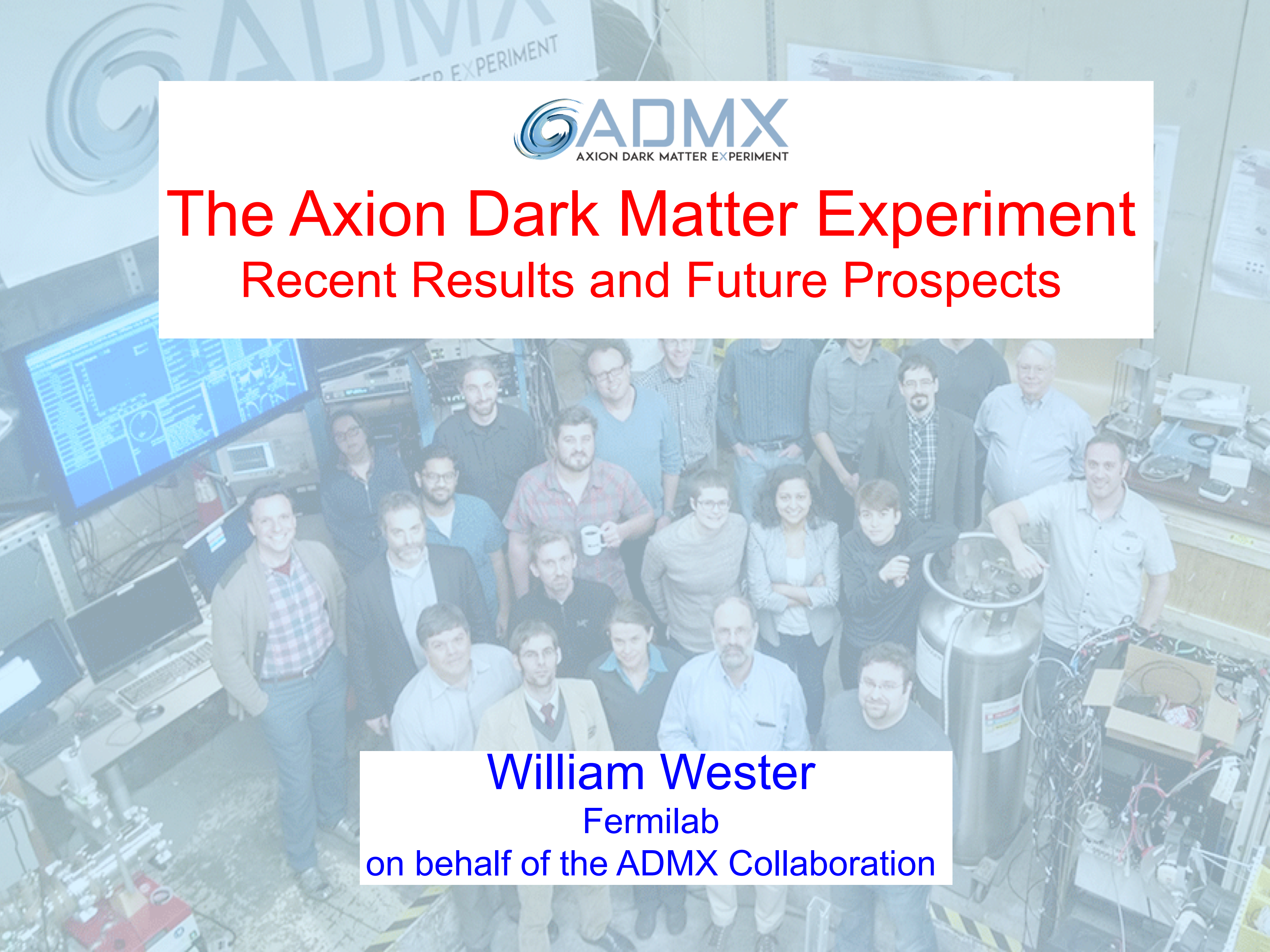


The Axion Dark Matter Experiment

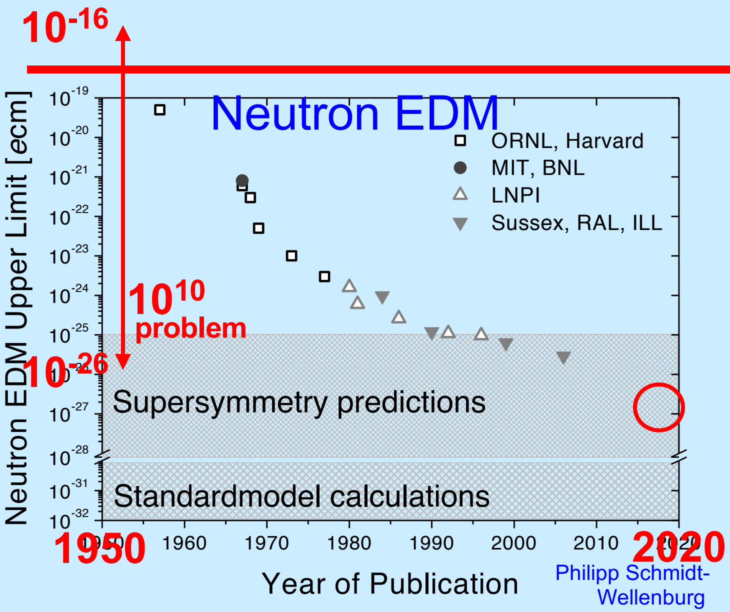
Recent Results and Future Prospects

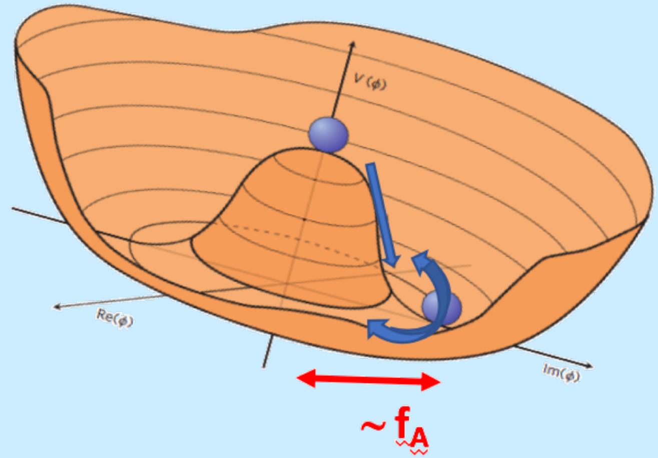
William Wester

Fermilab

on behalf of the ADMX Collaboration

Axions solve strong-CP problem





Peccei – Quinn Symmetry

