

New Data and New Perspectives from ADMX



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New Perspectives in Dark Matter
Fermilab

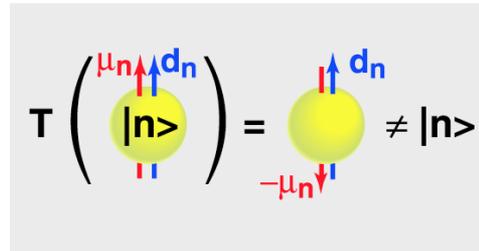


Axions: Motivation



The Strong CP Problem

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



$edm < 3 \cdot 10^{-26} \text{ e-cm}$
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

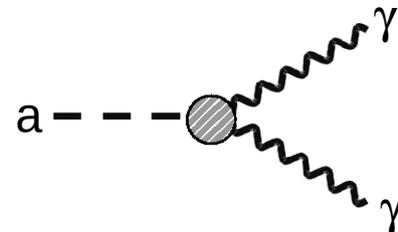
The Peccei-Quinn Solution

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

This results in a new pseudoscalar particle, the Axion

-Weinberg, Wilczek

Couples to two photons

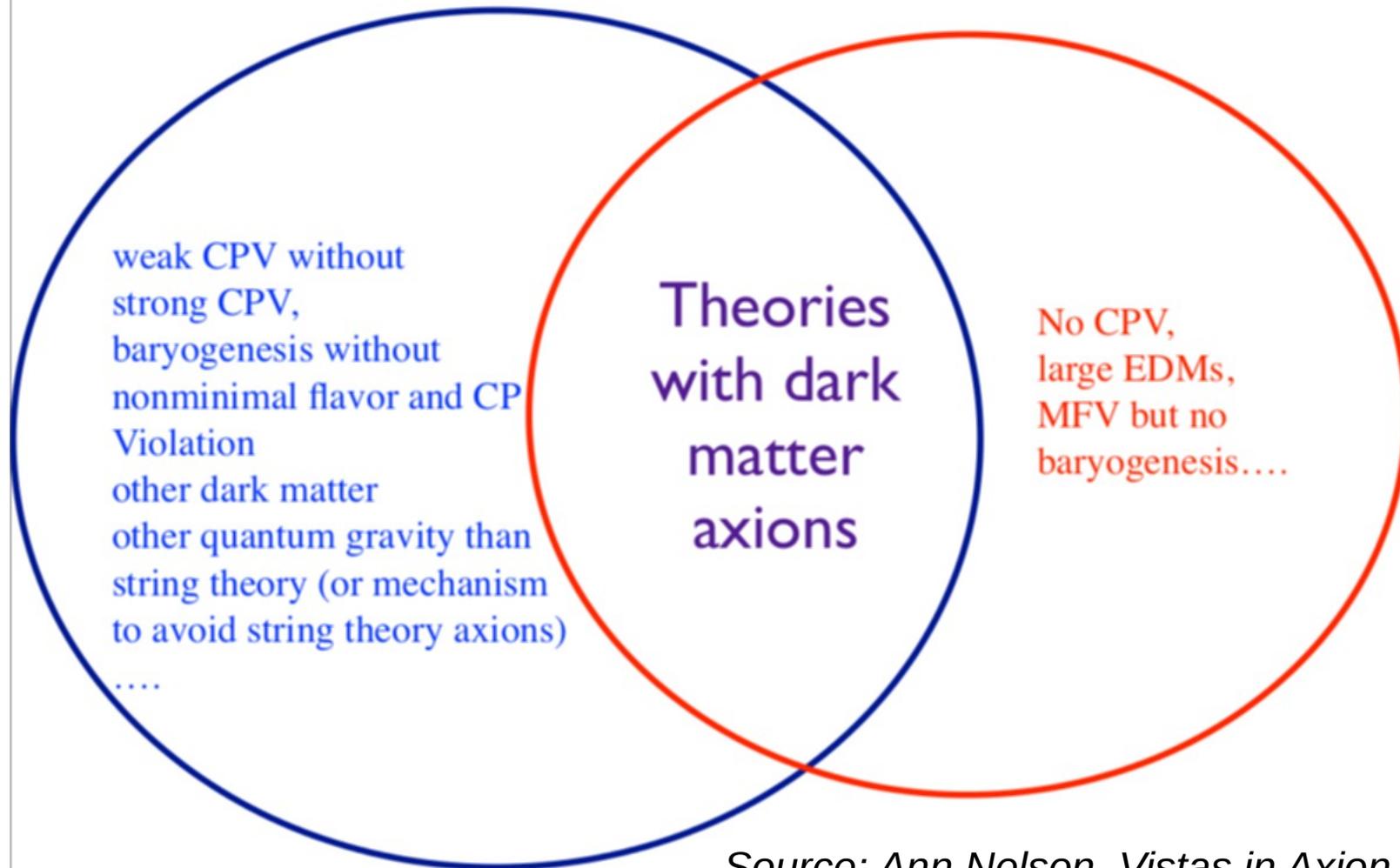


