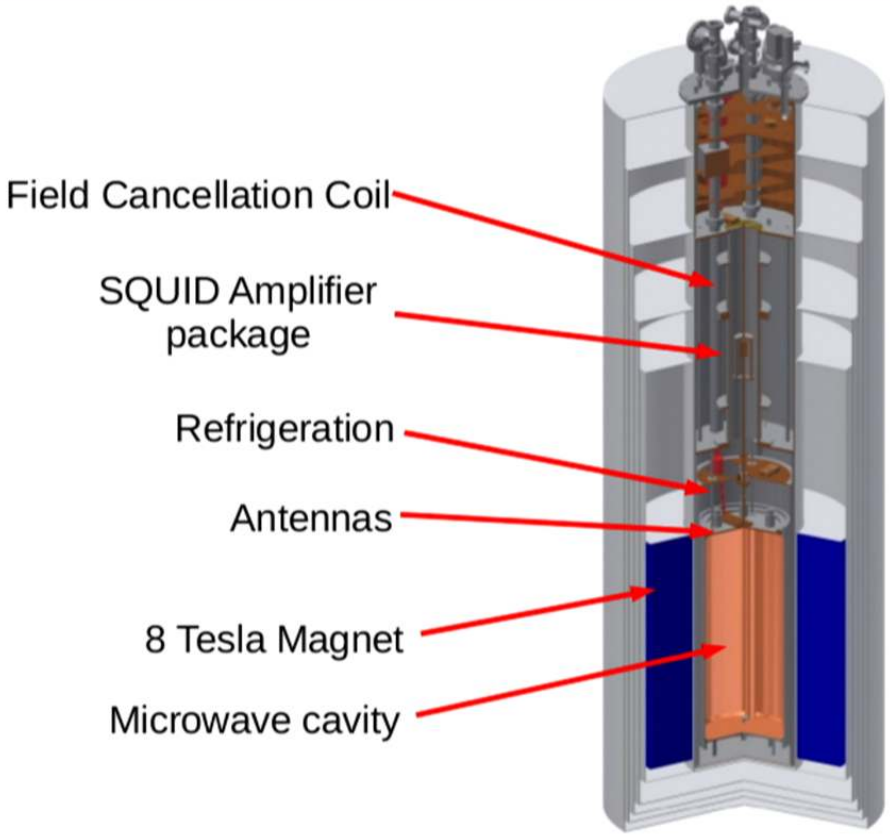
University of Florida

Yale

UC Berkeley

NRAO

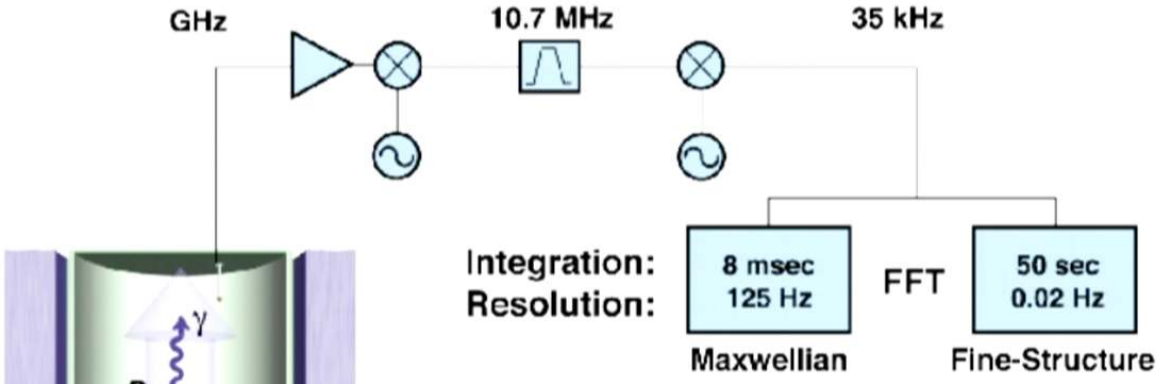
ADMX Design



Insert + Magnet Schematic

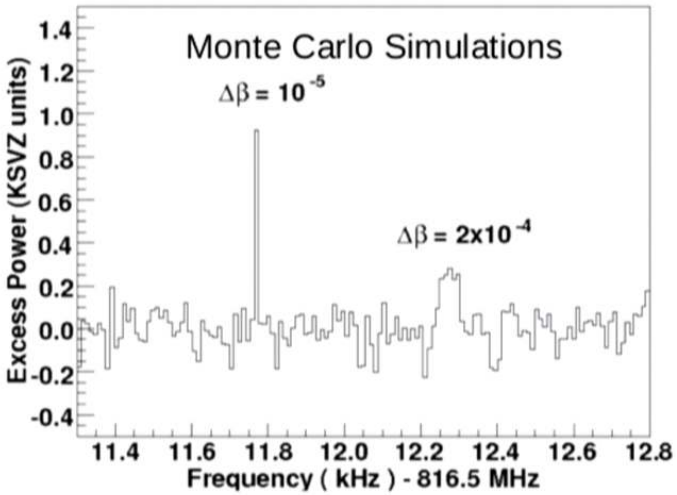
Insert extraction from magnet

ADMX Receiver

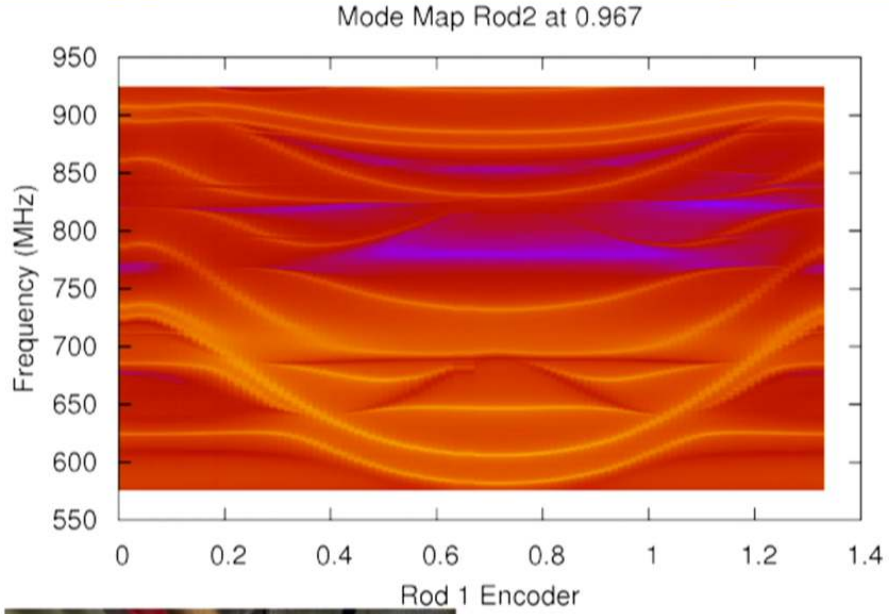


B=8 Tesla

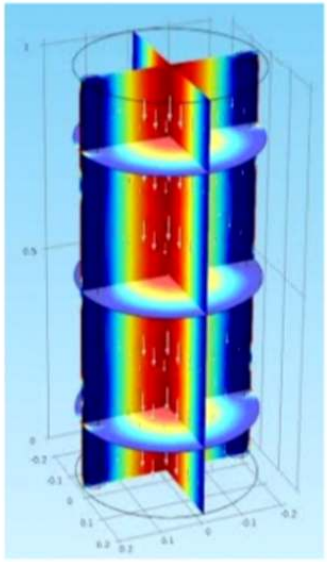
Axions, stimulated by a magnetic field, decay into microwave photons which resonate in the cooled cavity and are amplified and read out



Tuning

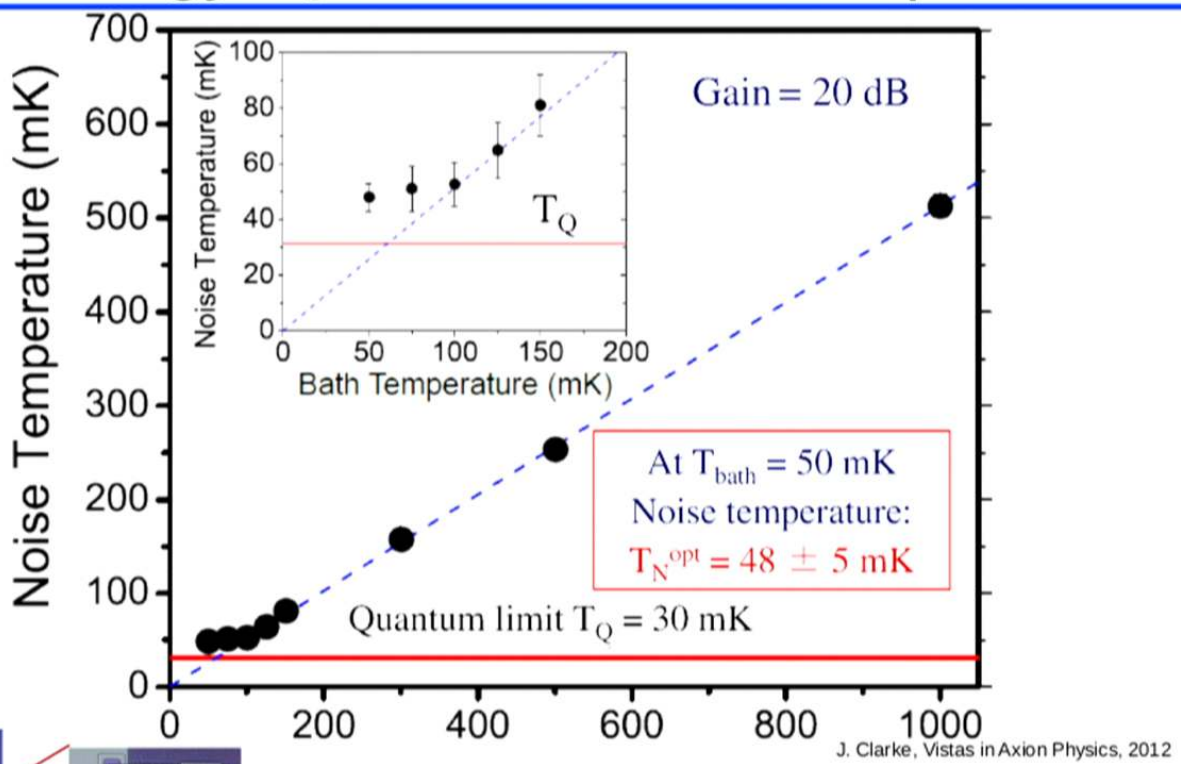


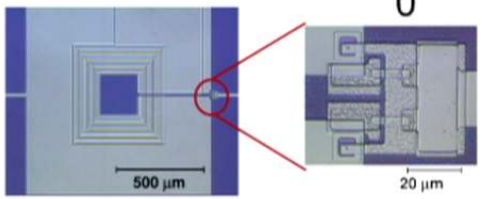
Cavity with lid off, showing tuning rods