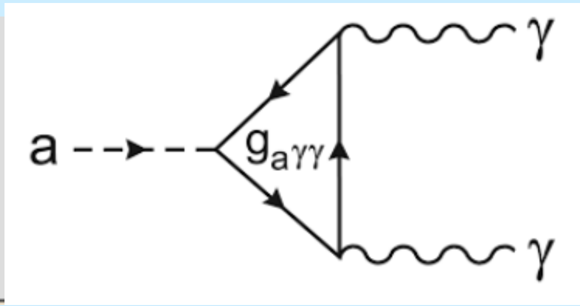
$$m_A f_A = \sqrt{\chi} \approx f_\pi m_\pi$$

$$m_a \approx 6\ \mu\text{eV}\left(\frac{10^{12}\ \text{GeV}}{f_a}\right)$$

Models: KSVZ – heavy quarks
DSFZ – new Higg's

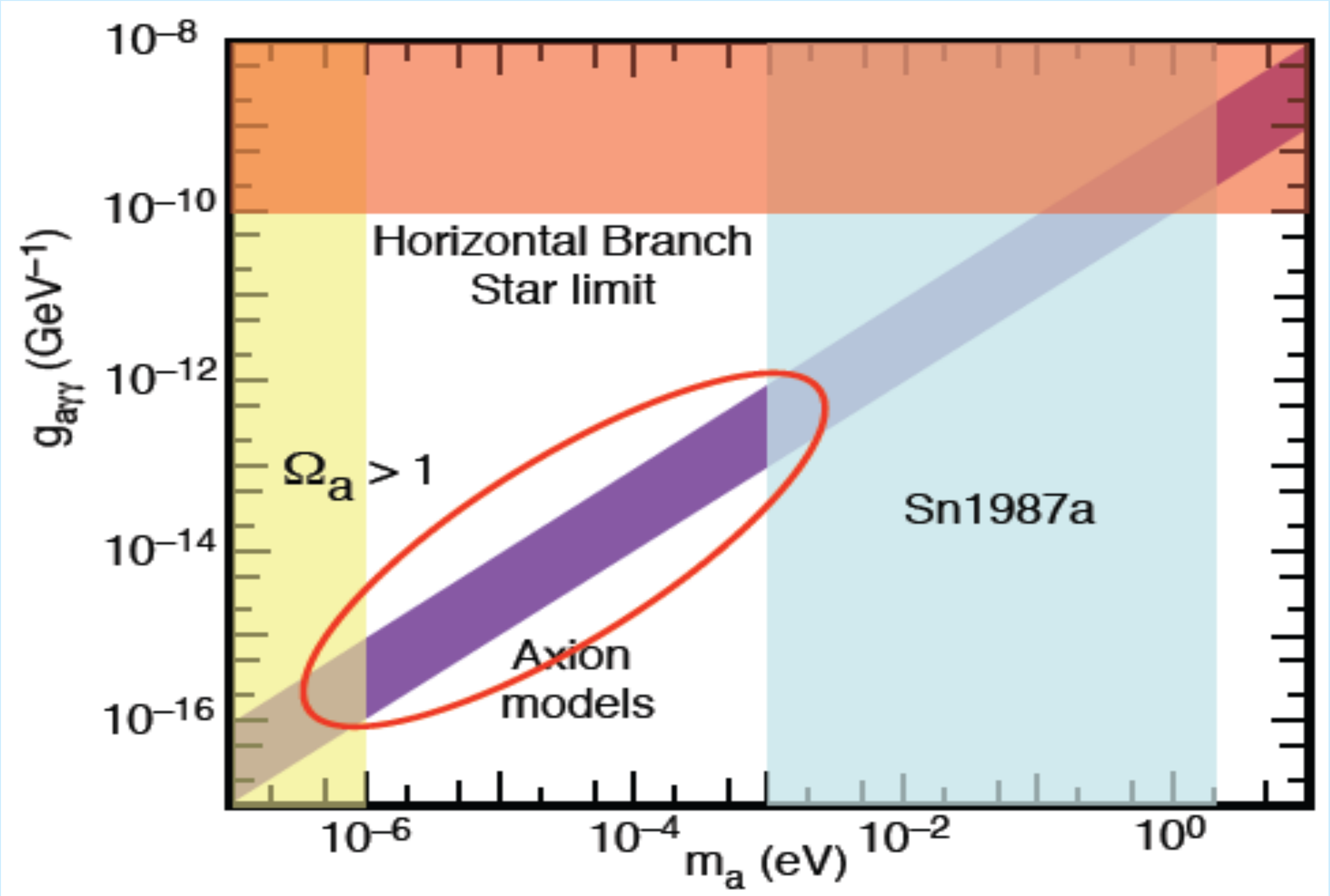
$$L_{a\gamma} = -\frac{g_{a\gamma}}{4} F\tilde{F} a = g_{a\gamma} \vec{E}\cdot\vec{B} a$$