Axion Theory Simplified



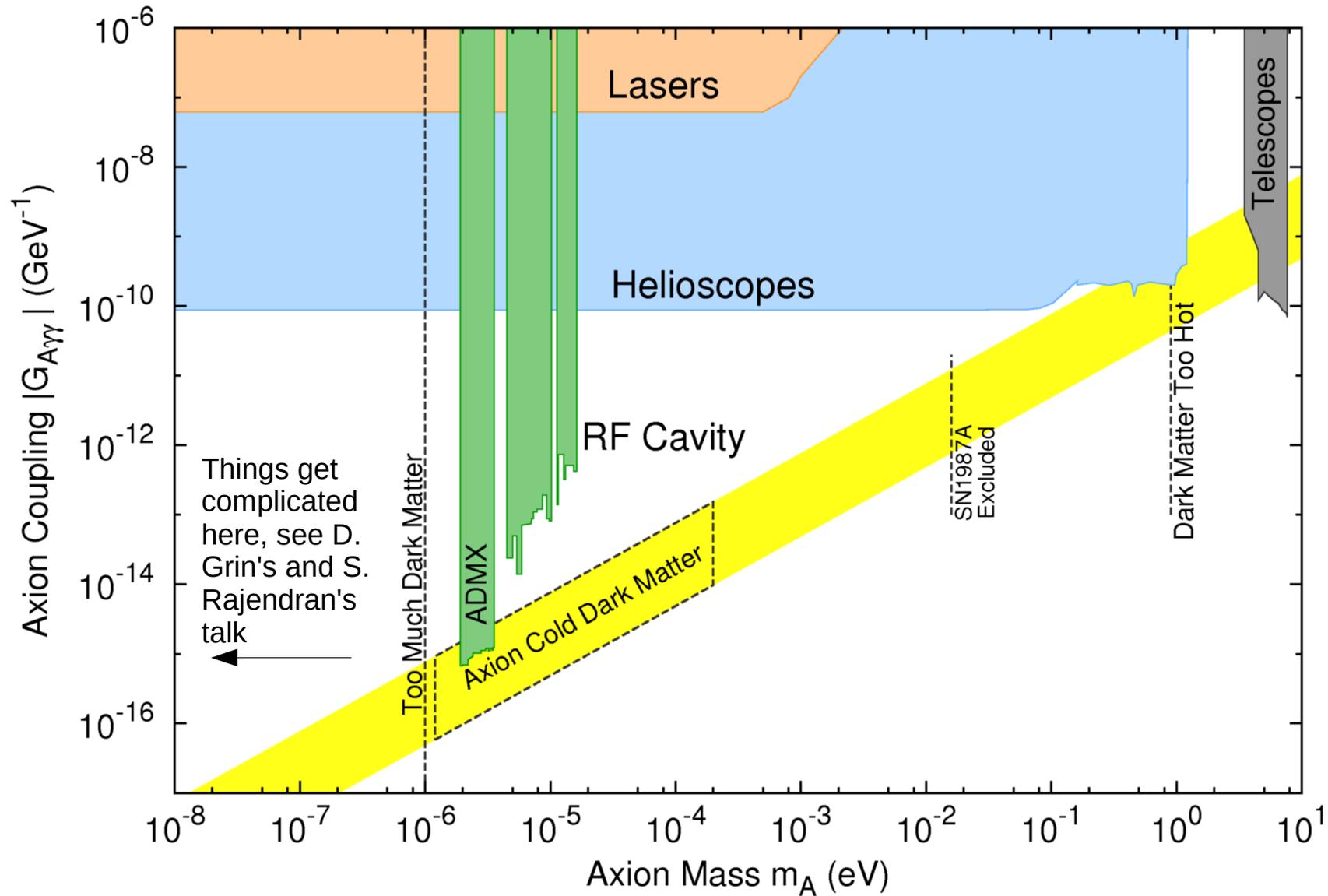
Viabale Theories

Natural and Elegant Theories

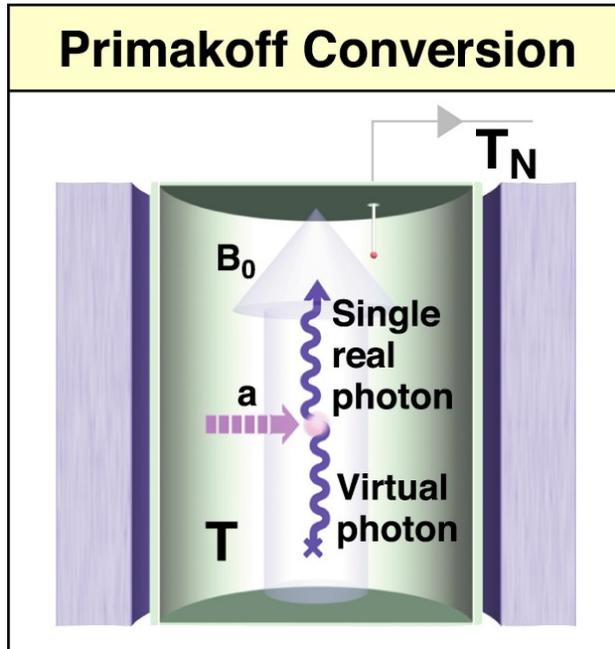


Source: Ann Nelson, *Vistas in Axion Physics 2012*

Axion Dark Matter Parameters



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

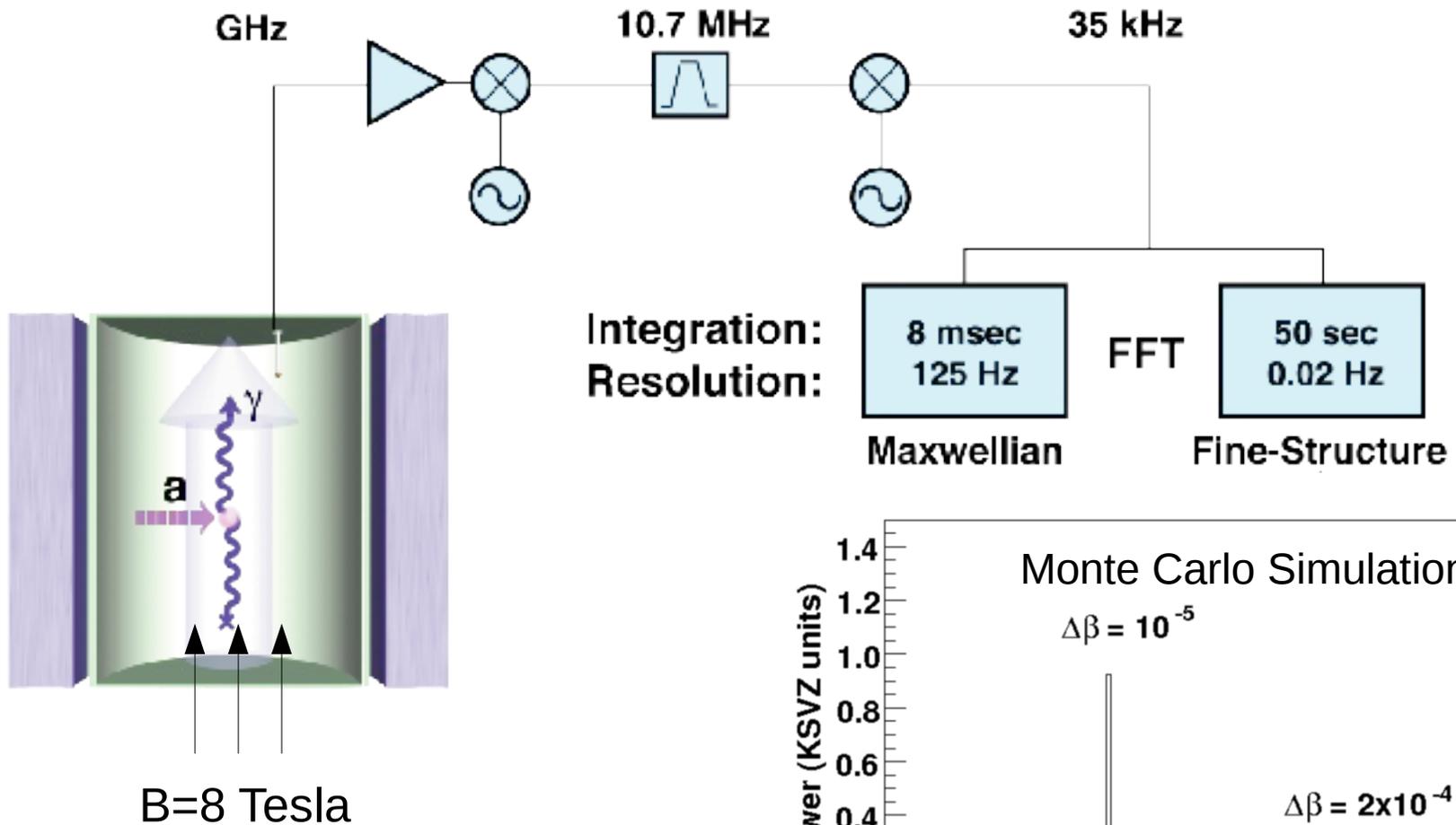
University of Florida

Yale

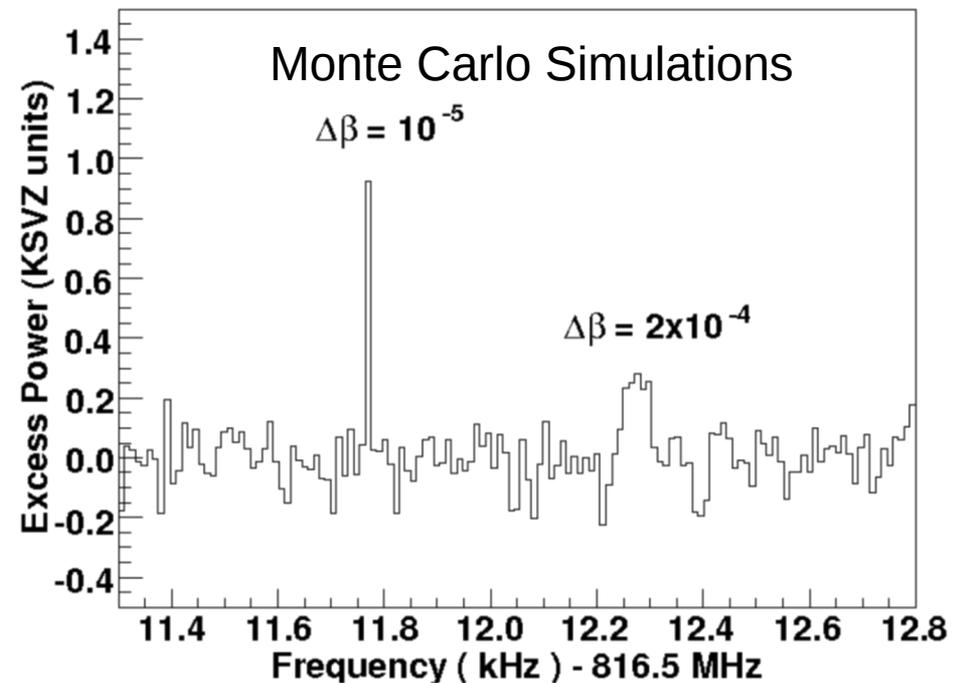
UC Berkeley

NRAO

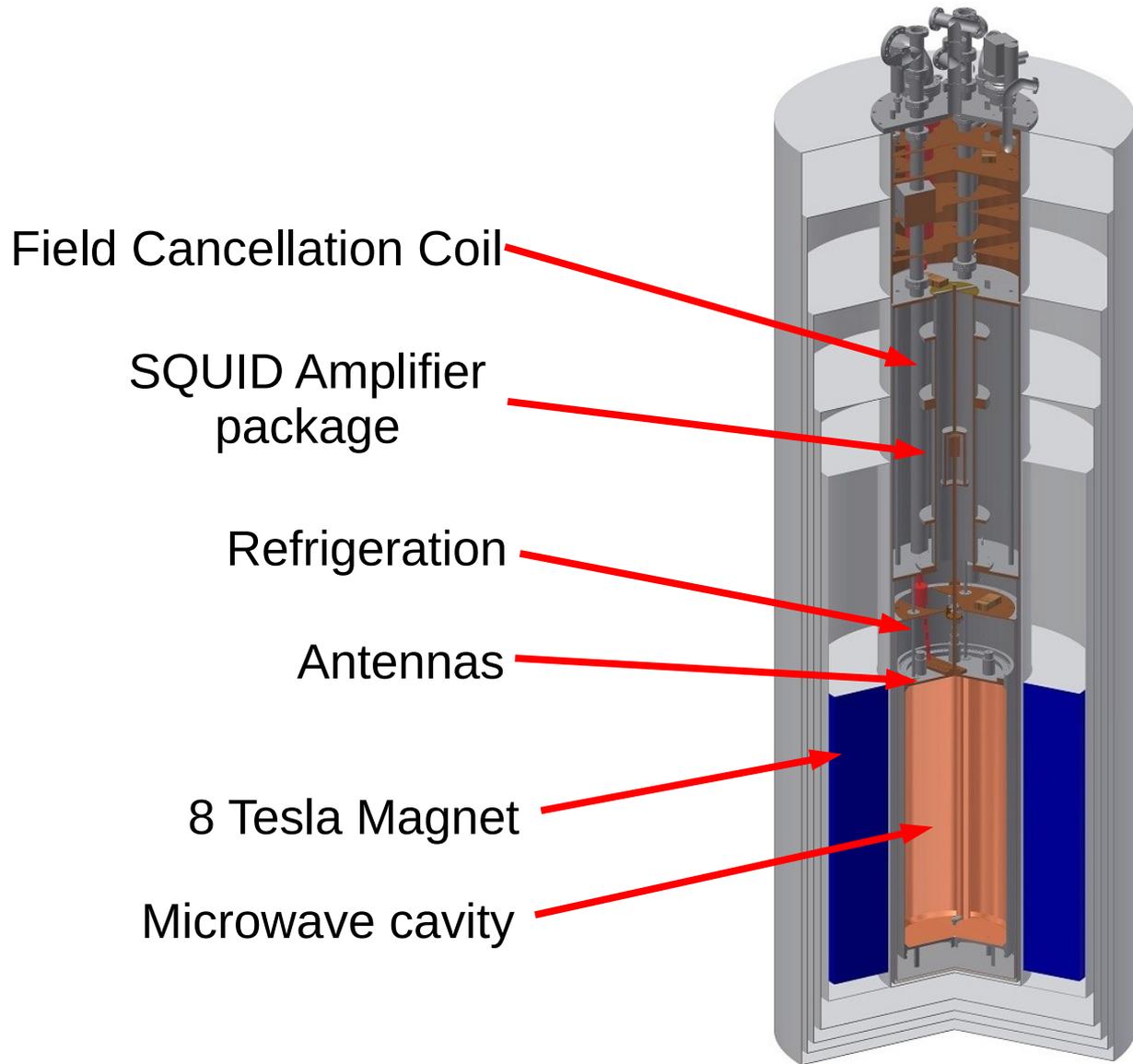
How ADMX Works



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



ADMX Design



Insert + Magnet
Schematic

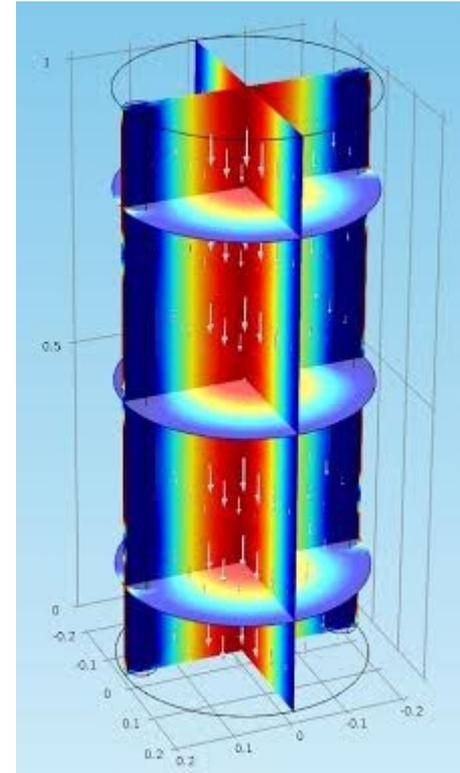
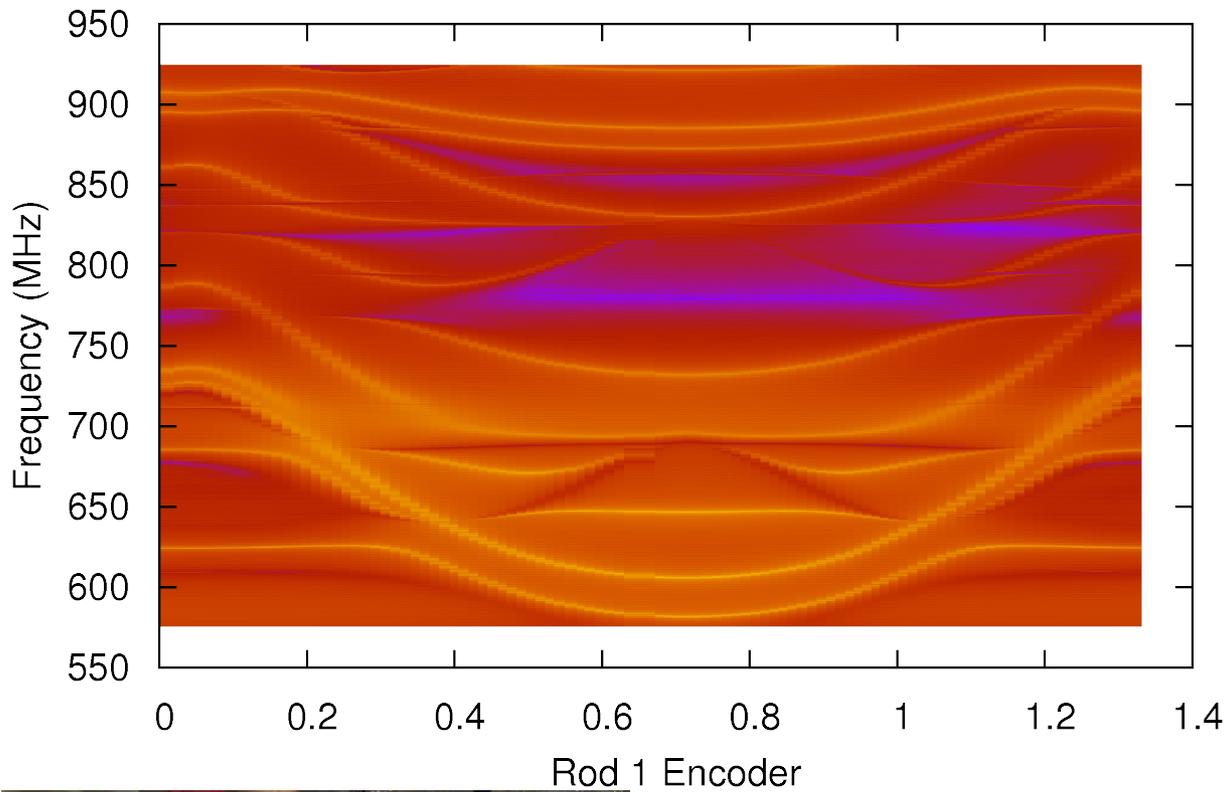