Field simulation of TM010 mode, no rods

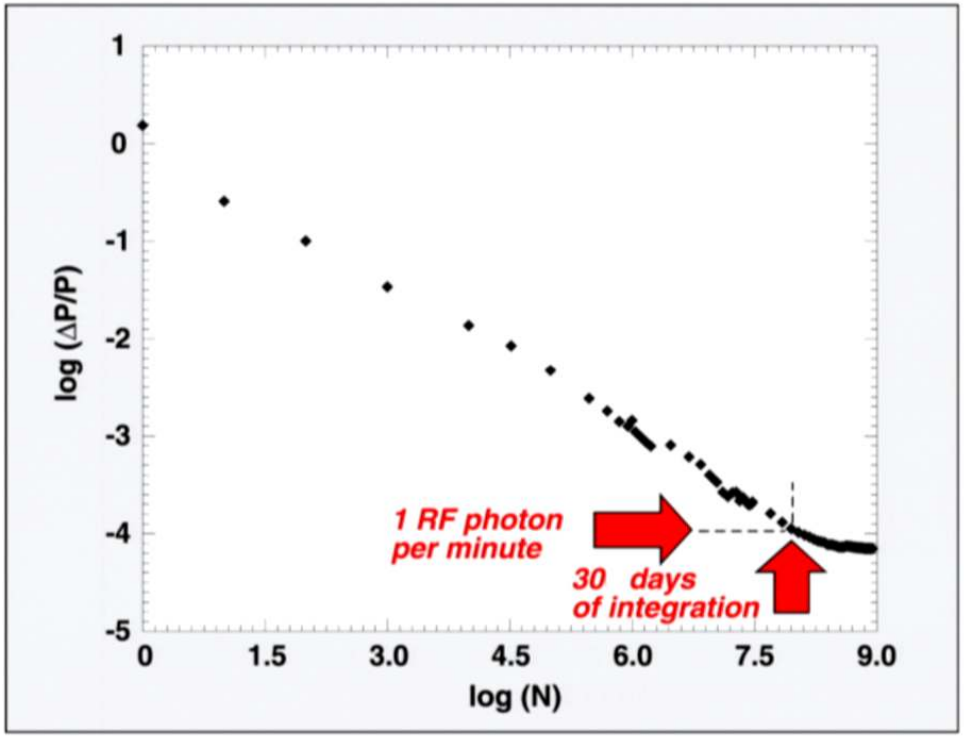
Key Technology: Quantum-limited Amplifiers





Below 1 GHz: SQUIDs
Above 1 GHz: JPAs

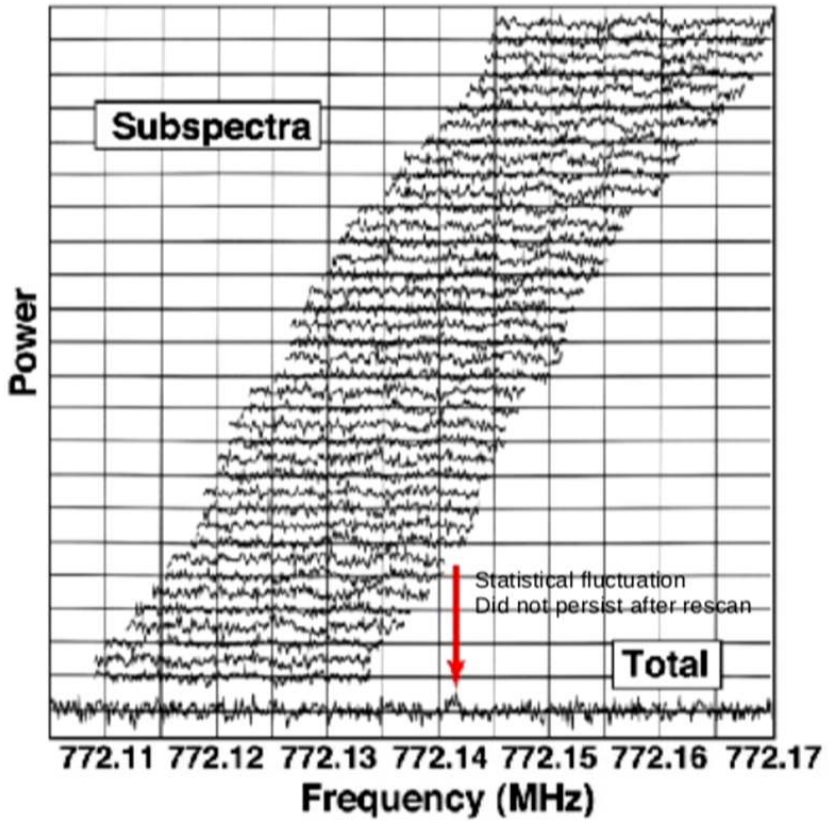
Sensitivity



Systematics limited after 1 month integration

Sensitivity 0.01 Yoctowatt. Characteristic Axion Power: 100 Yoctowatts

Axion Search Technique



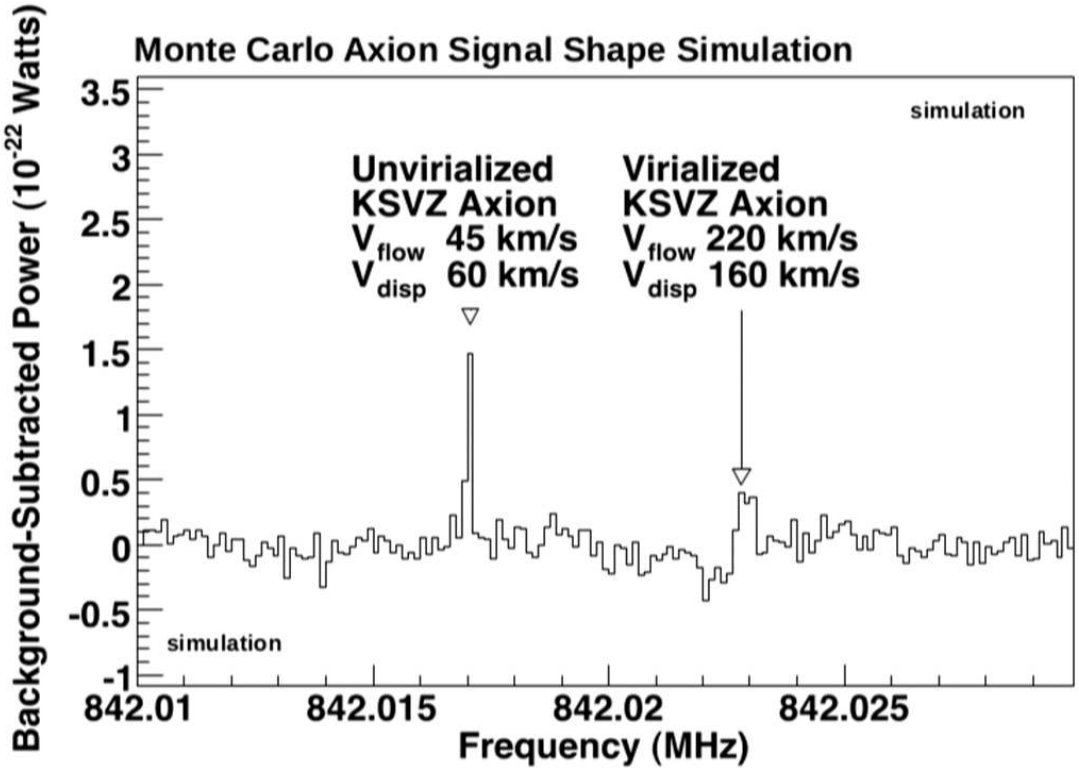
Cavity resonant frequency is tuned by two movable rods