$$g_{a\gamma} = \frac{\alpha}{2\pi f_a}\left(\frac{E}{N} - 1.92\right)$$



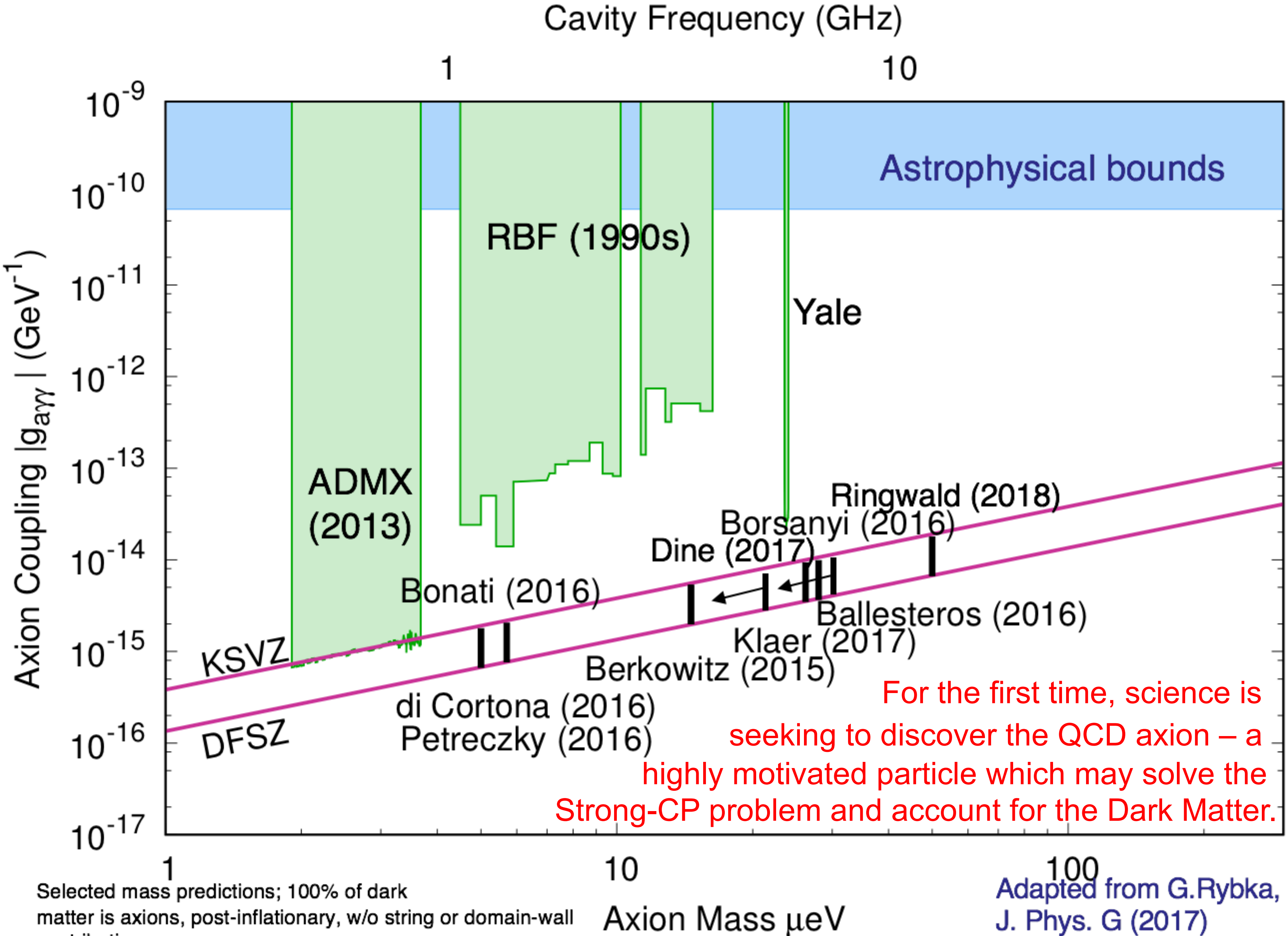
Axions as cold dark matter

The classic QCD axion window is well-defined as the axion field after PQ symmetry breaking (post-inflation) acts as a cold dark matter condensate.



If PQ is broken before inflation, ultra-light axions are possible.

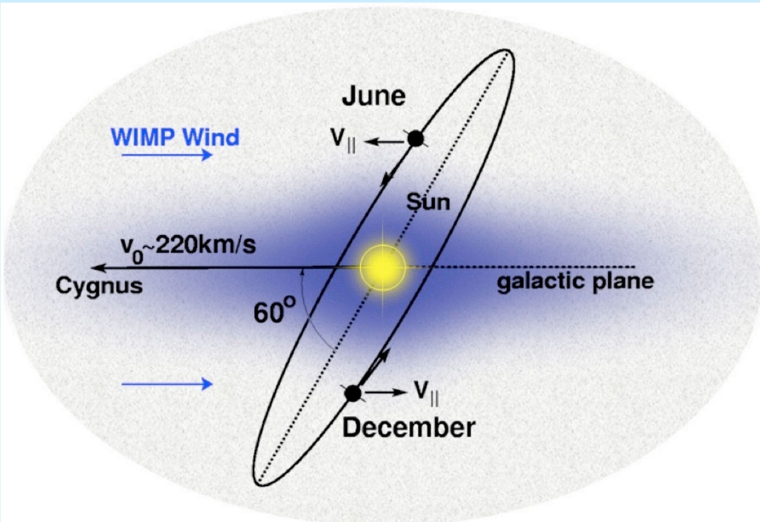
Astrophysical constraints give a target area for discovery!



Cavity Frequency (GHz)
1
10
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
Axion Coupling $|g_{a\gamma\gamma}|$ (GeV^{-1})
Astrophysical bounds
RBF (1990s)
Yale
ADMX
(2013)
Ringwald (2018)
Borsanyi (2016)
Dine (2017)
Bonati (2016)
Ballesteros (2016)
Klaer (2017)
Berkowitz (2015)
KSVZ
DFSZ
di Cortona (2016)
Petreczky (2016)
For the first time, science is seeking to discover the QCD axion – a highly motivated particle which may solve the Strong-CP problem and account for the Dark Matter.
1
10
100
Axion Mass μeV
Selected mass predictions; 100% of dark matter is axions, post-inflationary, w/o string or domain-wall contributions
Adapted from G.Rybka, J. Phys. G (2017)