Insert extraction
from magnet

Tuning



Mode Map Rod2 at 0.967

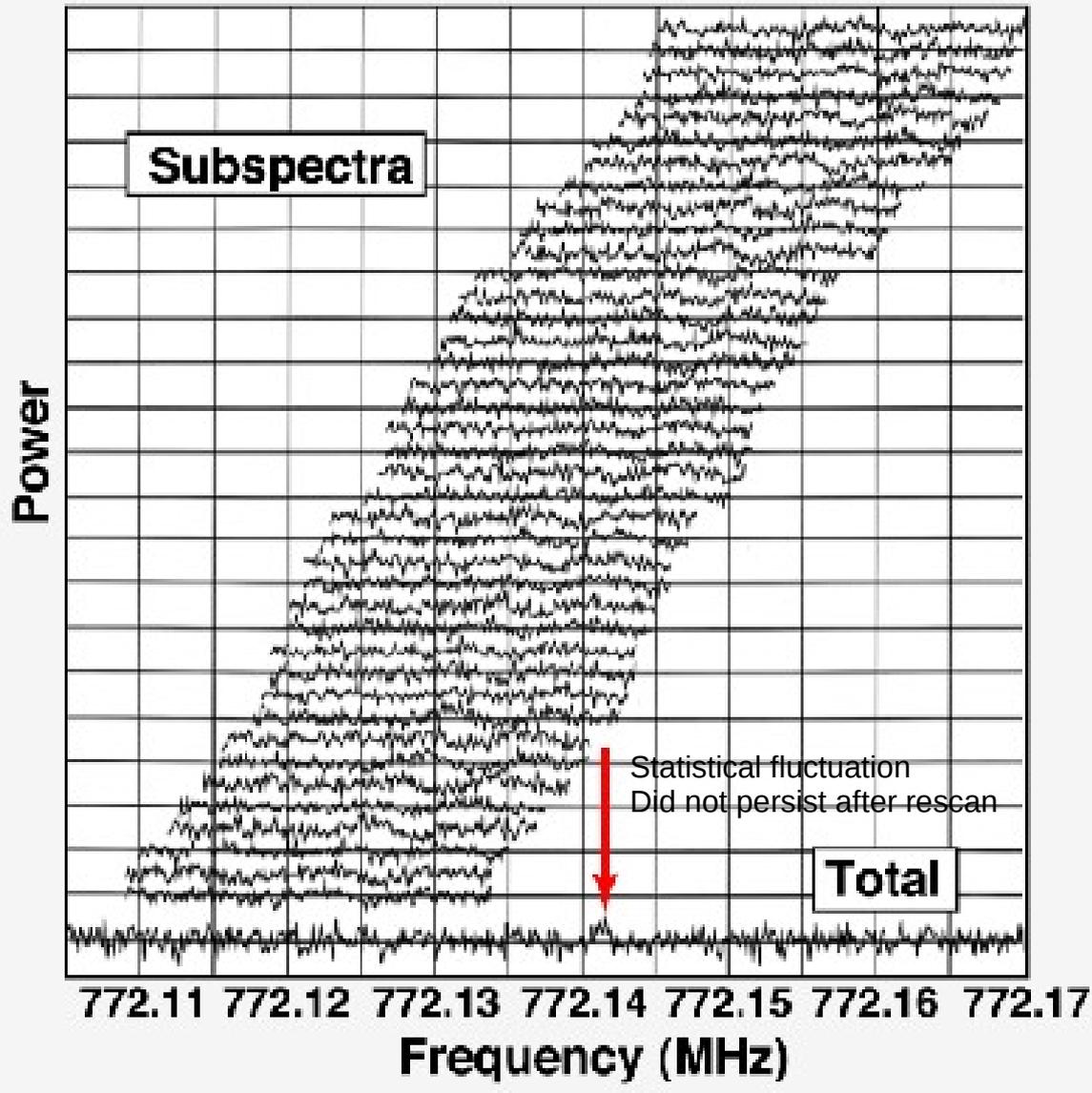


Field simulation of
TM₀₁₀ mode, no rods



Cavity with lid off,
showing tuning rods

Axion Search Technique



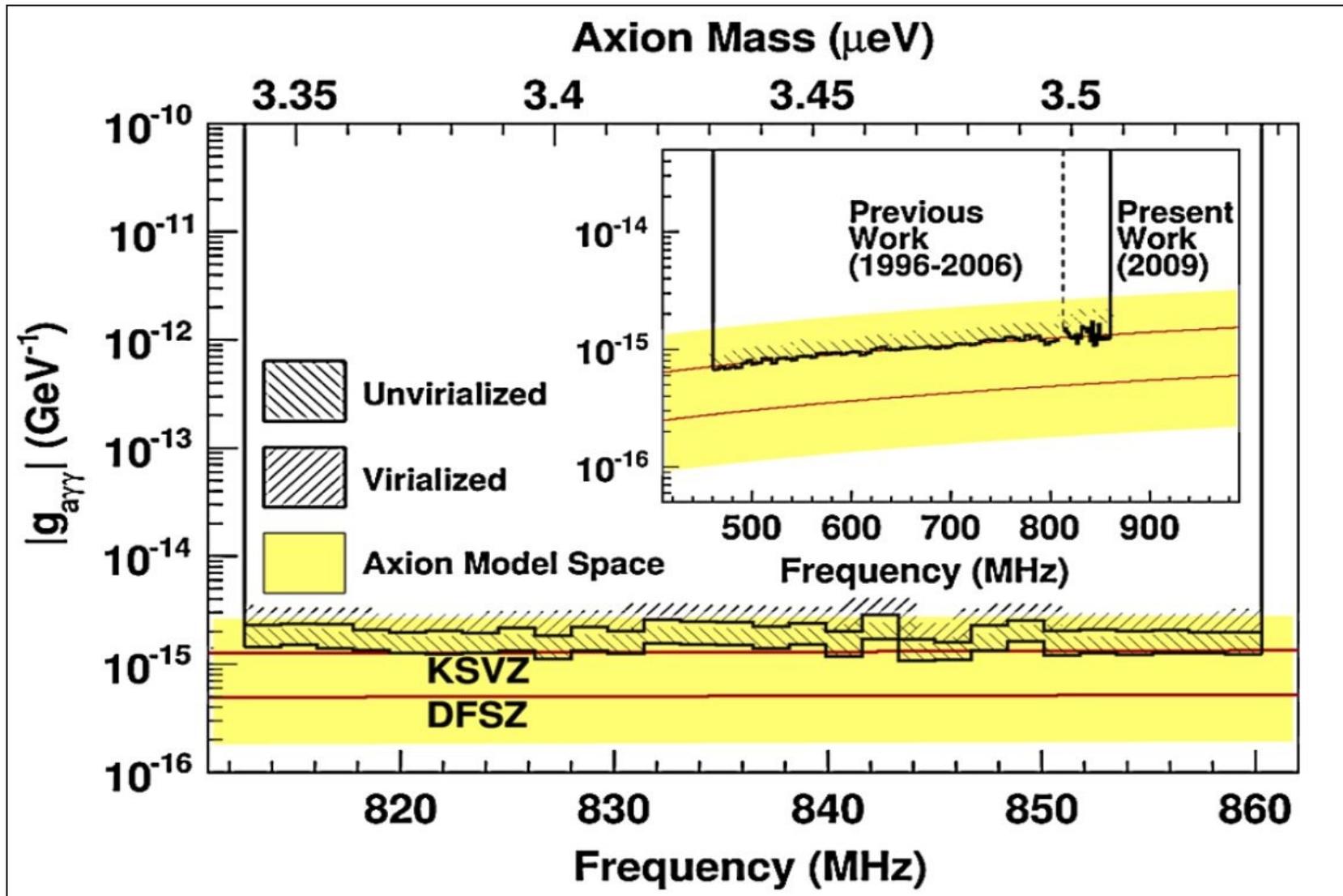
Cavity resonant frequency is tuned by two movable rods

Power spectra are measured at each rod position

Axion signal would appear as a constant power excess

Most backgrounds do not persist

Limits from ADMX 2010 run

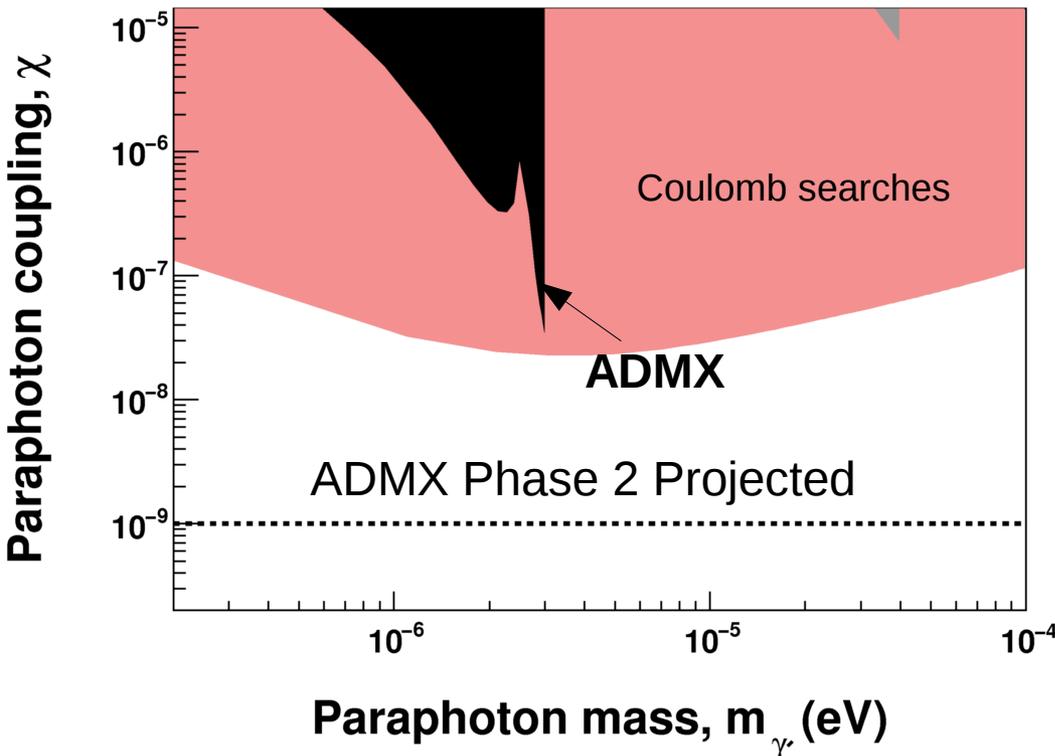


Asztalos et al, PRL 104, 041301 (2010)

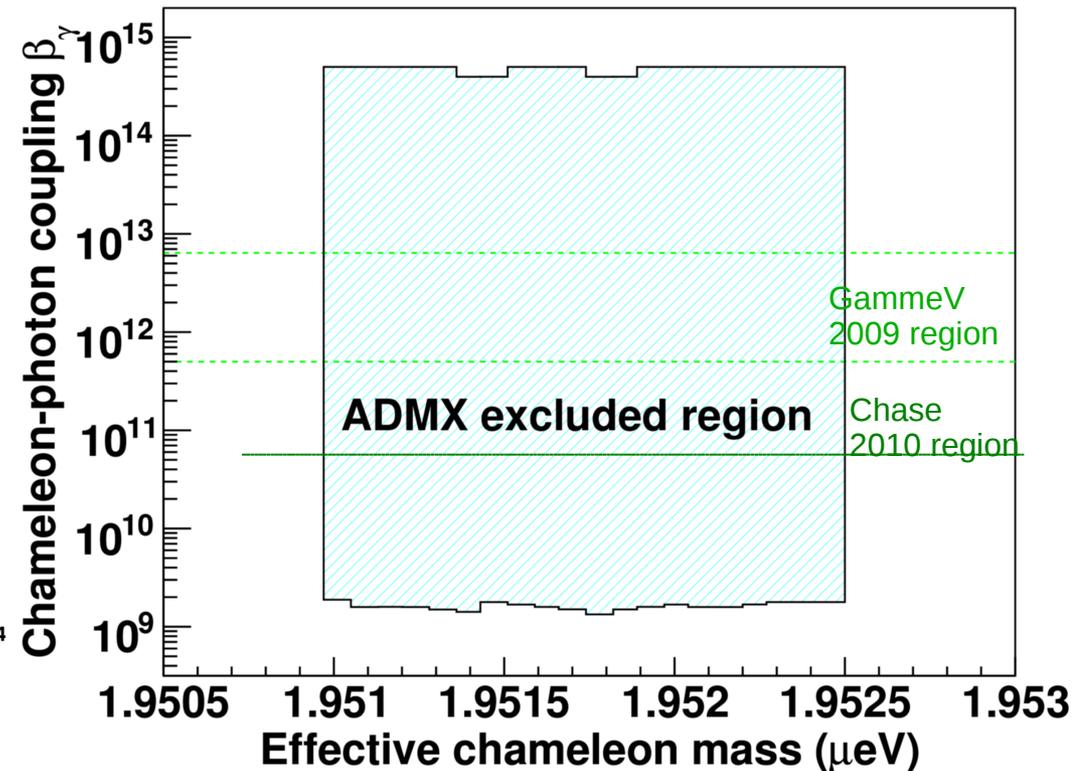
Other Light Particles with ADMX



Dark Photons



Chameleons



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

Improving Scan Speed



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

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

Want to run faster?

Run colder!