Power spectra are measured at each rod position

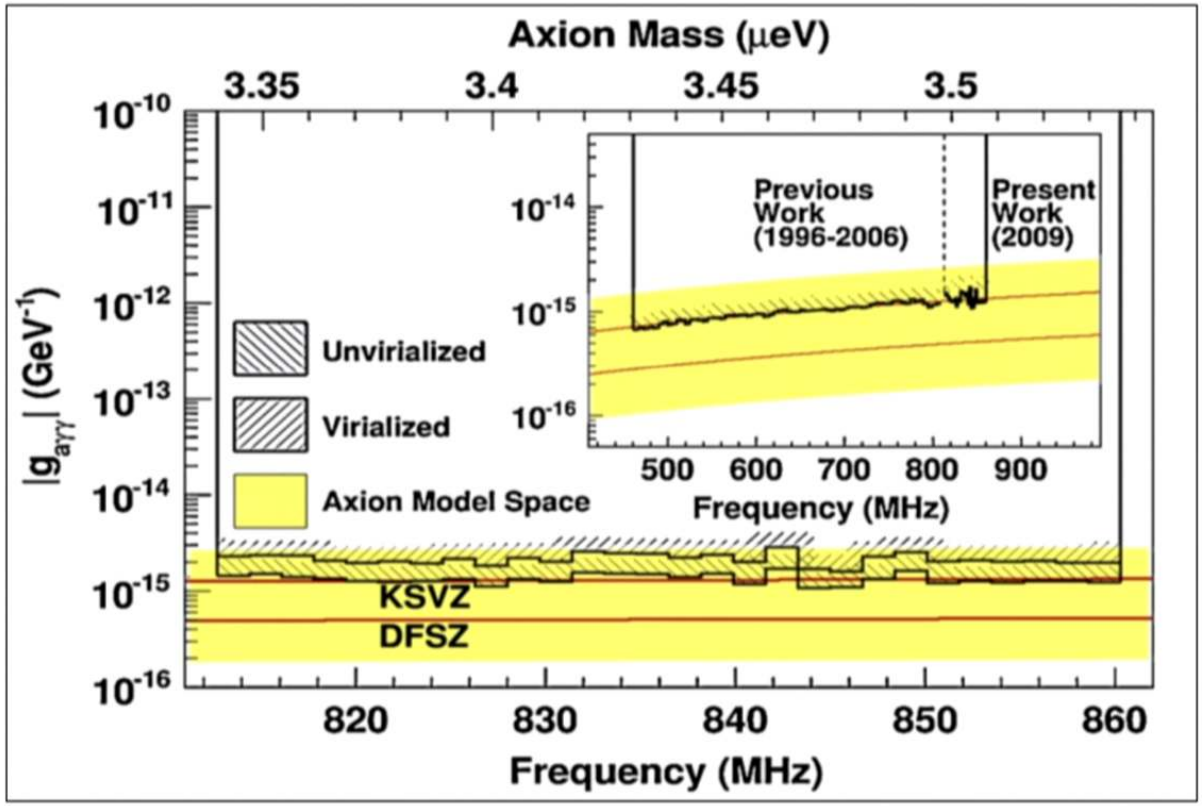
Axion signal would appear as a constant power excess

Most backgrounds do not persist

Predicted Axion Signal Shape



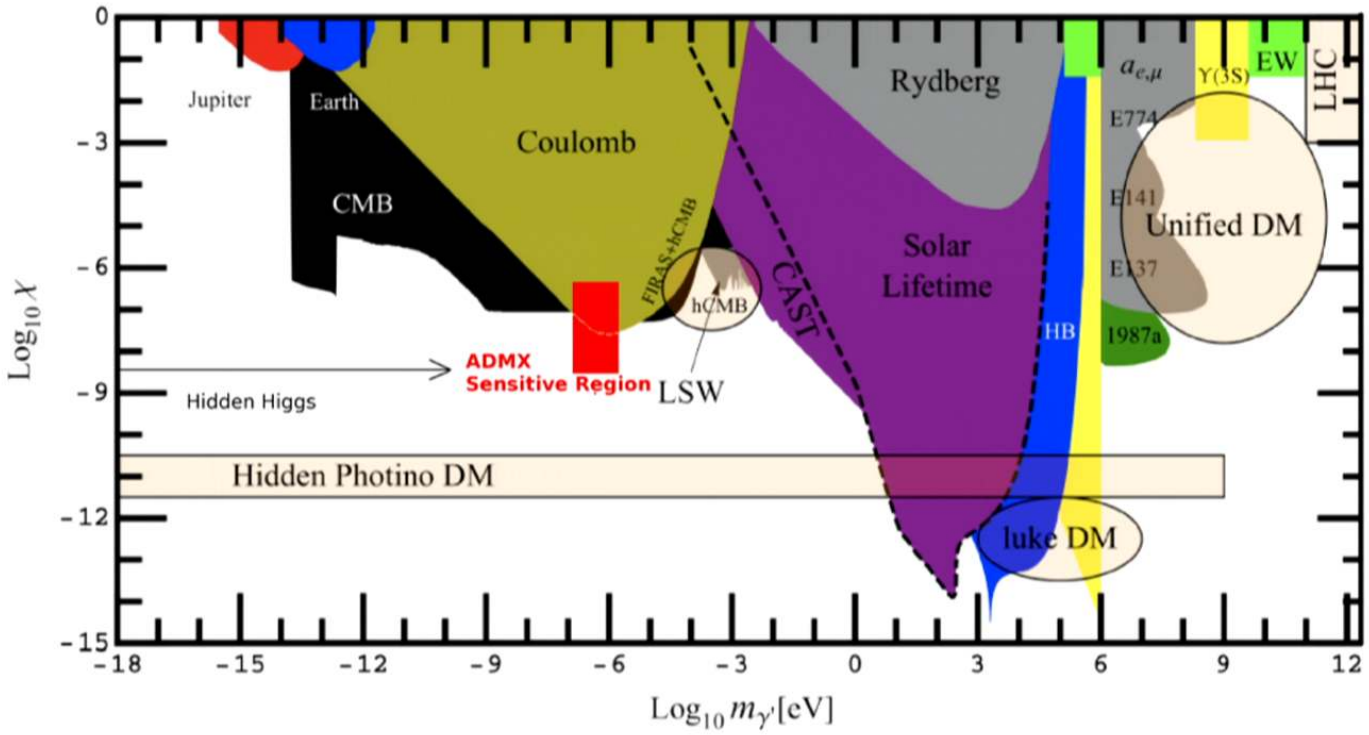
Limits from ADMX 2010 run



Asztalos et al, PRL 104, 041301 (2010)

Interlude: Other Light Particles with ADMX

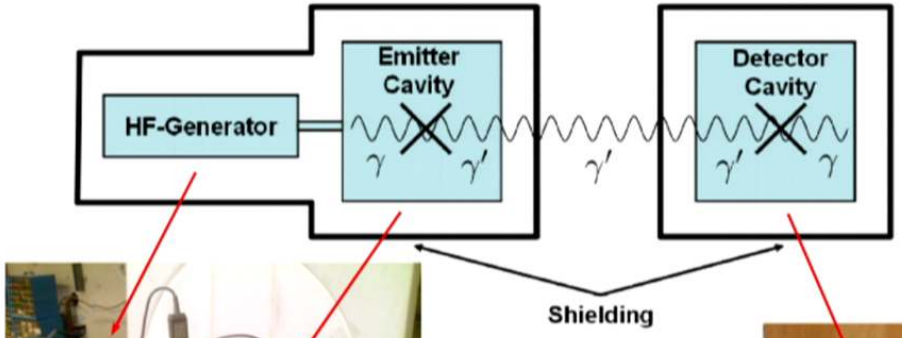
Paraphoton Searches

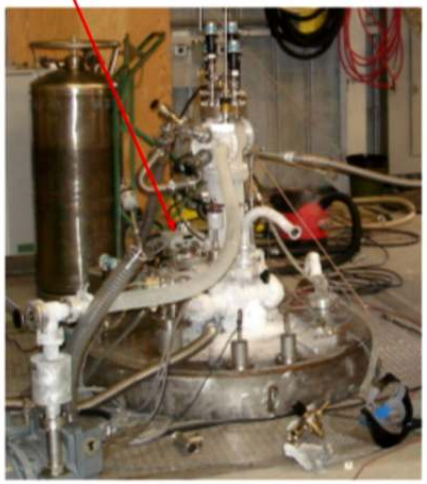


ADMX as a cavity paraphoton search

Light HSPs couple nearby electromagnetic resonant cavities

See: Jaeckel and Ringwald, Phys. Lett. B 659 (2008) 509





ADMX as a Chameleon Search

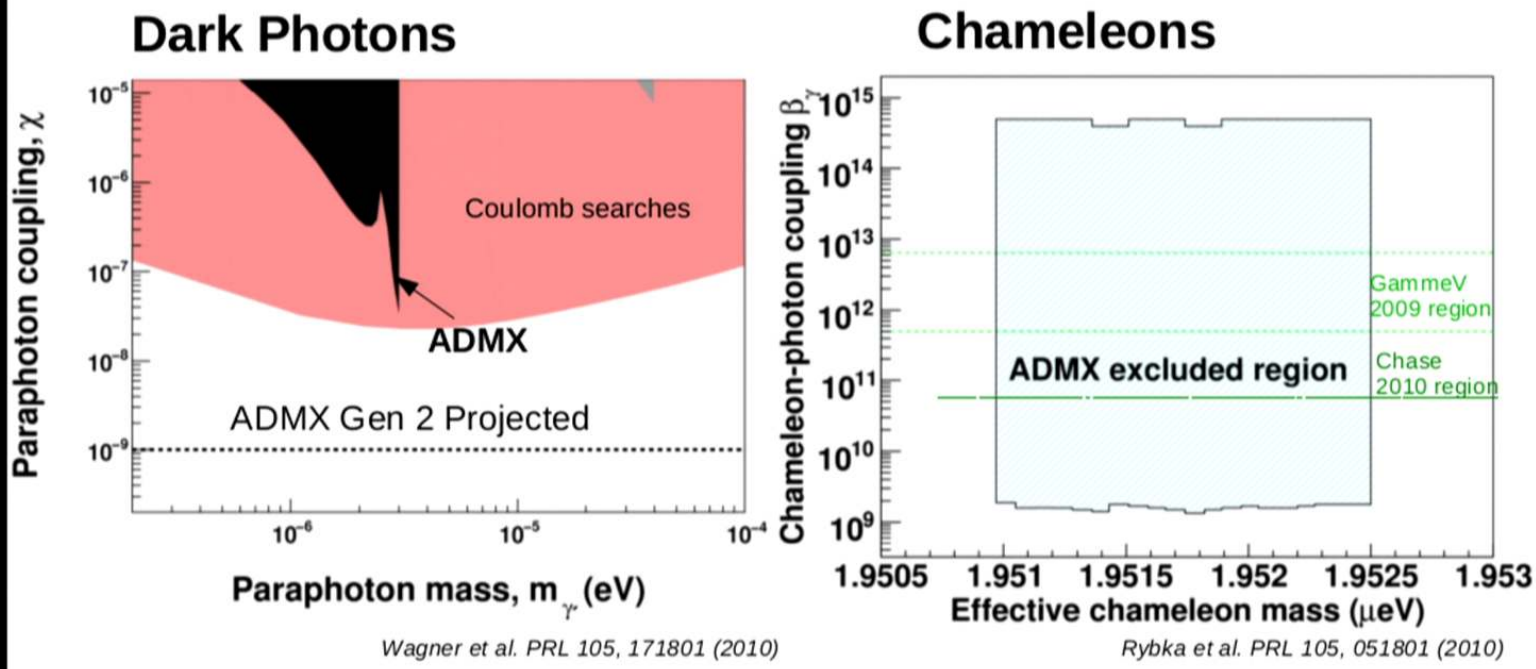
A chameleon is an exotic particle with the following properties