A gen2 Dark Matter Experiment

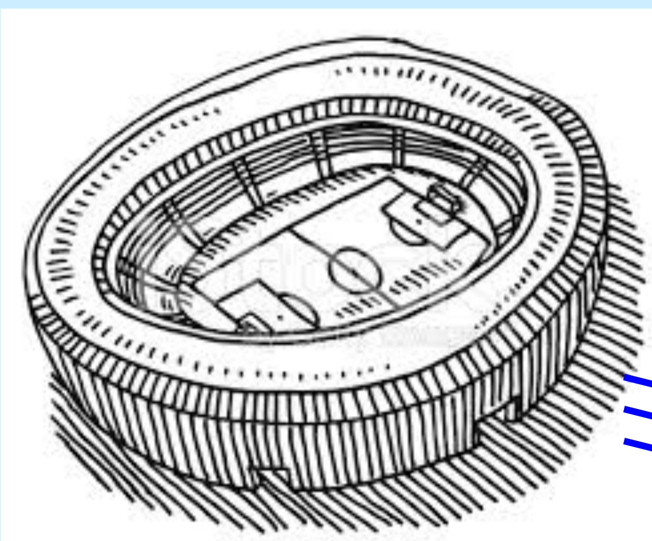
Direct Detection



Solar system is moving at ~200km/s through a dark matter halo with a density of 0.3 – 0.5 GeV/cm^3.

Axion searches look for the axion field coherently interacting with a sensitive apparatus

Suppressing backgrounds such as electronic and thermal noise is key in having sensitivity.

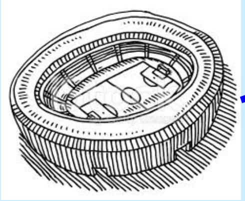


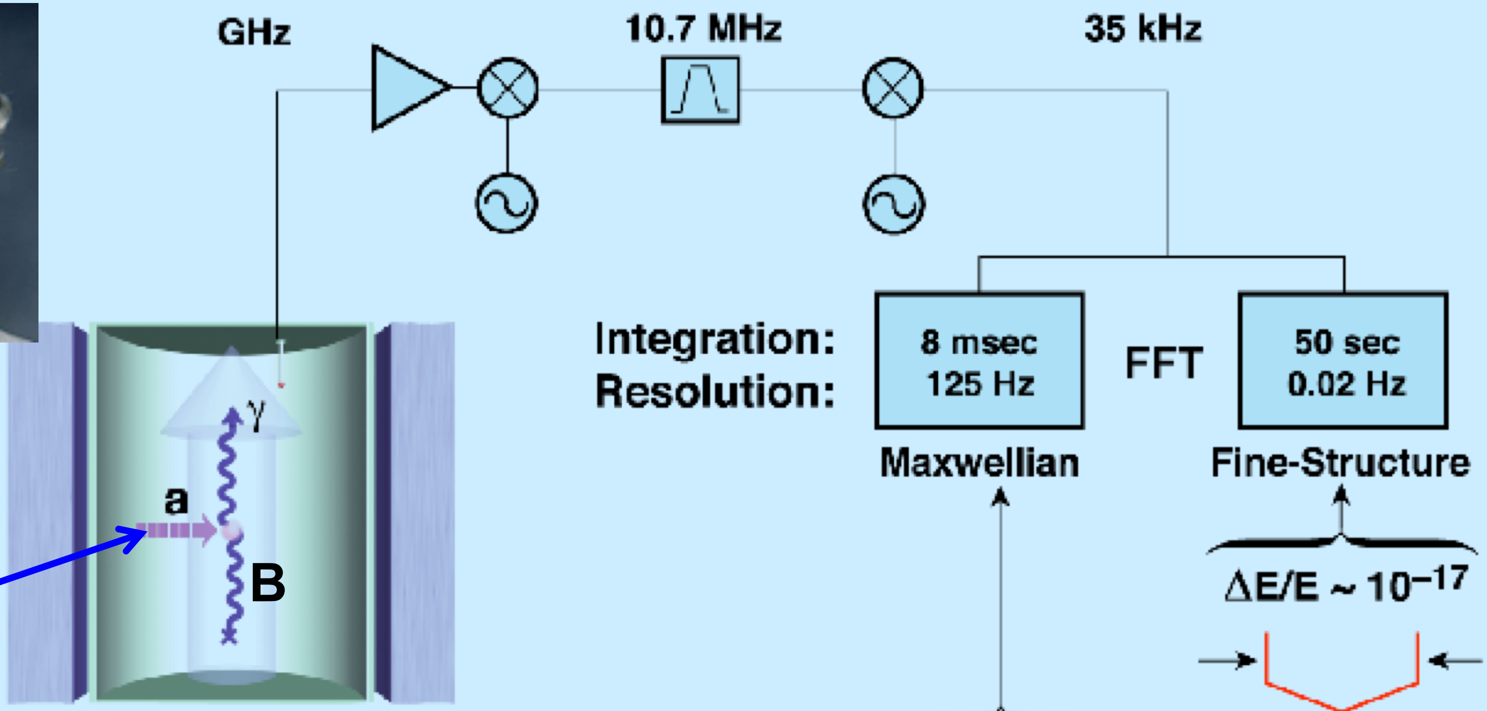
ADMX

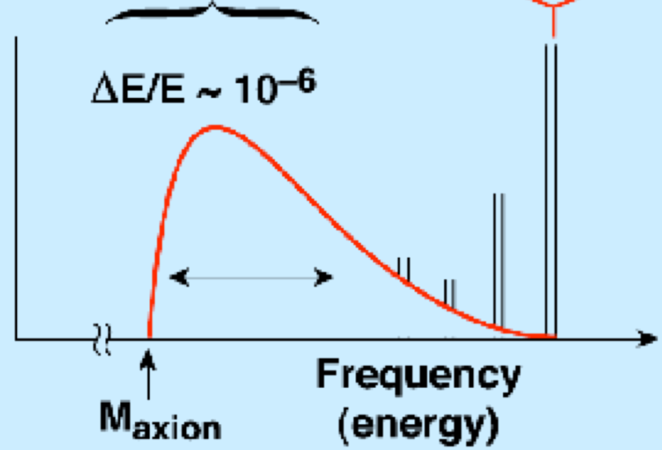
Phase coherent over 10^{-3}s or 100s of meters