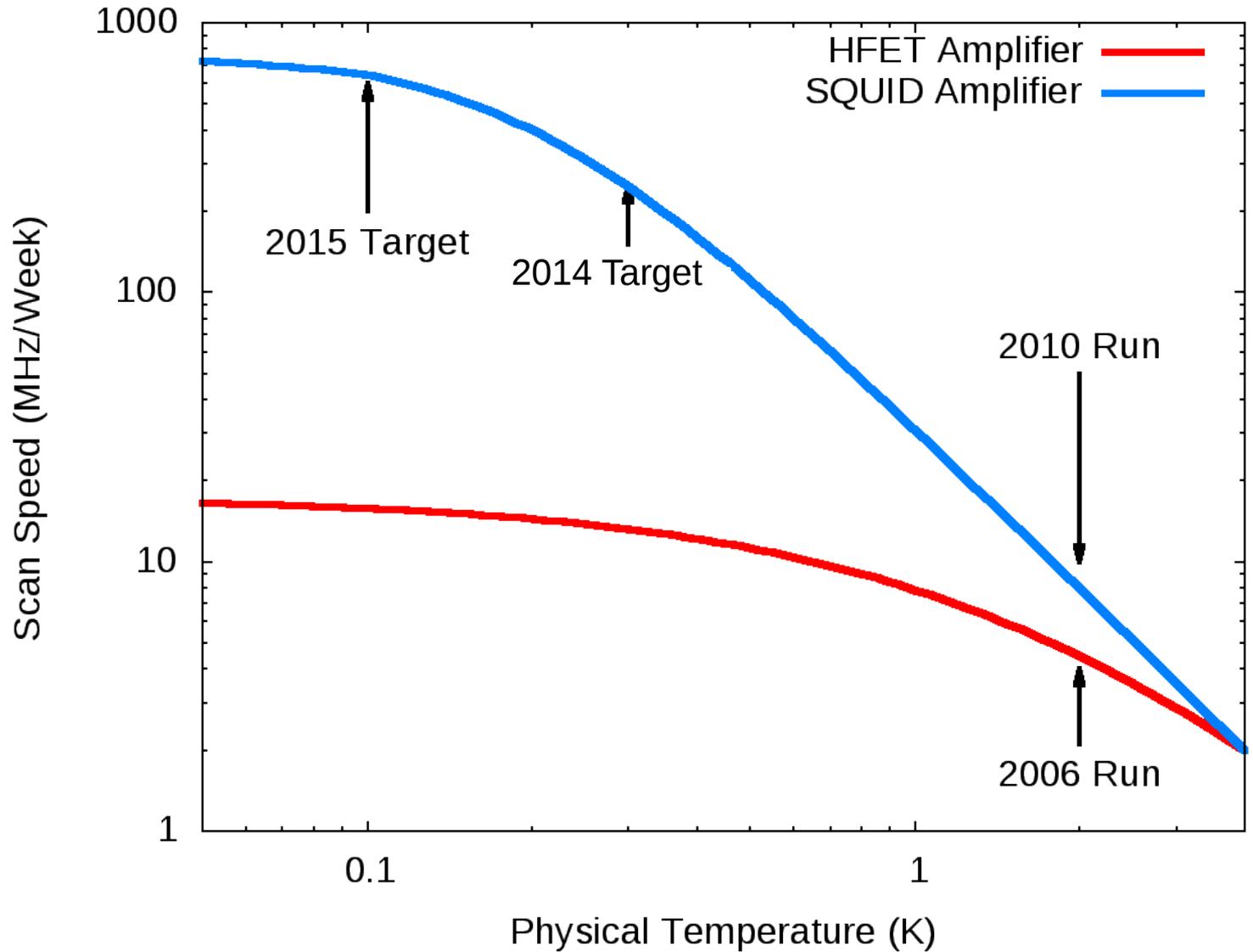
Noise comes from amplifiers and physical temperature

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

Cooling



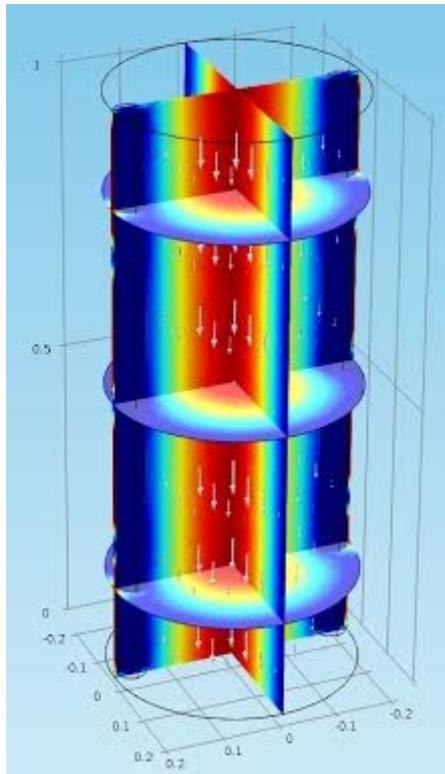
Dilution refrigerator will allow us to reach much colder temperatures, increasing scan speed tremendously



Multiple Channel Improvements



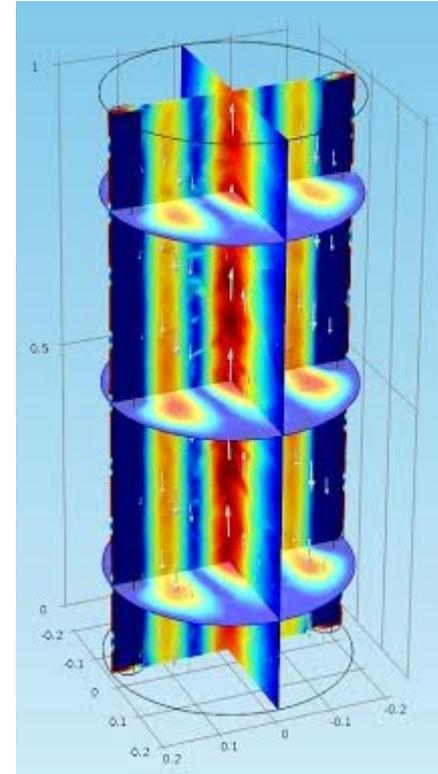
$$\text{Sensitivity} \propto E_z \cdot B_z$$



TM₀₁₀

Tuning Range 400-900 MHz

Relative Power 1.0



TM₀₂₀

Tuning Range 920-2,100 MHz

Relative Power 0.41

Current Status and Schedule



After 3 years of rebuilding the experiment,

ADMX is now taking data!

Current operations are at 1.5 K

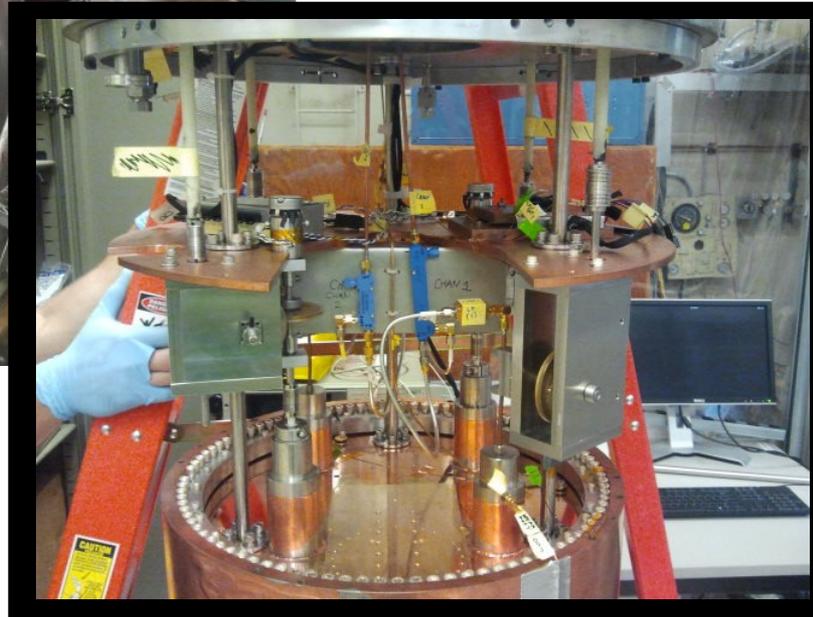
Helium 3 refrigeration stages are set to be delivered end of summer

Then definitive search will begin

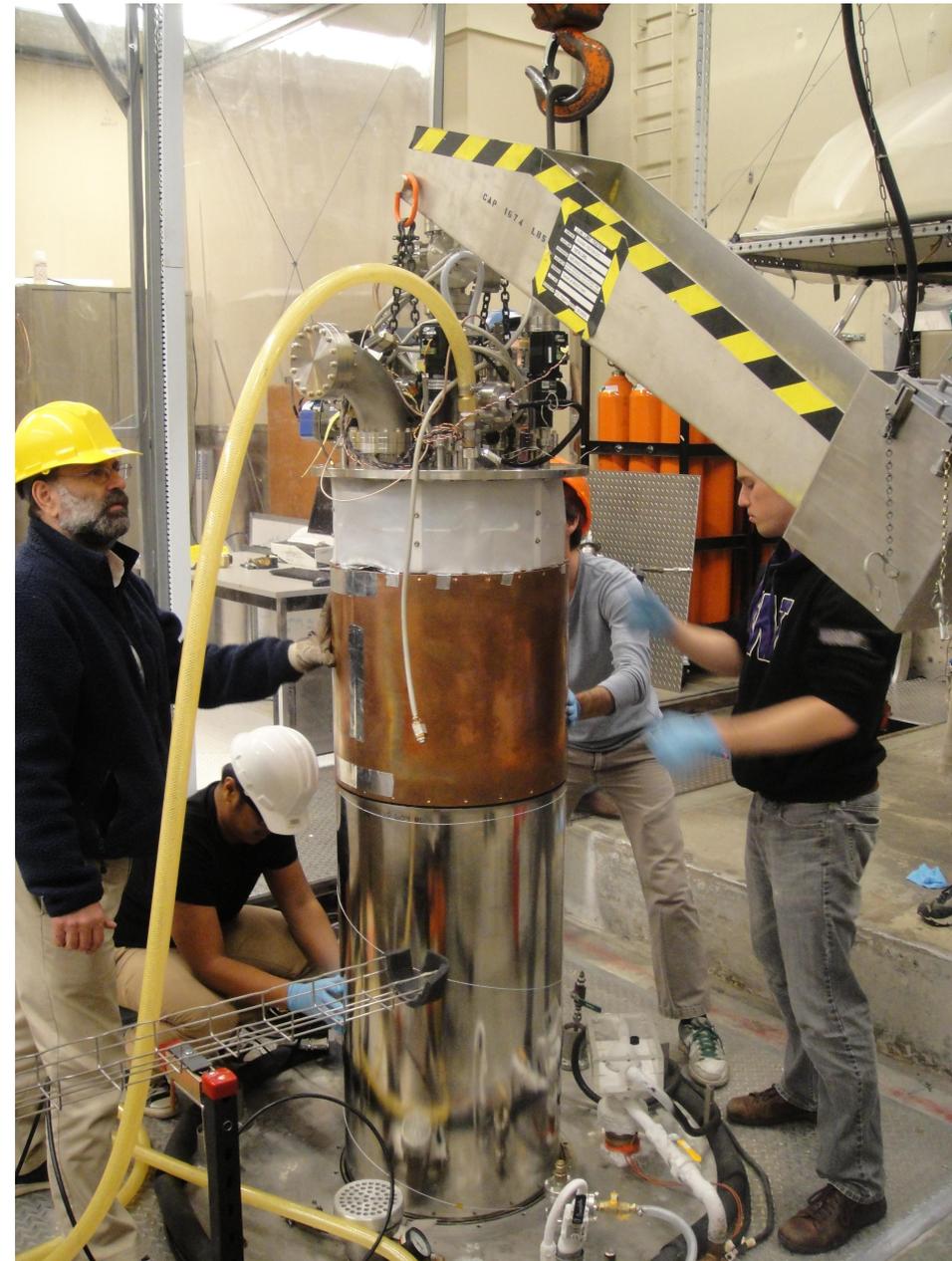
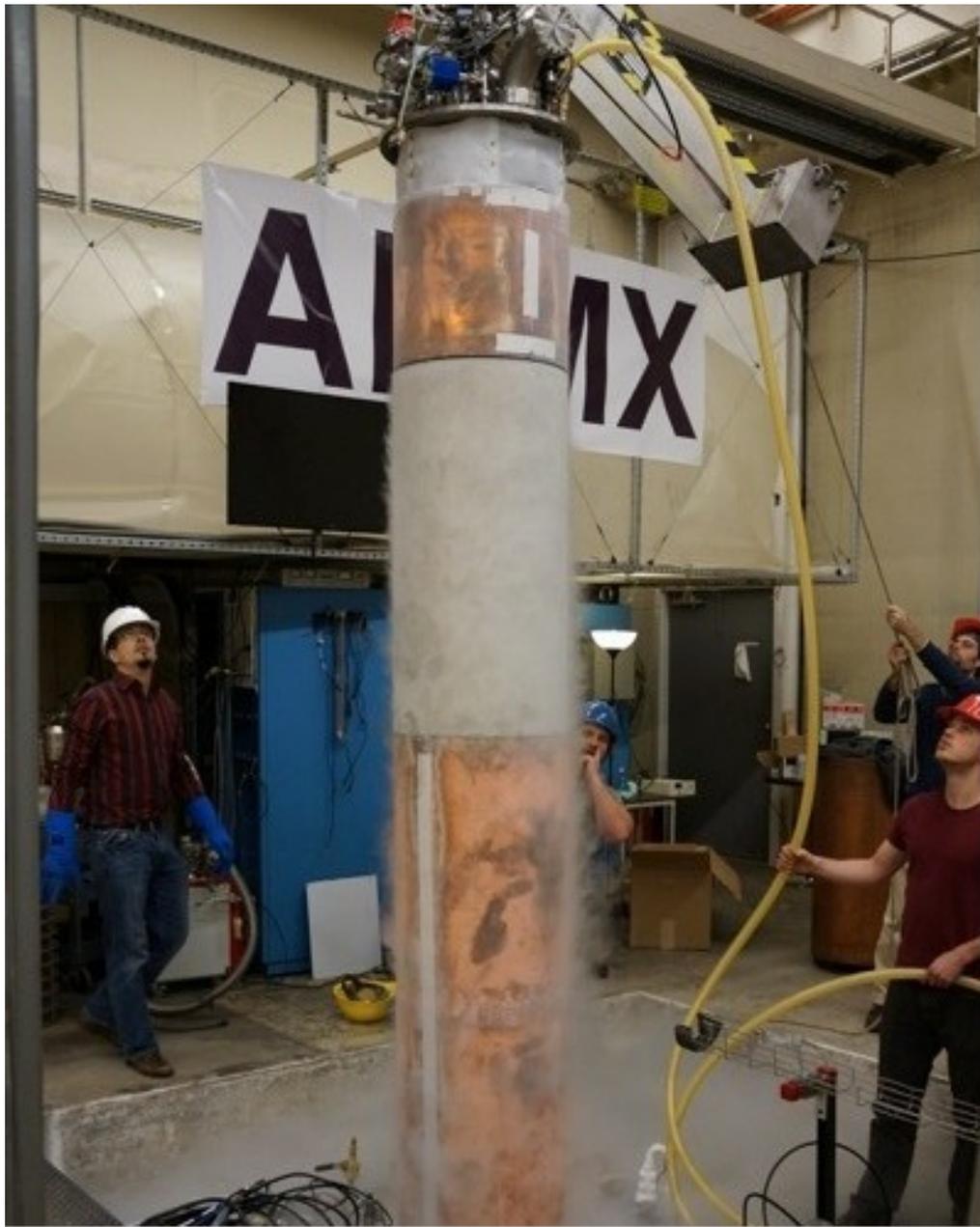
ADMX Assembly