- Large mass in solid matter ← Necessary to avoid short-range gravity deviations
- Small mass in vacuum ← Both model and experiment dependent
- Couples to photons

One might see them with this type of experiment

1) Put photons in a cavity
2) Photons mix with chameleons
3) Remove the photons from the box
4) Look for the “afterglow” produced as chameleons mix back Into photons

Interlude: Other Light Particles with ADMX



Wagner et al. PRL 105, 171801 (2010)

Rybka et al. PRL 105, 051801 (2010)

ADMX can be configured to search for other light hidden-sector particles

End of Interlude
Back to Axions

Courtesy of IIASA

breaking

July 11, 2014

US reveals its next generation of dark matter experiments

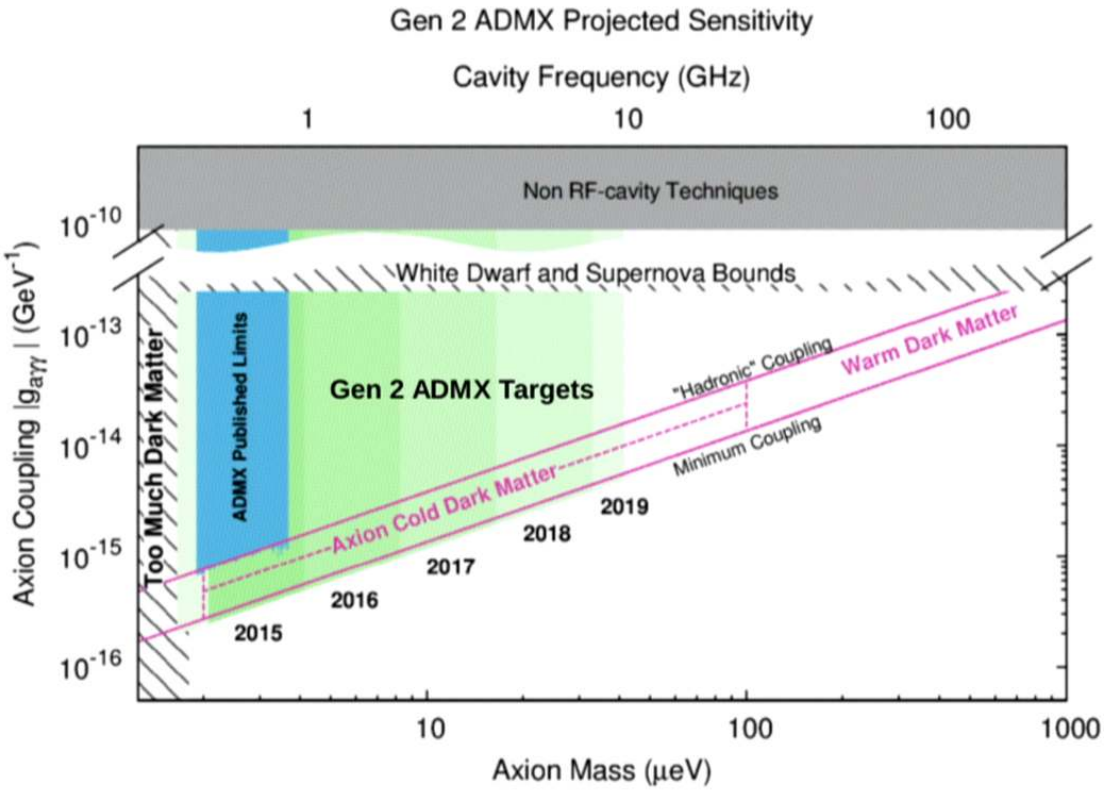
Together, the three experiments will search for a variety of types of dark matter particles.

By Kathryn Jepsen

Two US federal funding agencies announced today which experiments they will support in the next generation of the search for dark matter.

Symmetry Magazine

Gen 2 ADMX Program



Gen 2 ADMX Goal: Cover most pessimistic axion couplings up to 10 GHz

Improving Scan Speed

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

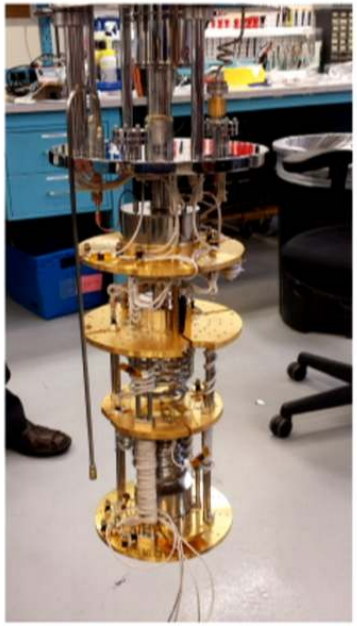
Scan Speed $\frac{df}{dt} \propto \frac{1}{T_{noise}^2}$

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

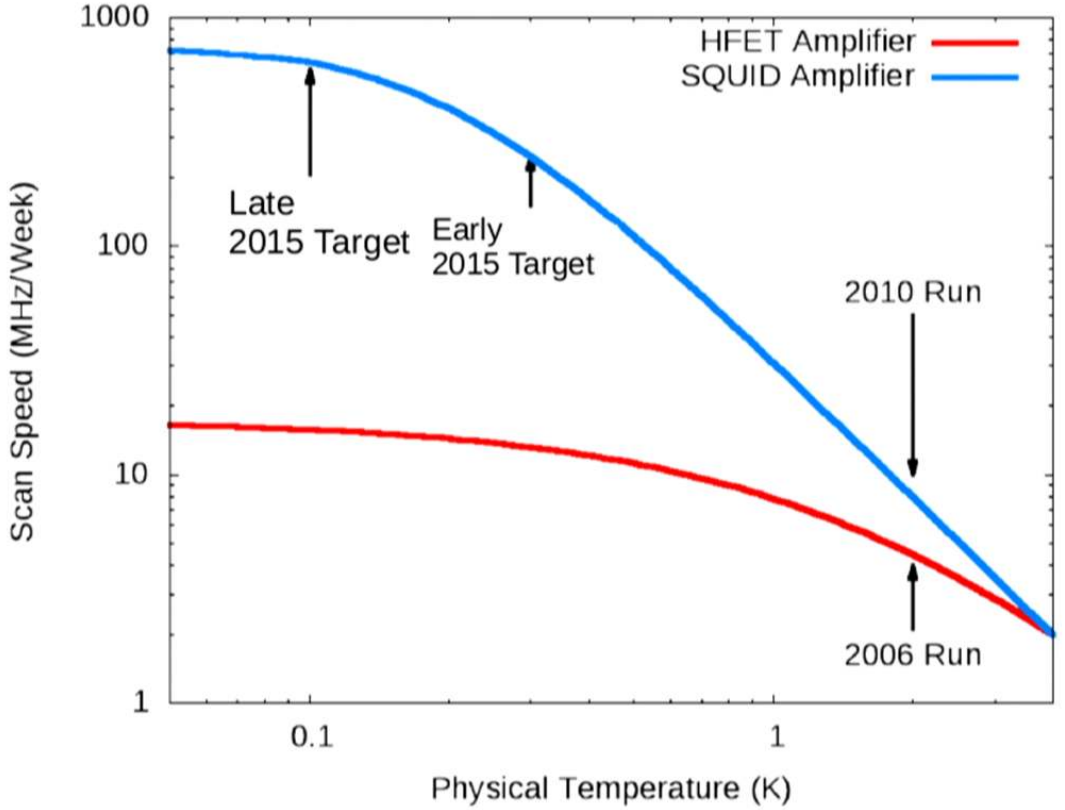
Noise comes from amplifiers and physical temperature

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

Cooling

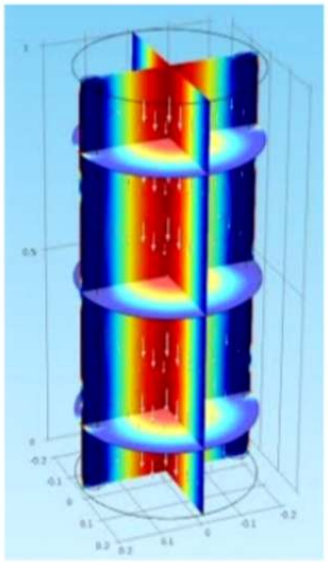


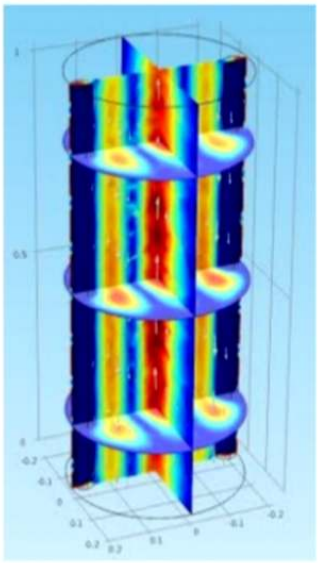
Dilution refrigerator will allow us to reach much colder temperatures, increasing scan speed tremendously