Axion Haloscope

Pierre Sikivie



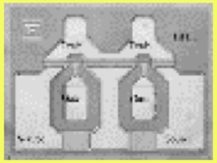
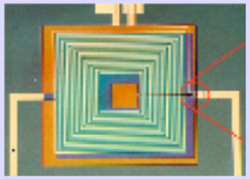




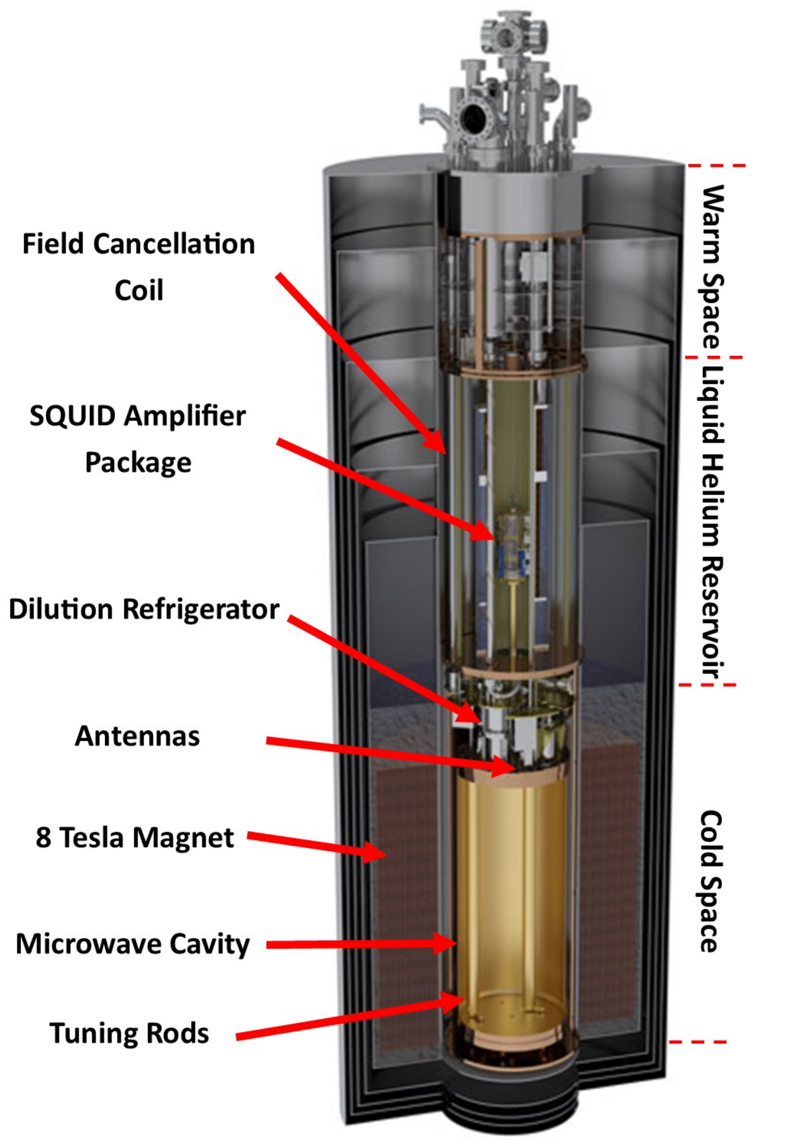
Axions interact with B field photon in a cavity converting into a detectable microwave photon. Resonant process when the cavity is tuned to the energy (i.e. KE of the axion). Scan vs. frequency.