ADMX has been completely redesigned and rebuilt at UW to work at colder temperatures



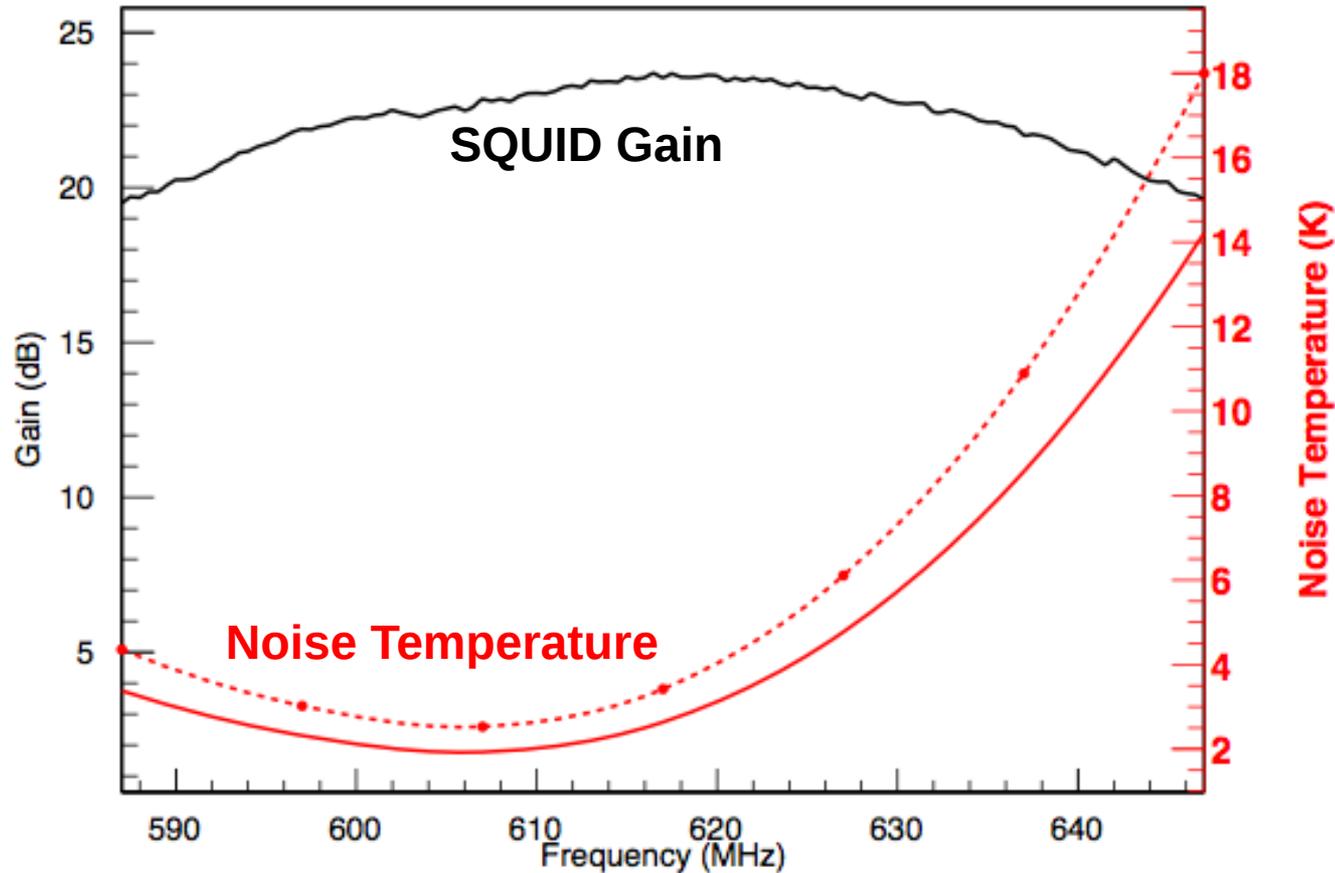
ADMX Cold Commissioning



In-Situ SQUID Calibration



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



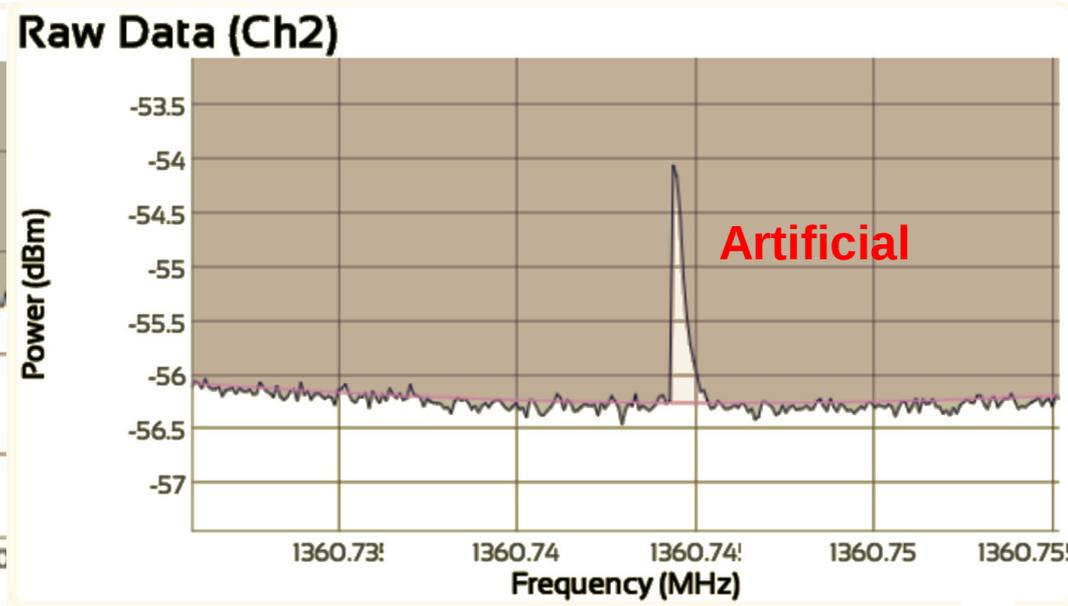
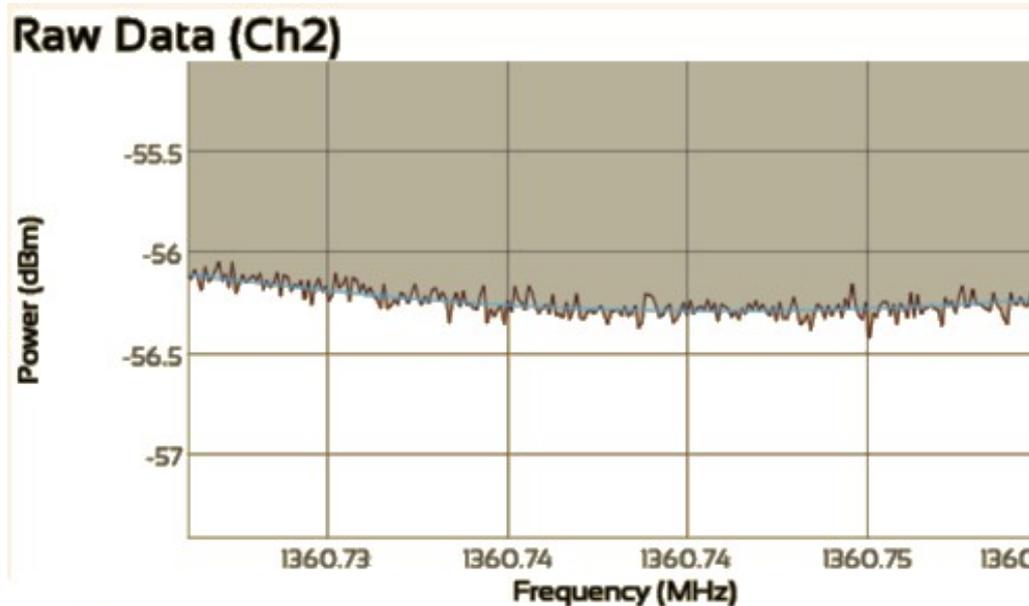
We can measure our amplifier noise temperature during data taking

Axion-Like Signal Calibration



Single Raw Power Spectrum
(100 second integration)