Multimode Data Taking

$$Sensitivity \propto E_z \cdot B_z$$





TM_{010}

Tuning Range 400-900 MHz

Relative Power 1.0

TM_{020}

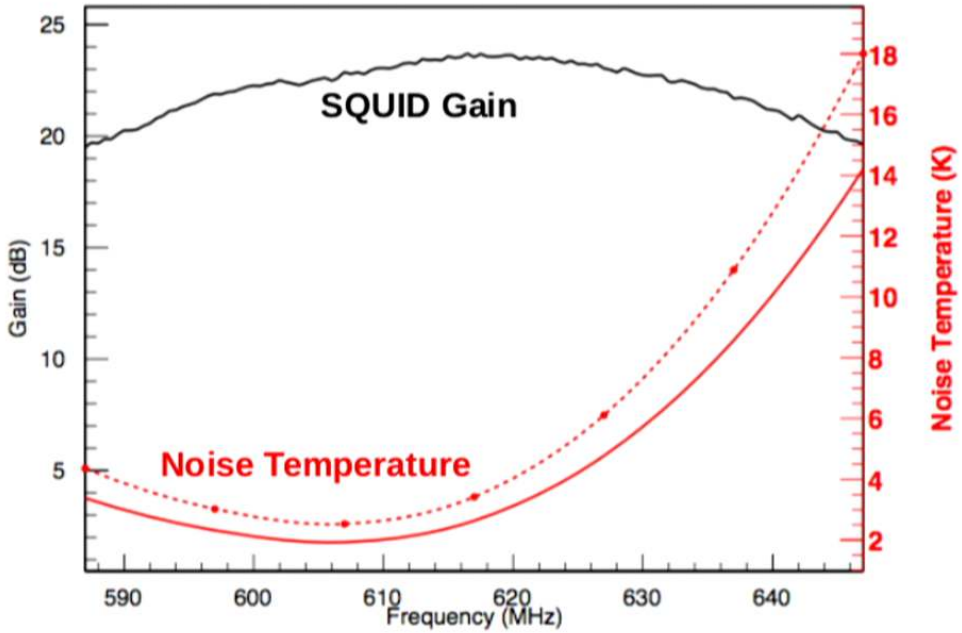
Tuning Range 920-2,100 MHz

Relative Power 0.41

ADMX Cold Commissioning

In-Situ SQUID Calibration

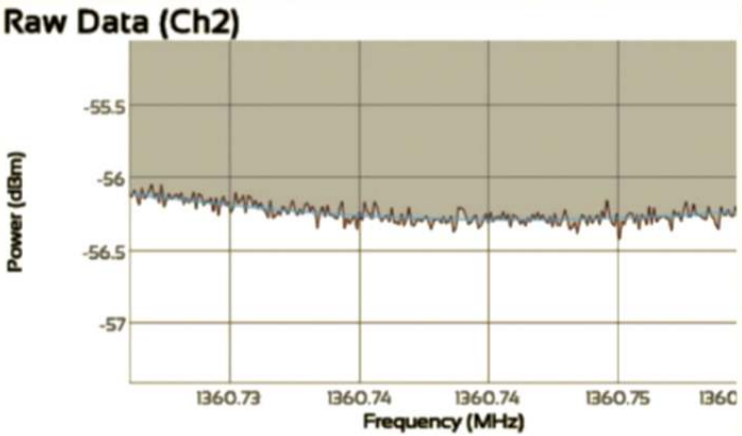
First Test of In-Situe SQUID Calibration (Not at Optimal Temperature)



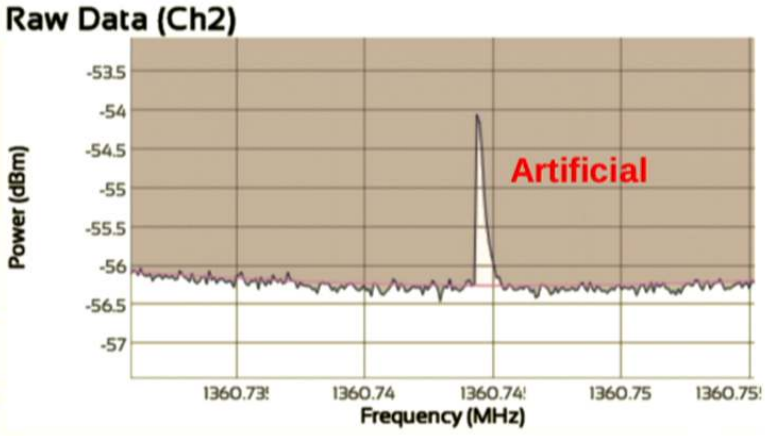
We can measure our amplifier noise temperature during data taking

Axion-Like Signal Calibration

Single Raw Power Spectrum (100 second integration)



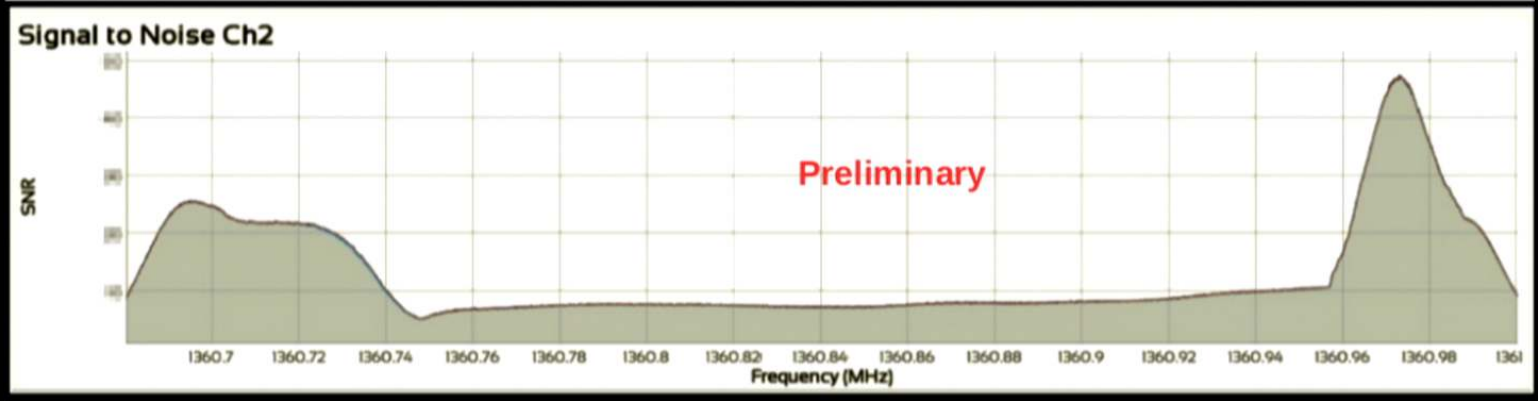
Raw Spectrum with Artificially Generated Axion-Like Signal



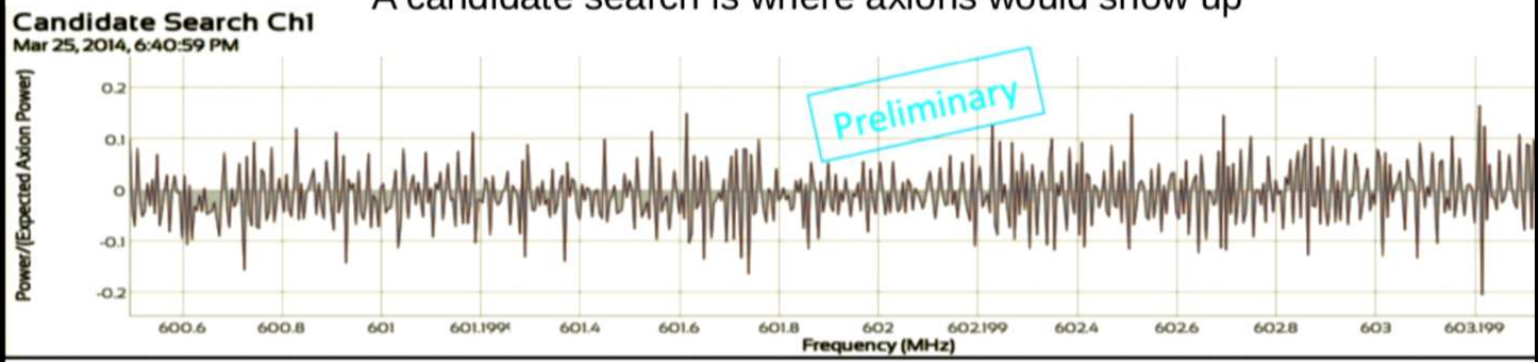
Injection of Axion-Like signals into cavity allow us to calibrate our analysis