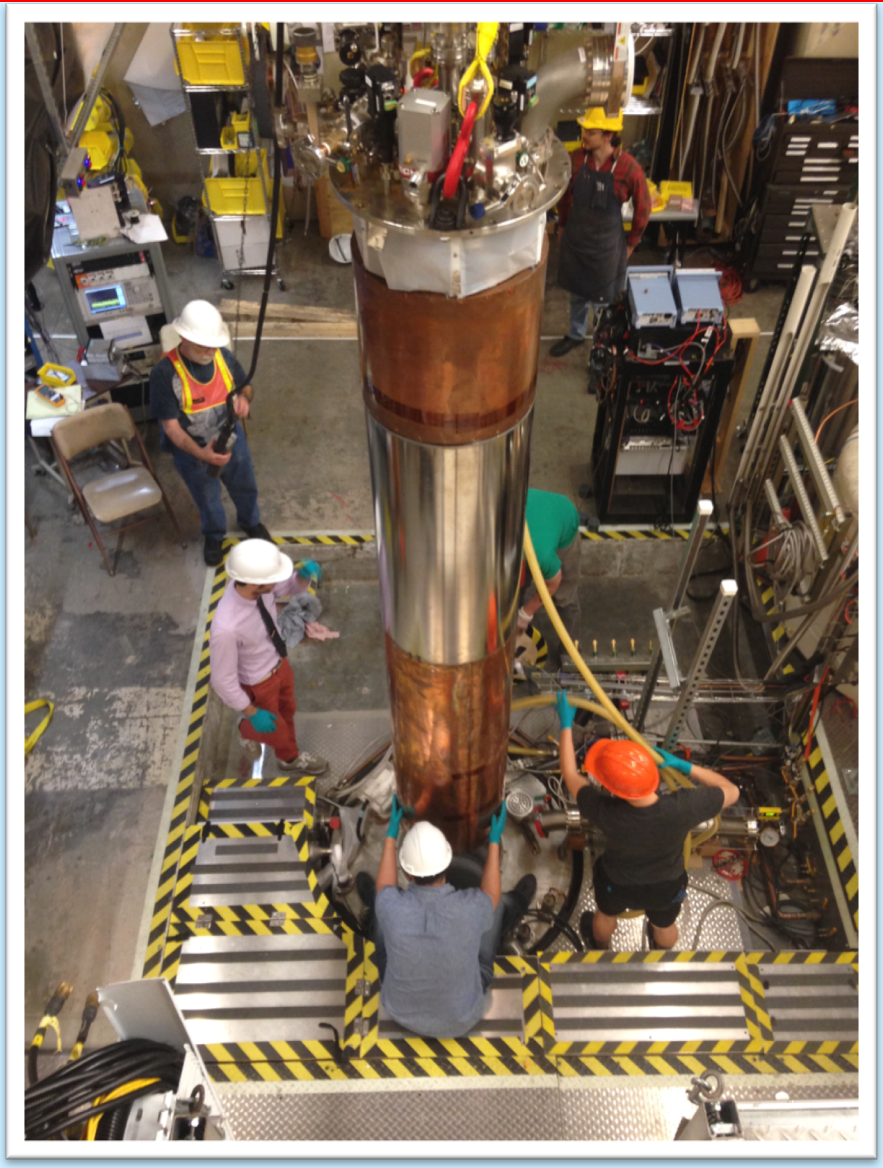
20+ yrs of ADMX

The system temperature controls sensitivity and the scan rate

Stage	**Phase 0**	**Phase I**	**Gen 2** **2014**
Technology	HEMT; Pumped LHe 	Replace w. SQUID 	Add Dilution Fridge 
T_{phys}	2 K	2 K	100 mK
T_{amp}	2 K	1 K	100 mK
$T_{sys} = T_{phys} + T_{amp}$	4 K	3 K	200 mK
Scan Rate $\propto (T_{sys})^{-2}$	1 @ KSVZ	1.75 @ KSVZ *OR*	5 @ DFSZ *AND !*
Sensitivity Reach $g^2 \propto T_{sys}$	KSVZ	0.75 x KSVZ	DFSZ
	1996-2006	**2006-2010**	**2010-Present**