Raw Spectrum with Artificially
Generated Axion-Like Signal

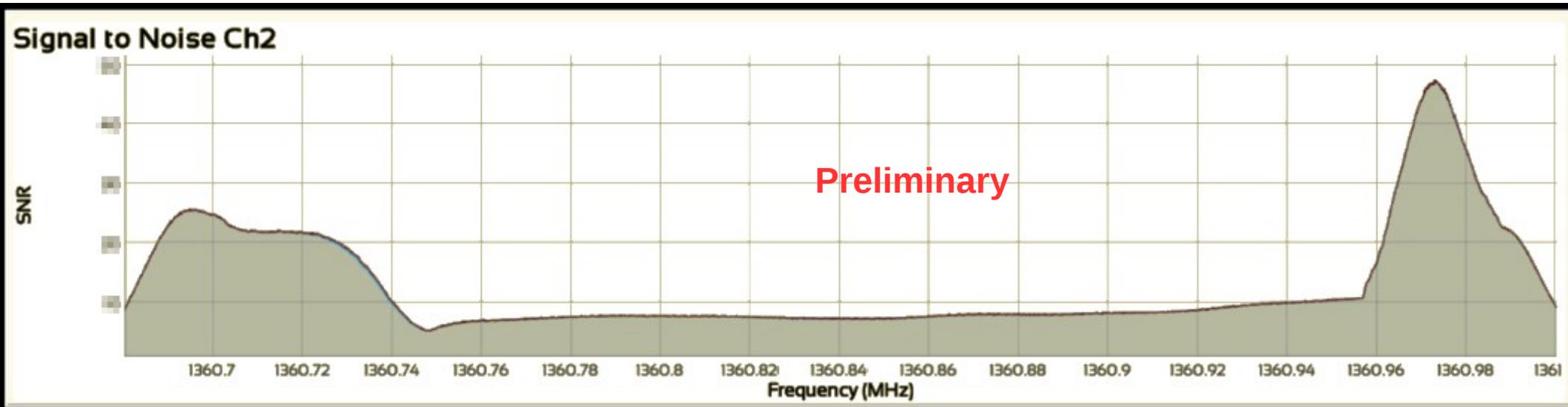


Injection of Axion-Like signals into cavity allow us to calibrate our analysis

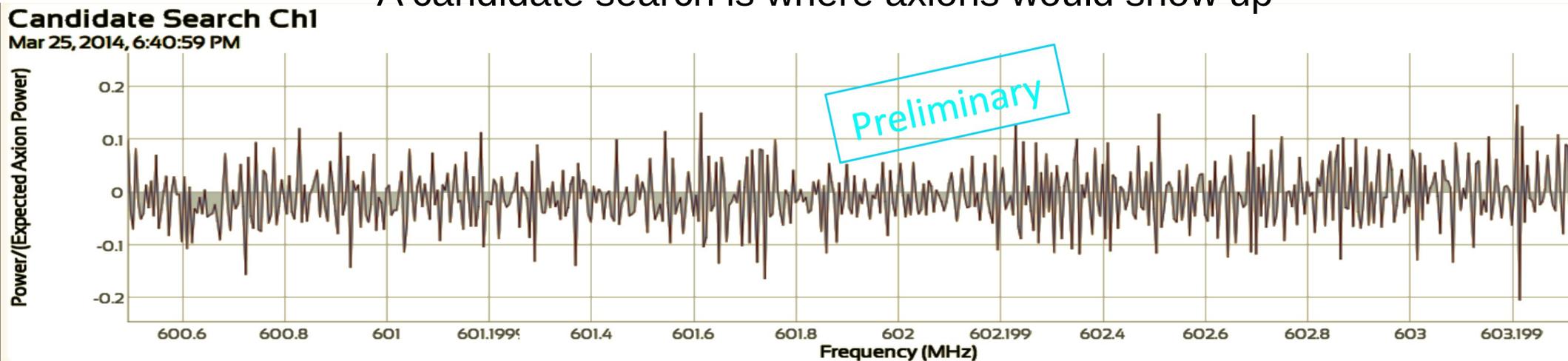
Recent Data



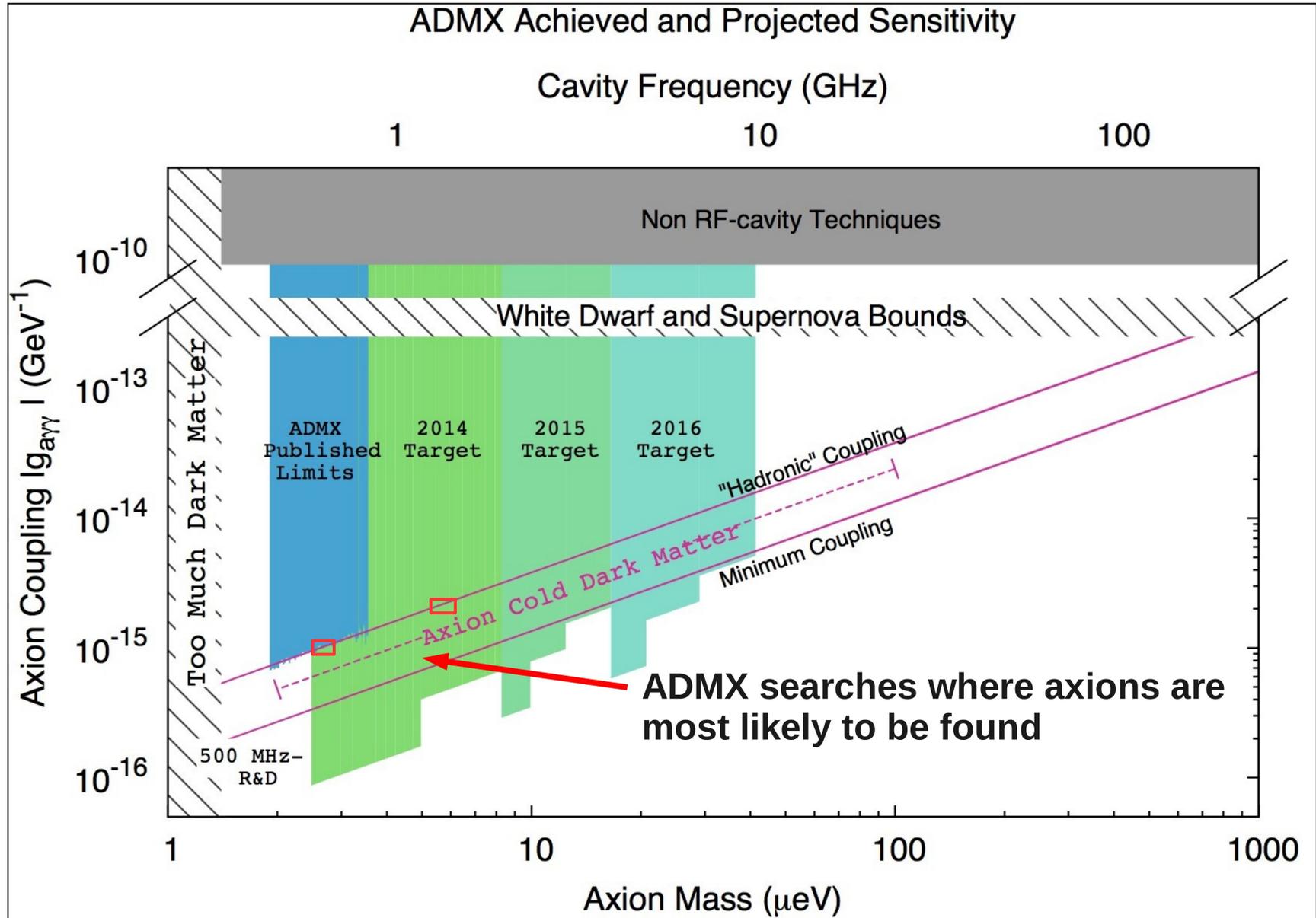
SNR determines our sensitivity



A candidate search is where axions would show up



Looking forward



Reaching Higher Frequencies



As we reach to higher axion masses:

Cavity volume shrinks

Q's get lower

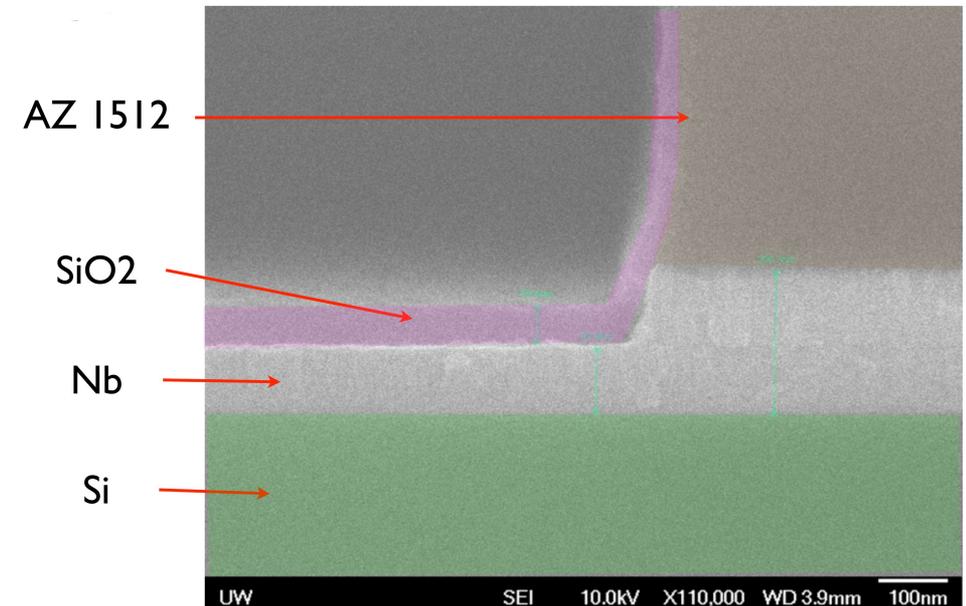
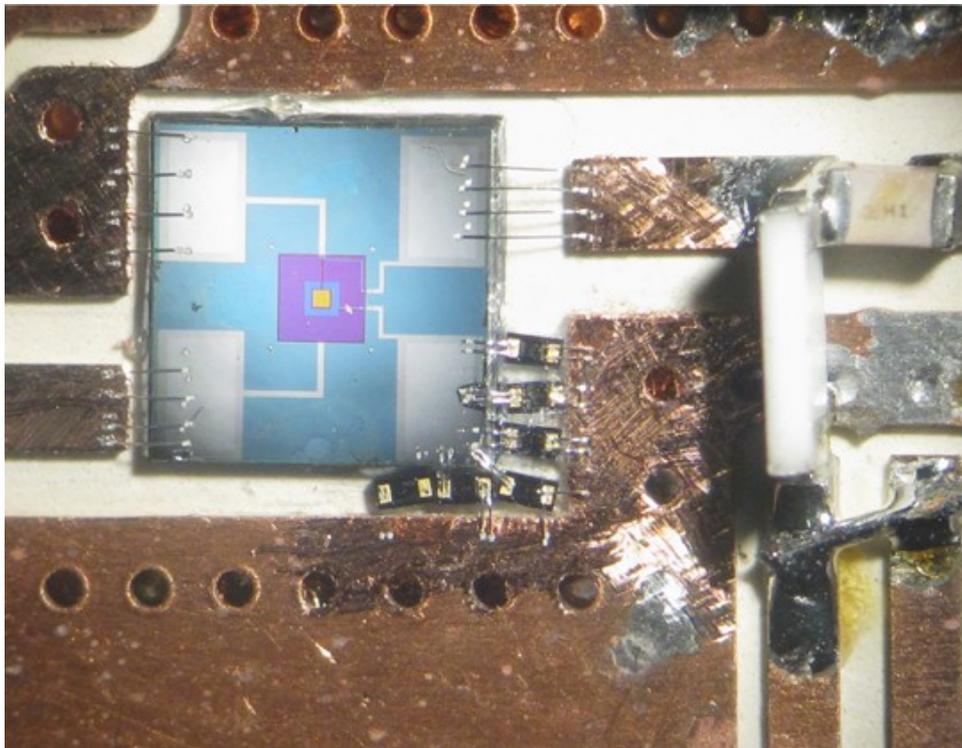
Amplifier Noise Increases

ADMX has a strong R&D program to counter these effects

Amplifier R&D



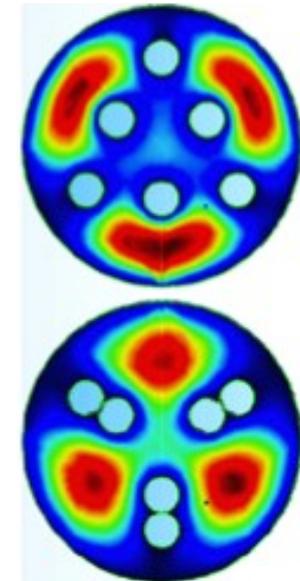
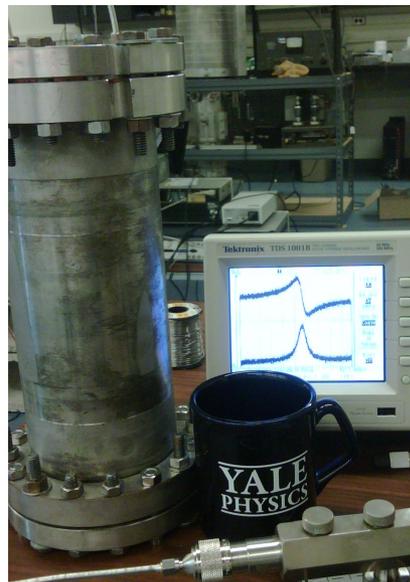
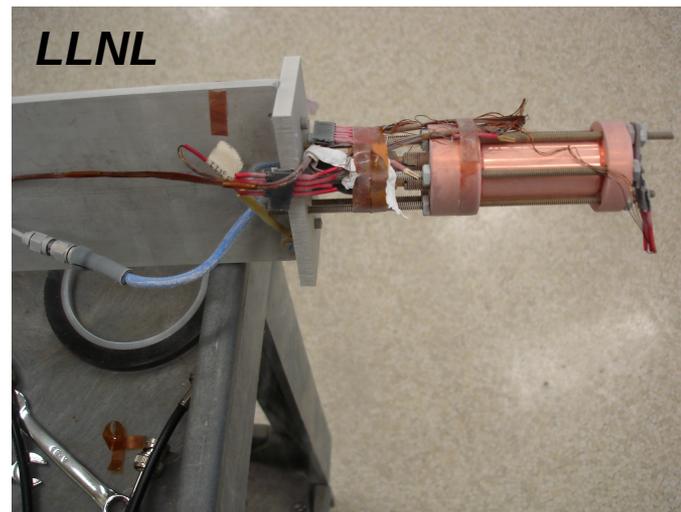
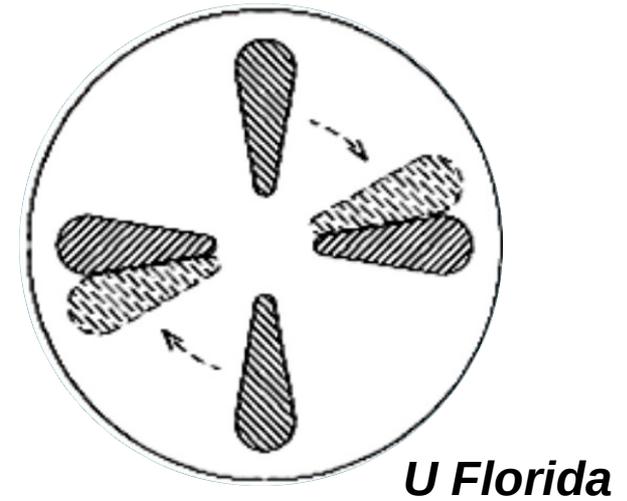
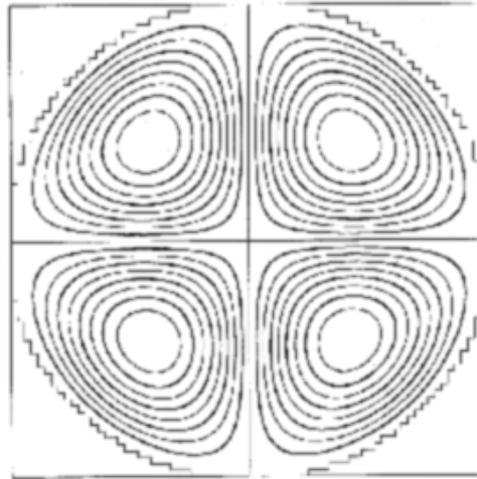
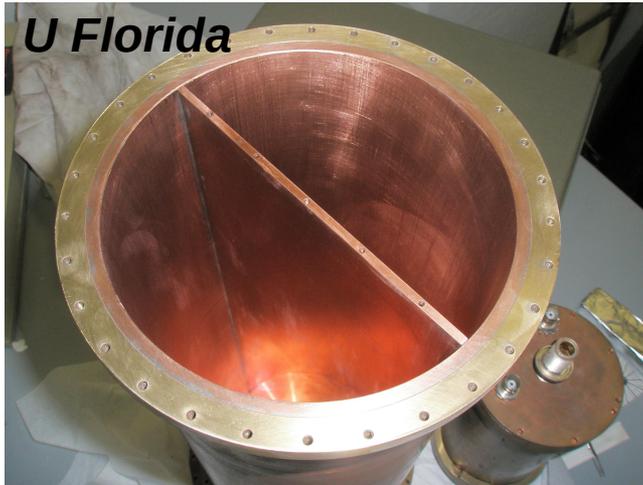
We are developing higher frequency quantum electronics (SQUIDs and JPAs) at Berkeley and UW