Recent Data

SNR determines our sensitivity



A candidate search is where axions would show up



Current Status and Schedule

2010-2013 Move Experiment to UW, rebuild insert

Spring 2014 Commissioning of New Insert

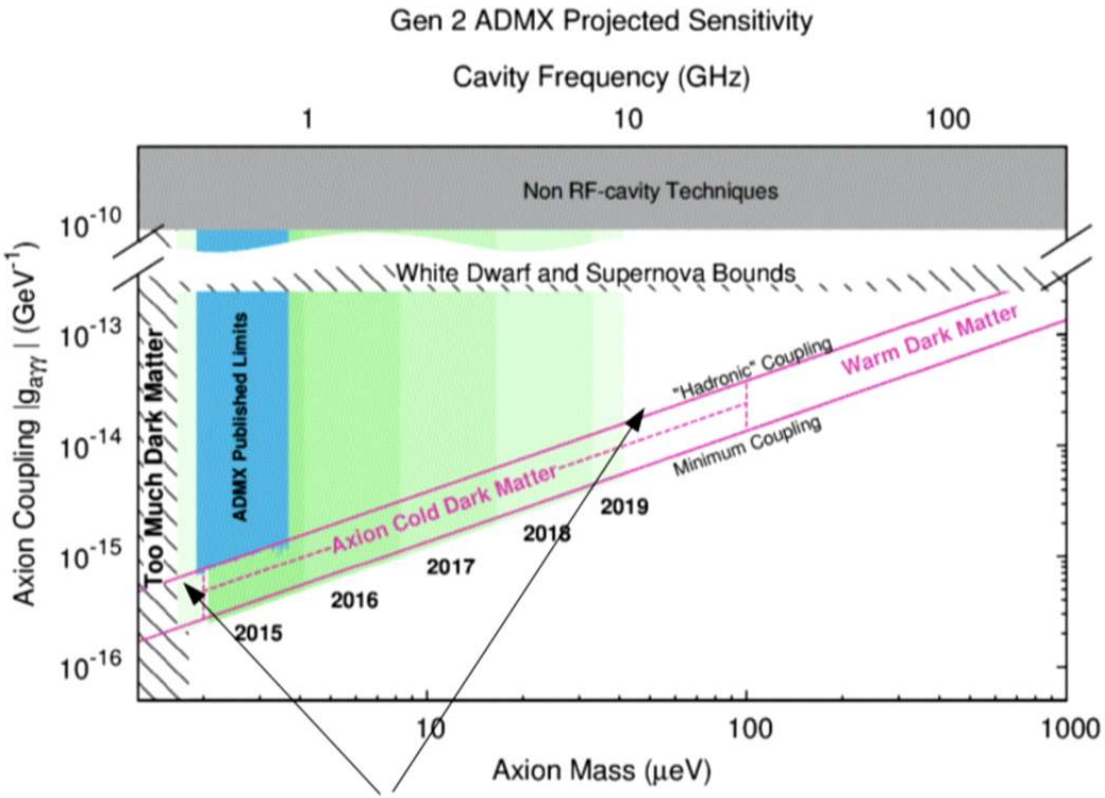
Summer 2014 Short 1K Run verifies new insert works

Now: Refitting for Dilution Refrigerator

Winter 2014: Dilution Refrigerator arrives

2015: Commission @ 100mK and begin data taking!

Expanding ADMX's Mass Range



How do we reach here?

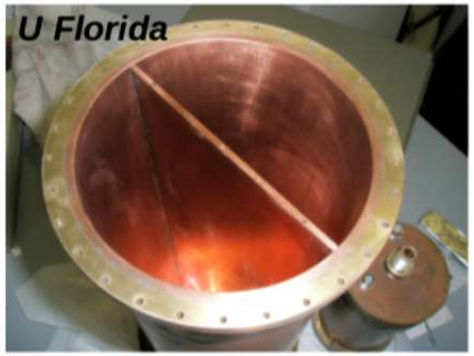
Expanding Experiment Mass Range

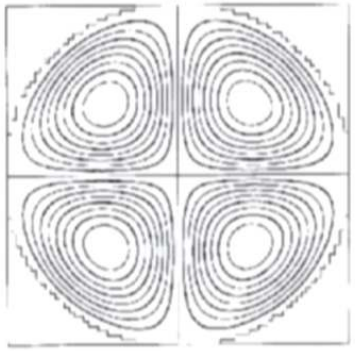
Higher axion masses:	Lower Axion Masses:
Cavity volume shrinks	Characteristic cavity radius exceeds reasonable magnet bore
Q's get lower	
Amplifier Noise Increases	Coupling decreases

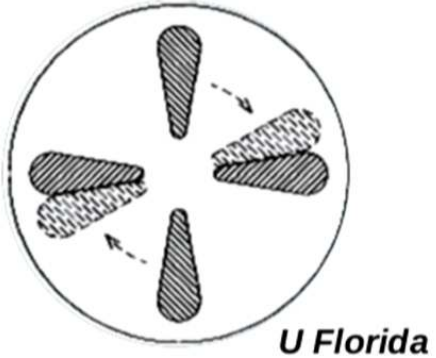
R&D is underway to access higher and lower axion masses

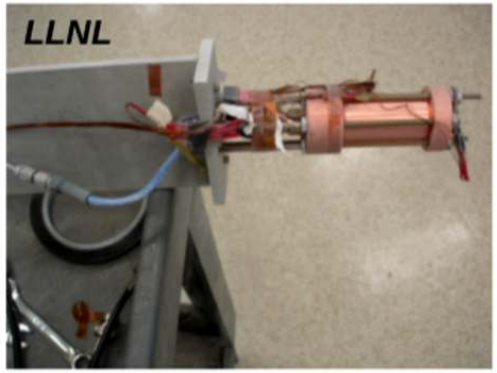
Higher Frequency Cavities

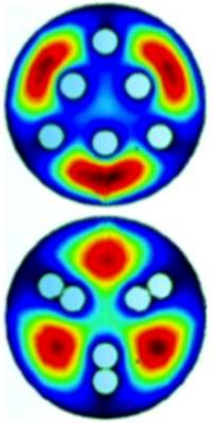
ADMX is developing higher frequency cavity structures