ADMX Experiment

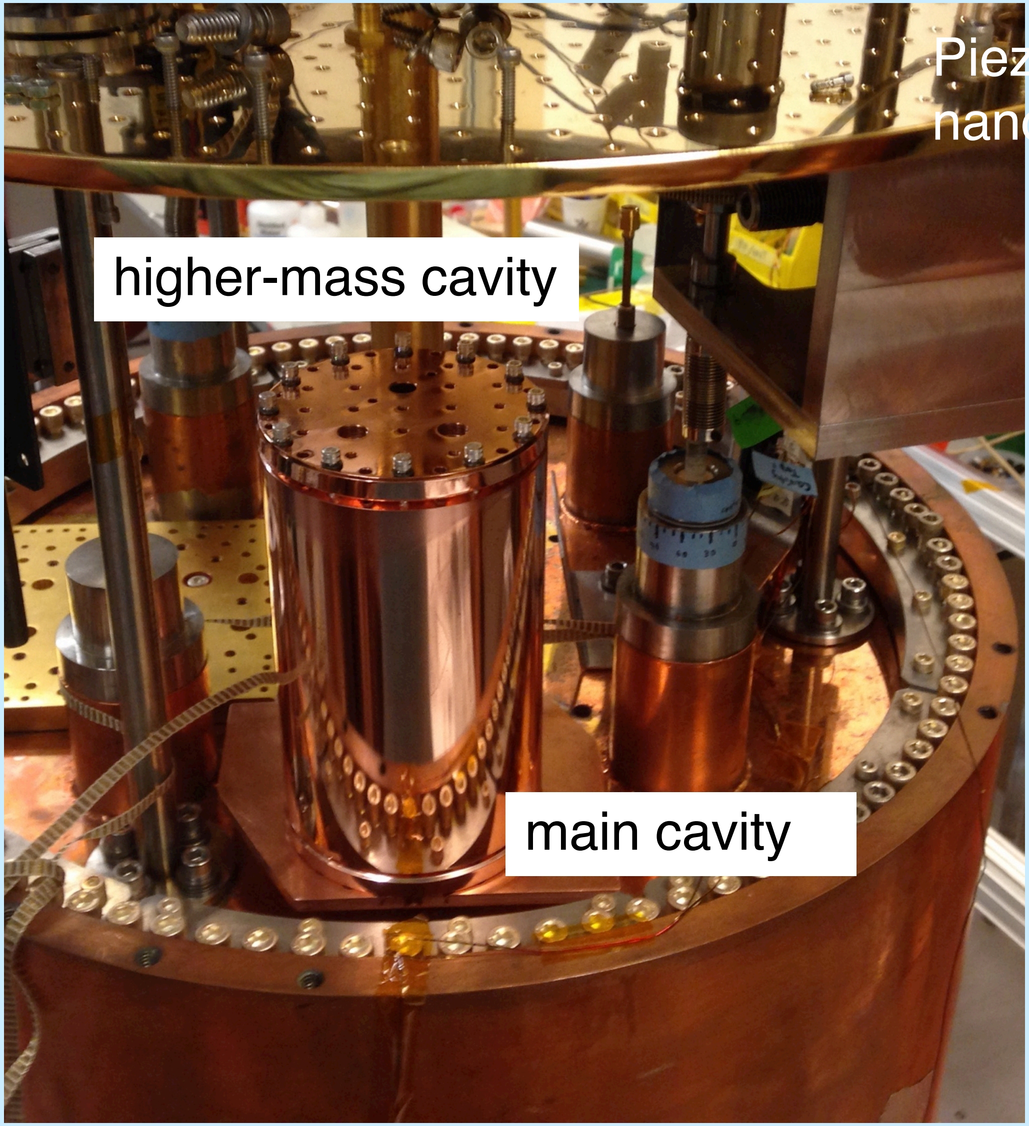


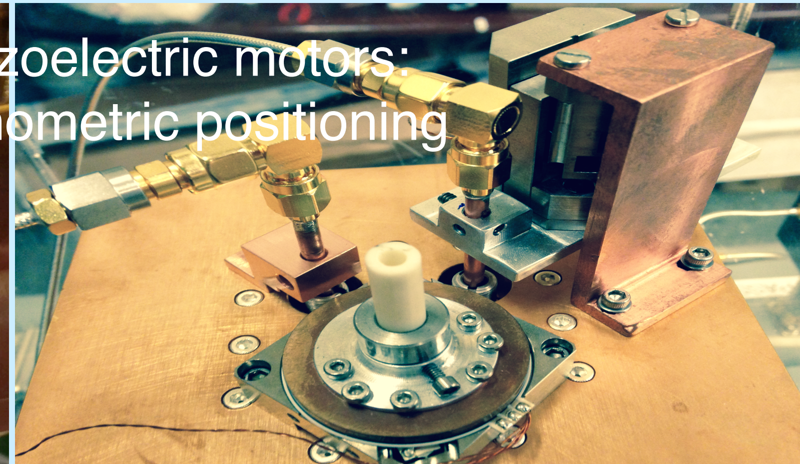


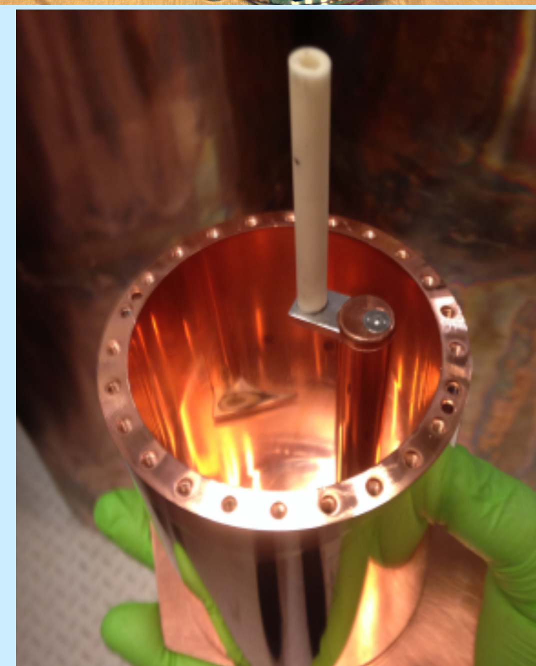
W. Wester, Fermilab, Division of Particles and Fields, Boston July 2019