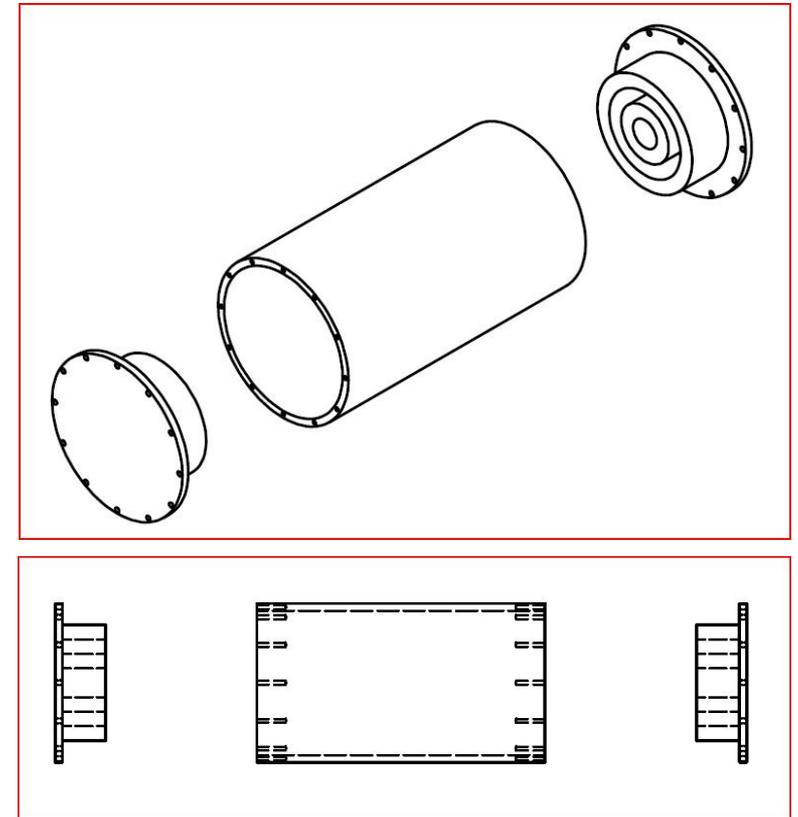
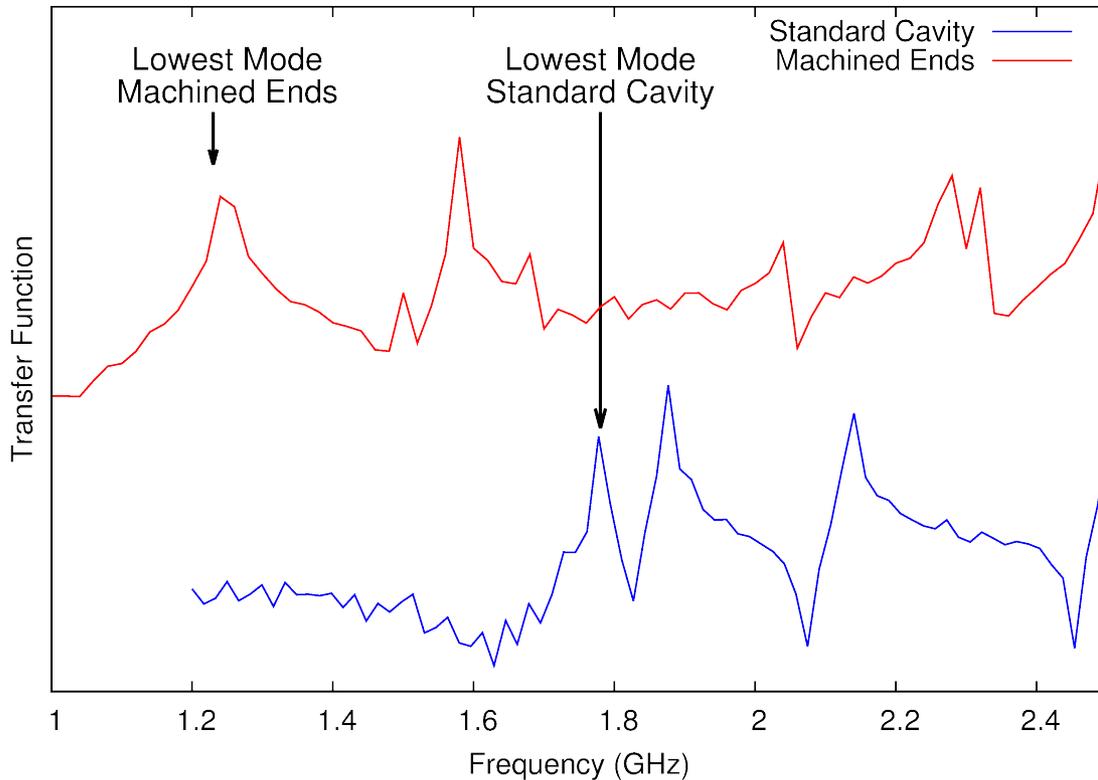
Higher Frequency Cavities



We are developing higher frequency cavity structures



Lower Frequency Cavities



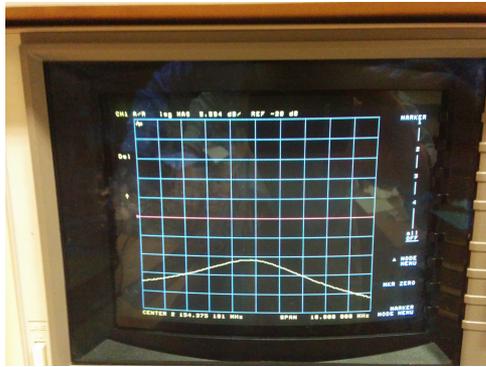
R&D is underway to access frequencies below those of previous cavities

Current work promises factor of two or more frequency reach increase

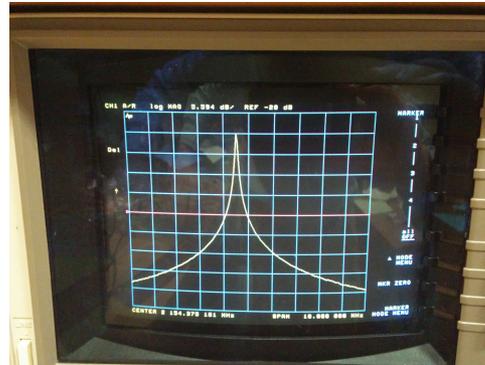
Active Resonators

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

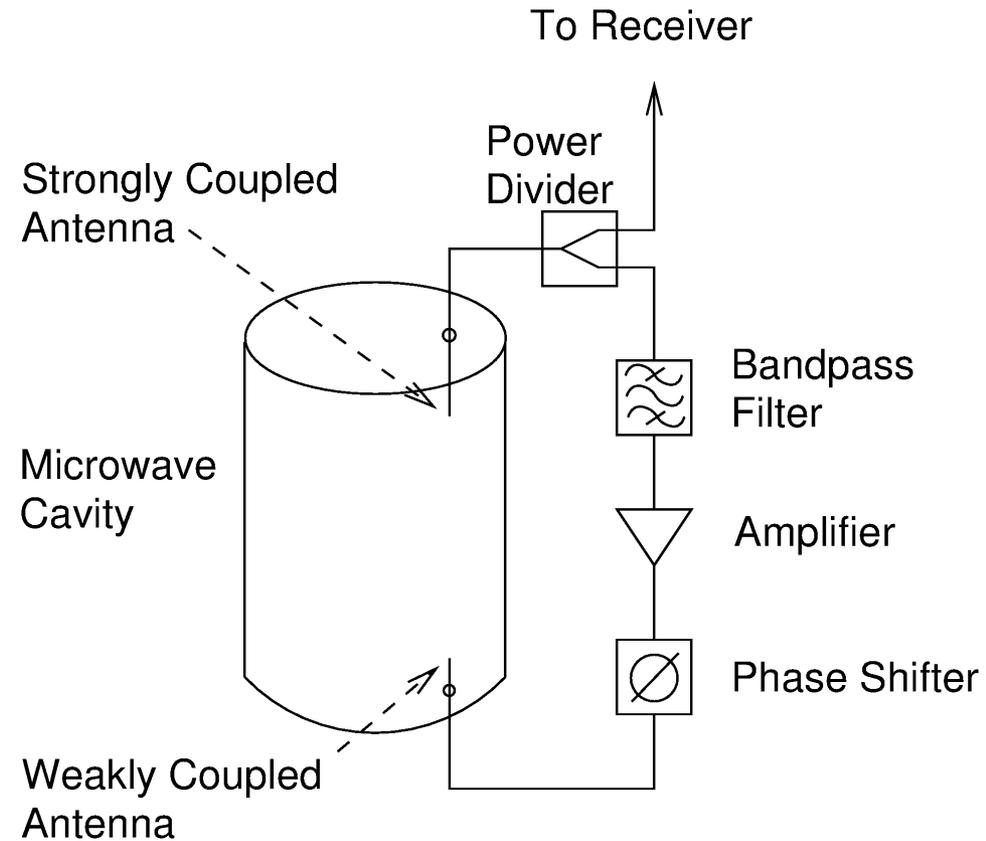
This could increase axion conversion signal, but noise increases as well