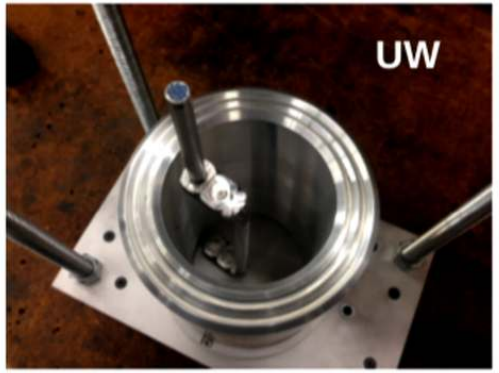




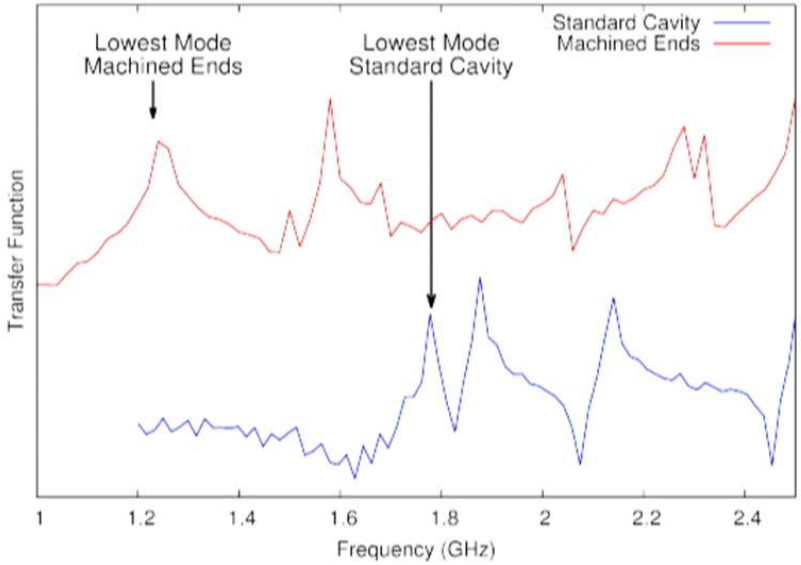


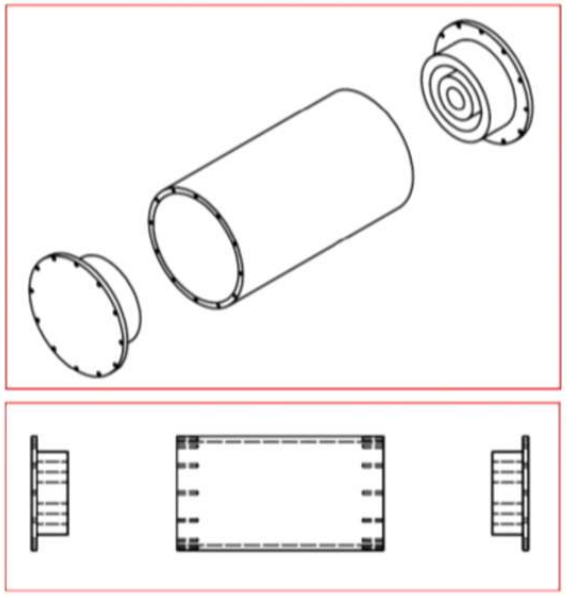






Lower Frequency Cavities

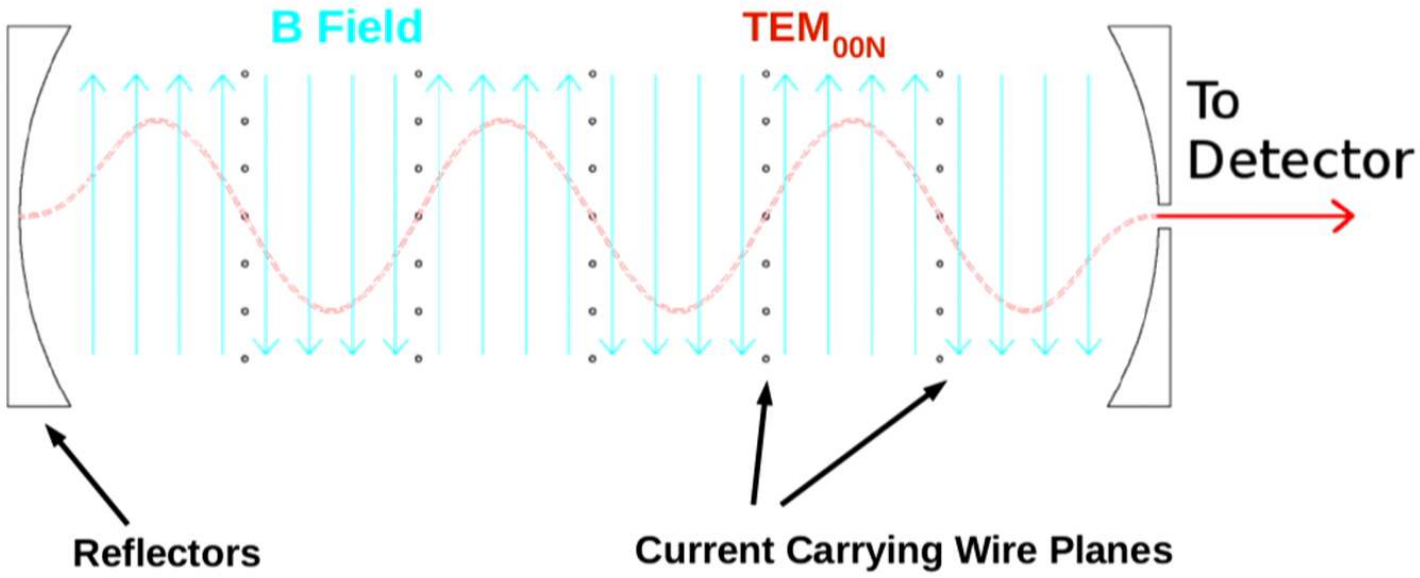




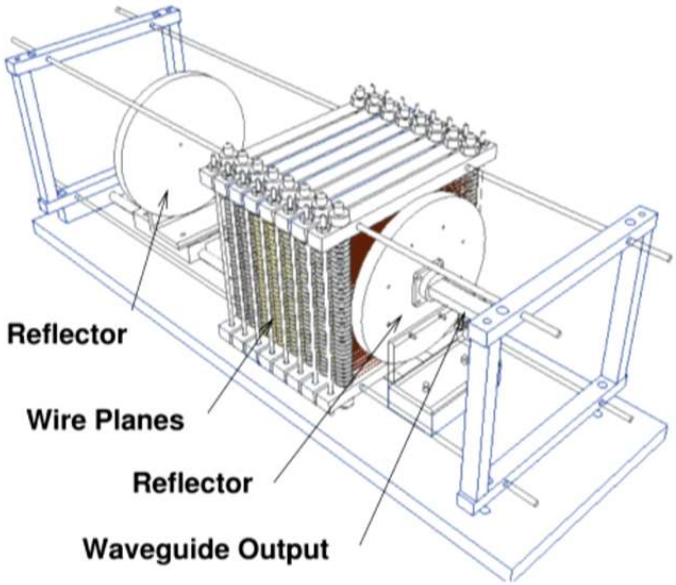
R&D is underway to access frequencies below those of previous cavities

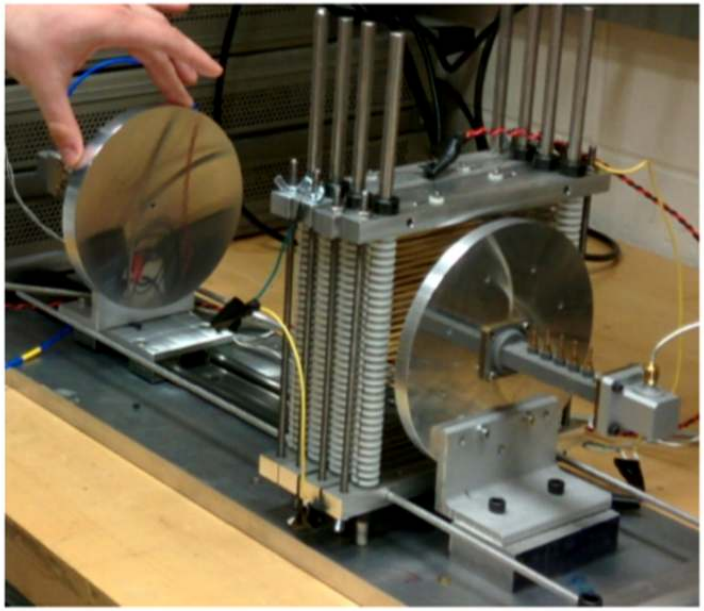
Current work promises factor of two or more frequency reach increase