Passive

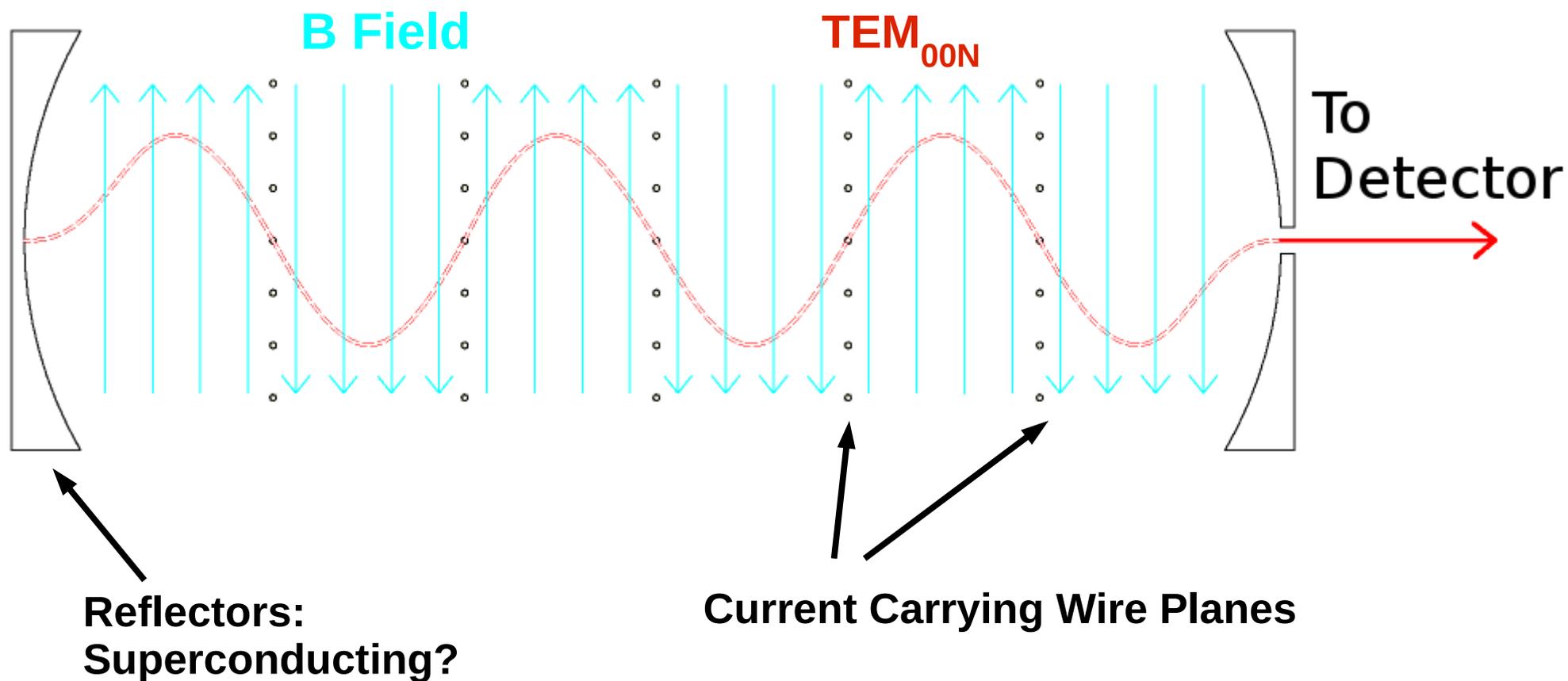


Active

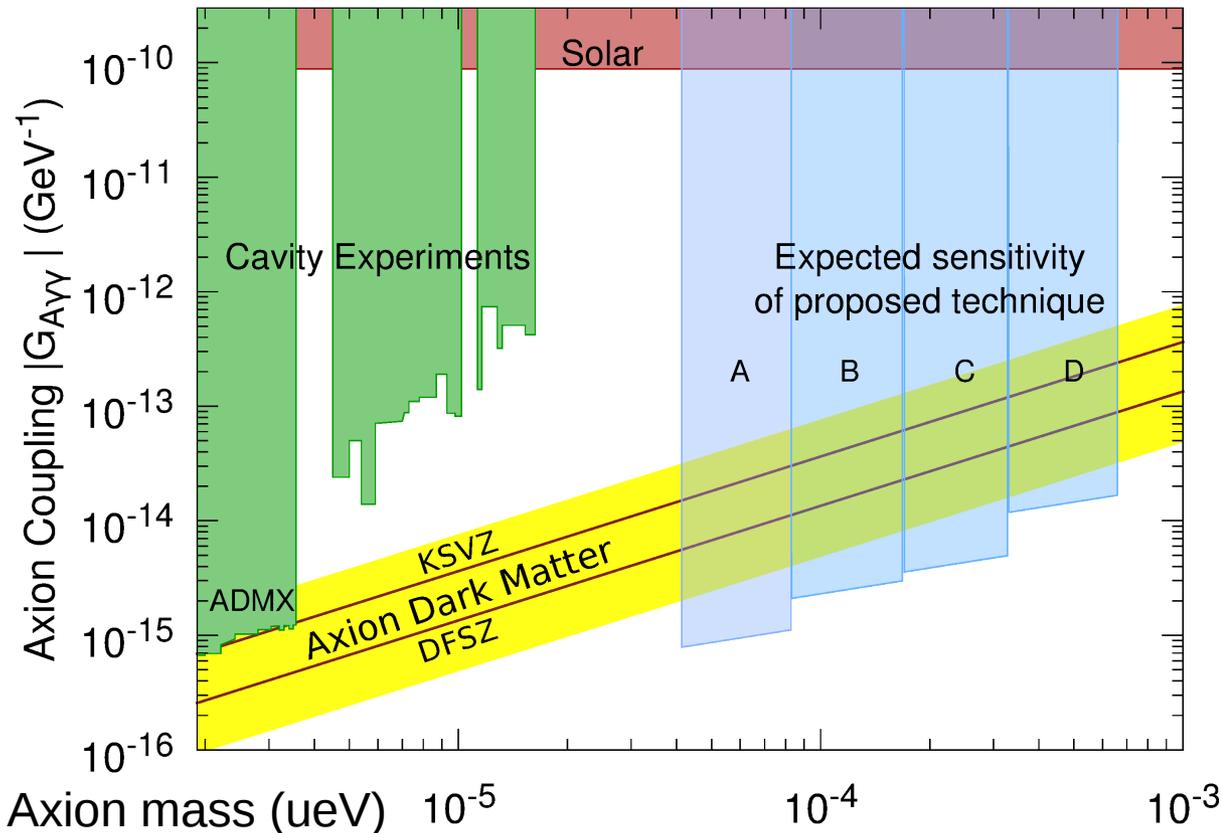


The use of active resonators to enhance sensitivity in ADMX is currently under study: [arxiv:1403.6720](https://arxiv.org/abs/1403.6720)

Open Resonator Concept



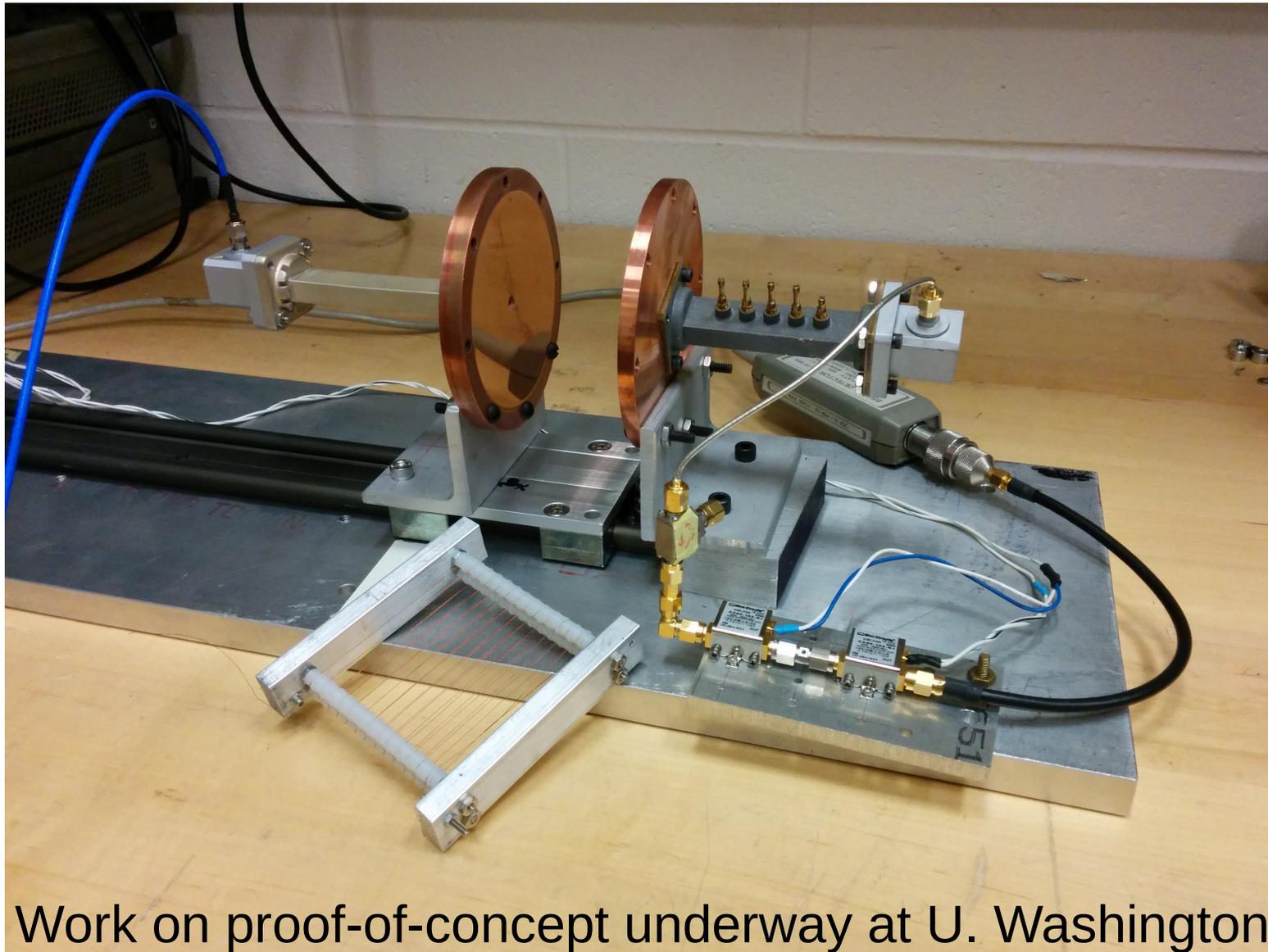
Open Resonators Potential Reach



May be able to extend
ADMX reach to meV masses
See: [arxiv:1403.3121](https://arxiv.org/abs/1403.3121)

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

Open Resonators 3



Work on proof-of-concept underway at U. Washington

Concluding Remarks



Axions are a well motivated dark matter candidate

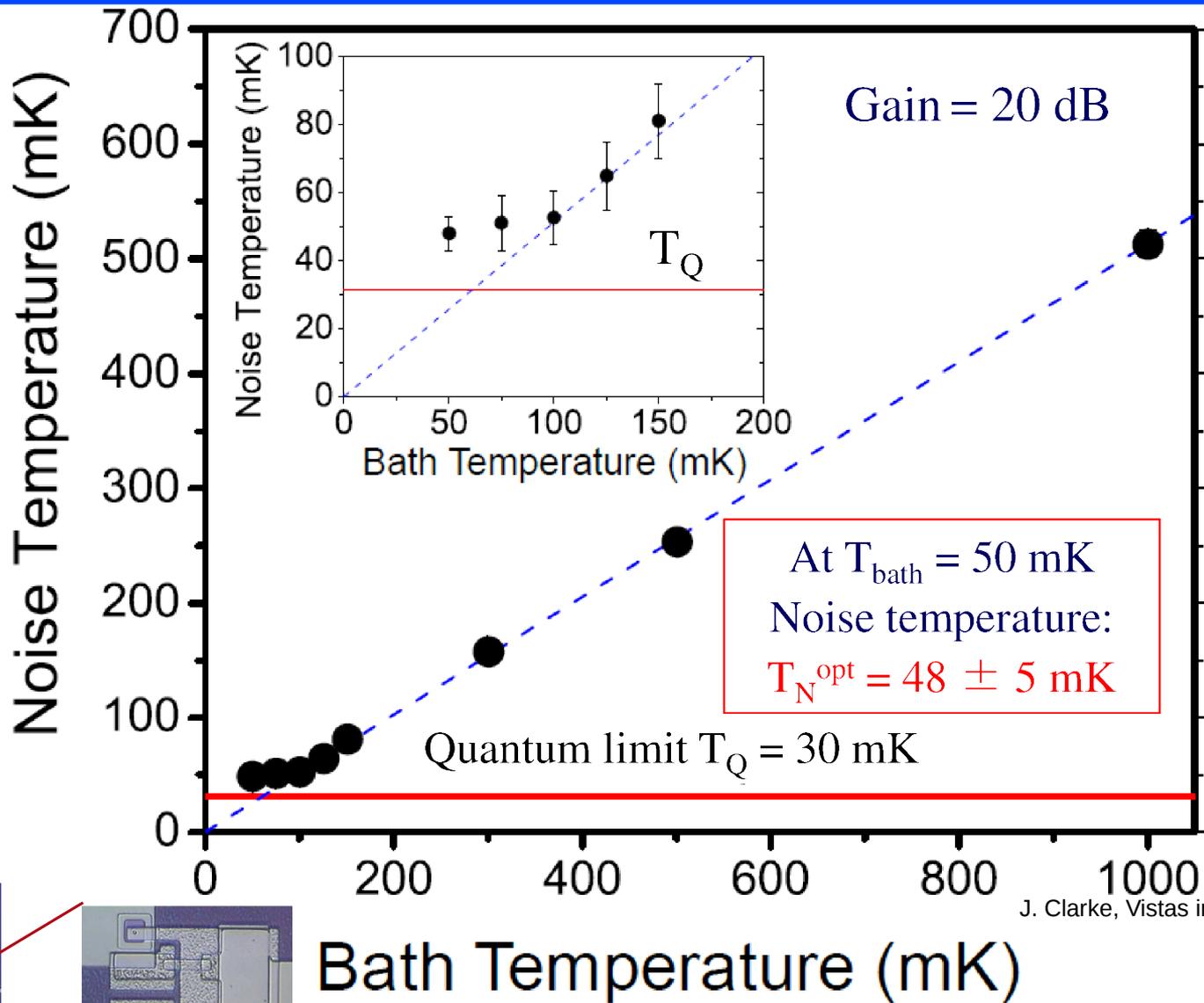
ADMX is taking data right now and will explore a significant fraction of likely axion dark matter masses in the near future

Work is underway to explore the entire plausible axion mass range

If the axion is out there, we will find it

Backup Slides

SQUID Advantage



J. Clarke, Vistas in Axion Physics, 2012