Open Resonator Concept



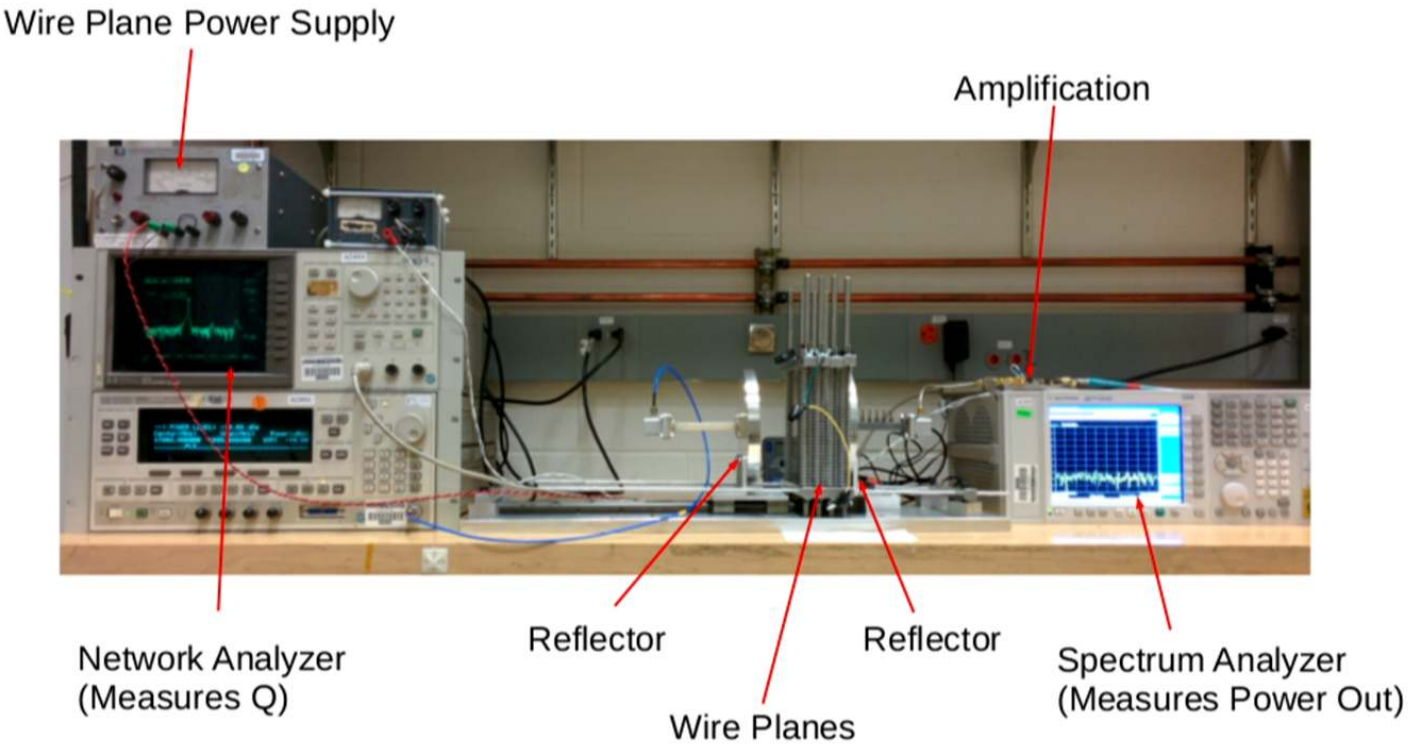
Orpheus Design



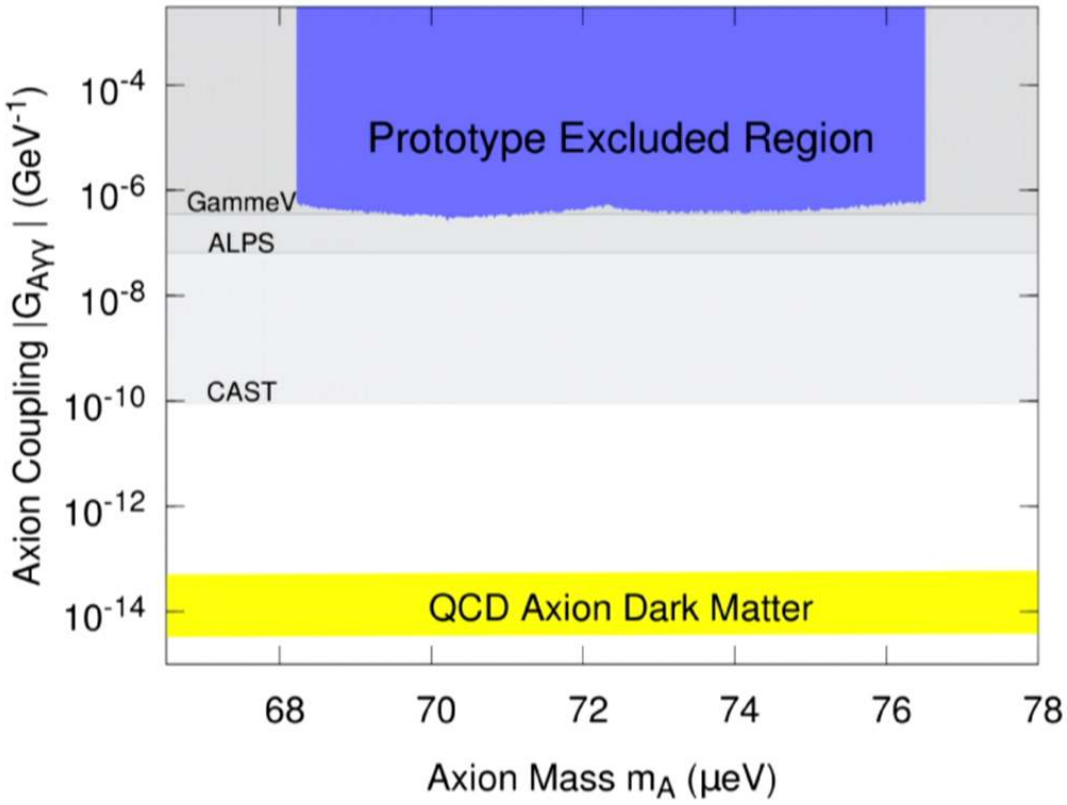


Open Resonator Prototype

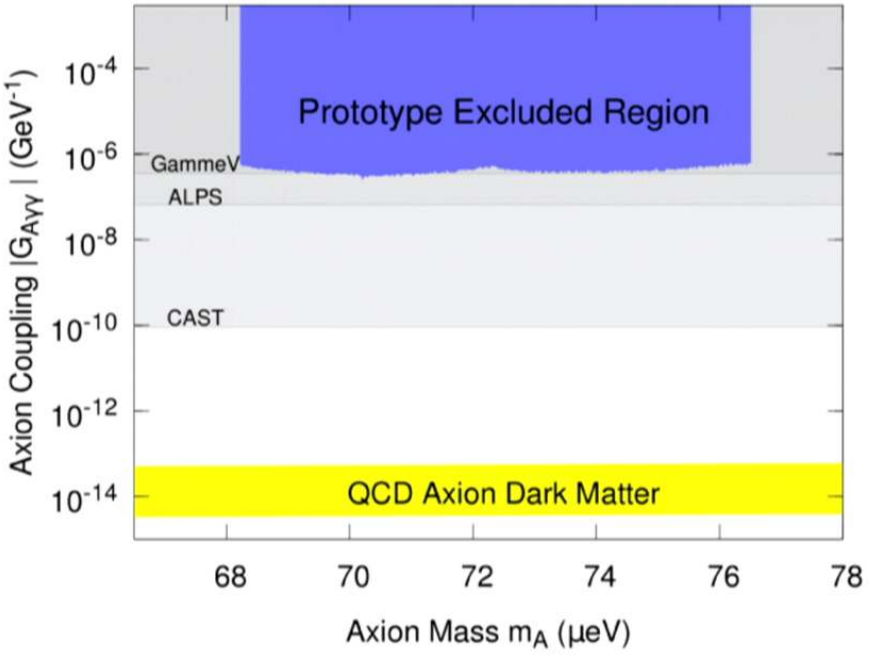
ADMX R&D: Orpheus



Orpheus Prototype Limits



Orpheus Parameters

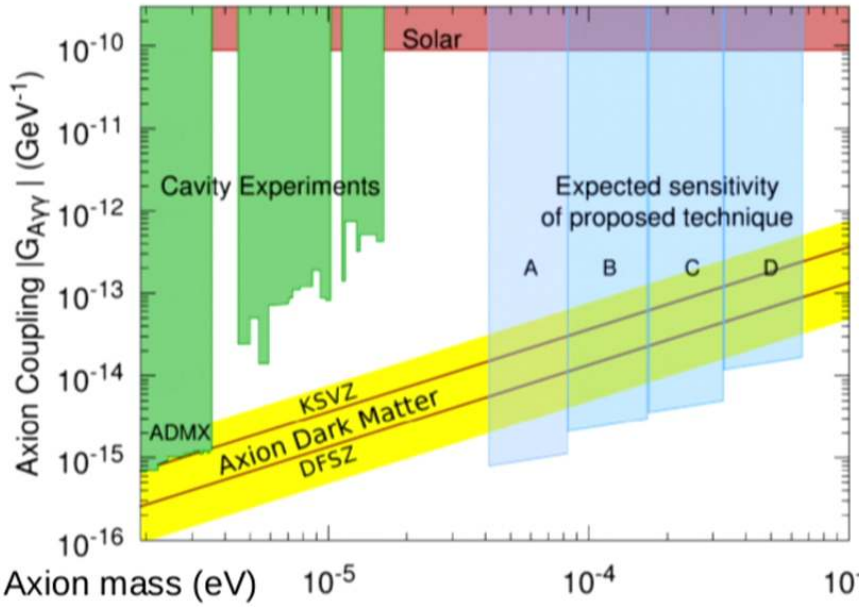


Improvable key experiment parameters

-Noise Temp: ~1500 K
- Loaded Q: ~3000
- B Field: ~ 5 Gauss
- Volume: ~ 200 cc

Many orders of magnitude improvement possible

Open Resonators Potential Reach



May be able to extend ADMX reach to meV masses
See: arxiv:1403.3121

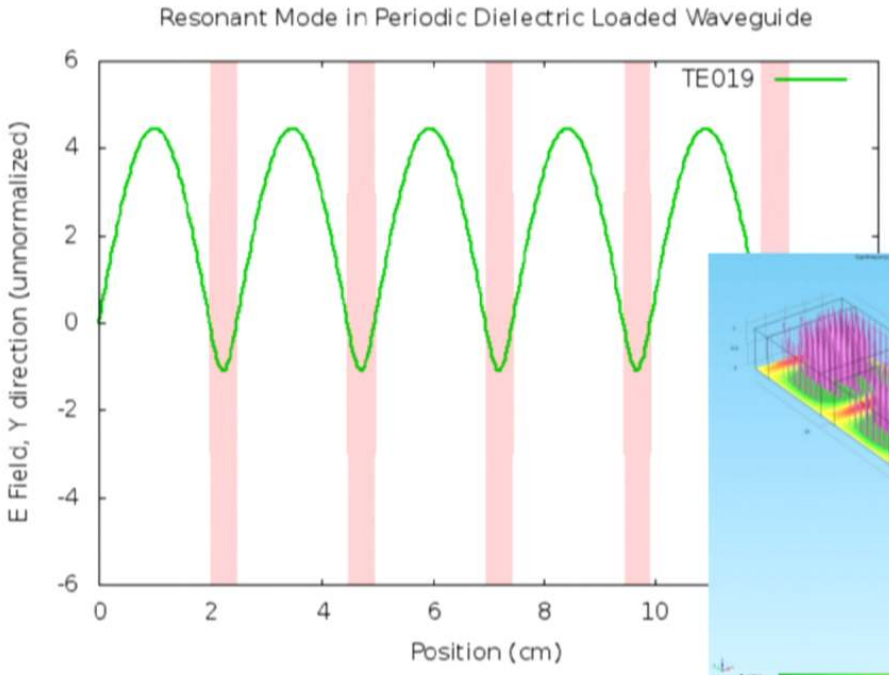
Potential Gen 3 Design?

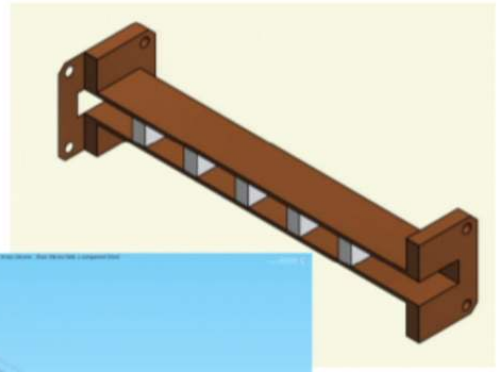
Experiment	Mass Target	Frequency	B Field	Q	Volume	Noise Temperature	Run Time
A	52 μeV	15 GHz	3 T	10^6	1×10^6 cm^3	750 mK	1 Year
B	103 μeV	30 GHz	3 T	10^6	8×10^5 cm^3	1.5 K	1 Year
C	207 μeV	60 GHz	6 T	10^6	4×10^5 cm^3	3 K	1 Year
D	414 μeV	120 GHz	6 T	10^6	2×10^5 cm^3	6 K	1 Year

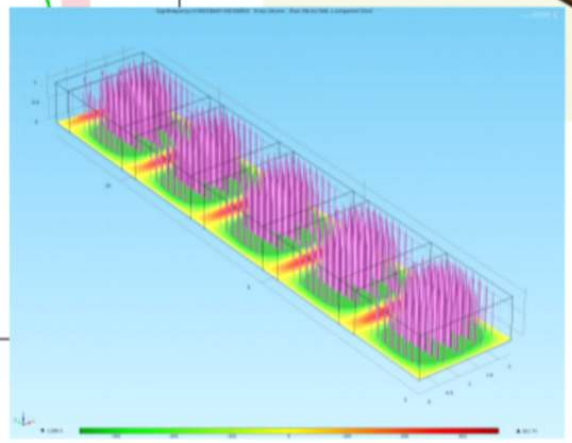
Dielectric Loaded Resonators

Strategically placed dielectric in resonators can enhance coupling

Example: Dielectric blocks spaced by half wavelength in a waveguide





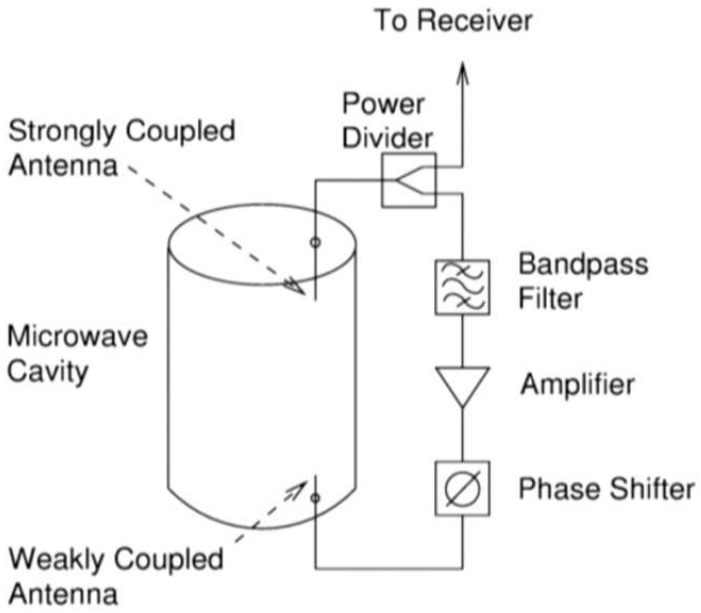


Active Resonators

Active feedback resonators can increase the Q of a resonant system by factors in excess of 1000

This could increase axion conversion signal, but noise increases as well

Passive **Active**



The use of active resonators to enhance sensitivity in ADMX is currently under study: arxiv:1403.6720

Conclusions

Axions are a well motivated dark matter candidate

Are we going to find the axion? Yes

The Gen 2 ADMX experiment will explore a wide range of plausible axion masses

If we don't find it there, we are working on ways to search the entire possible range.