Second R&D cavity: sidecar

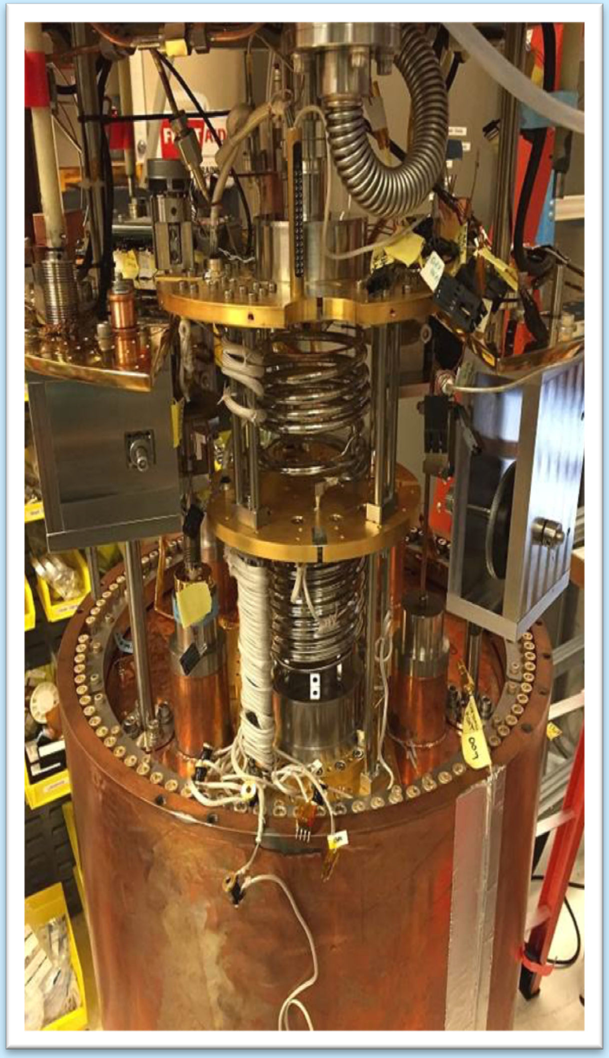
ADMX
AXION DARK MATTER EXPERIMENT



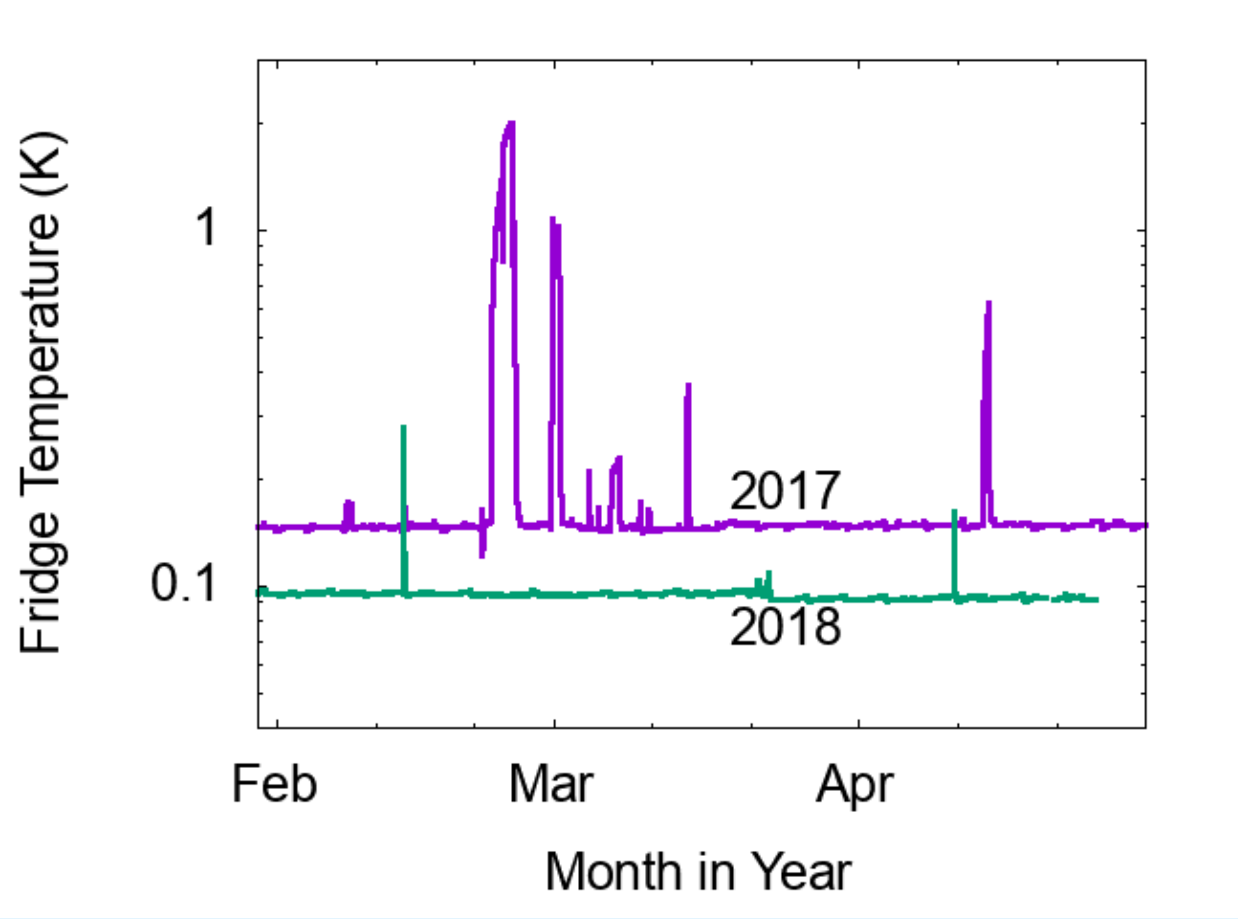




Dilution refrigerator



Dilution Refrigerator installed above ADMX Cavity

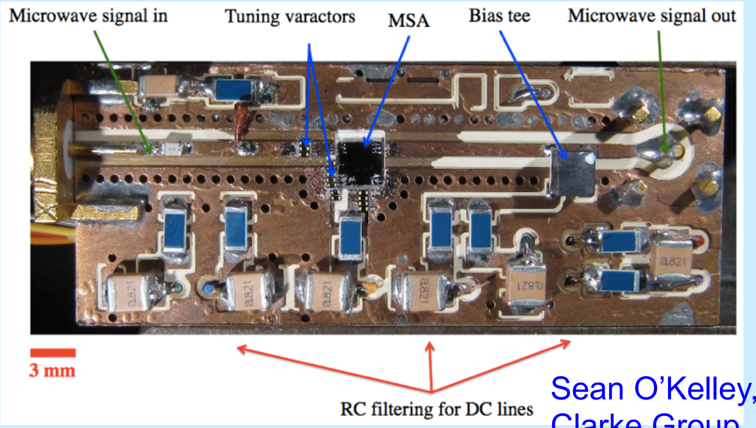


Stable operation for 2018 data taking

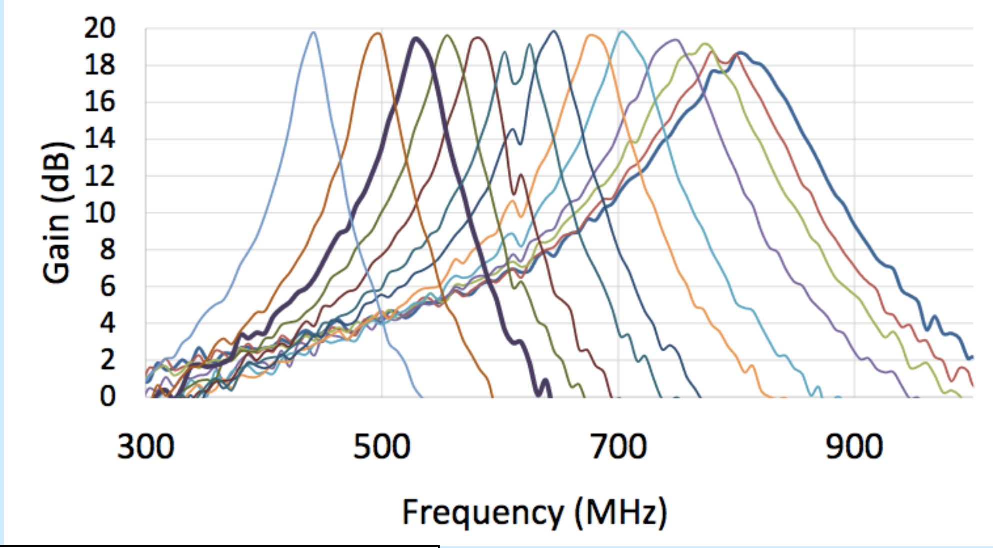
Cryogentic amplifiers

SQUID and JPA amplifiers enable low $T_{SYSTEM} = T_{PHYSICAL} + T_{AMP}$

ADMX Tunable SQUID

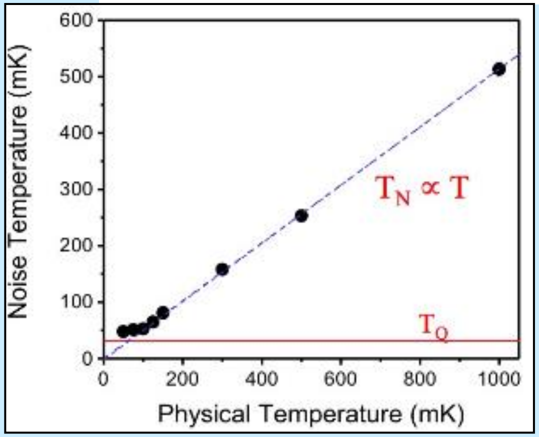


Sean O'Kelley,
Clarke Group,
UC Berkeley



ADMX JPA

Yanjie Qiu,
Siddiqi Group,
UC Berkeley



Quantum noise limit
is 48mK at 1GHz

Operations

Cavity frequency is scanned over a region until the desired SNR.

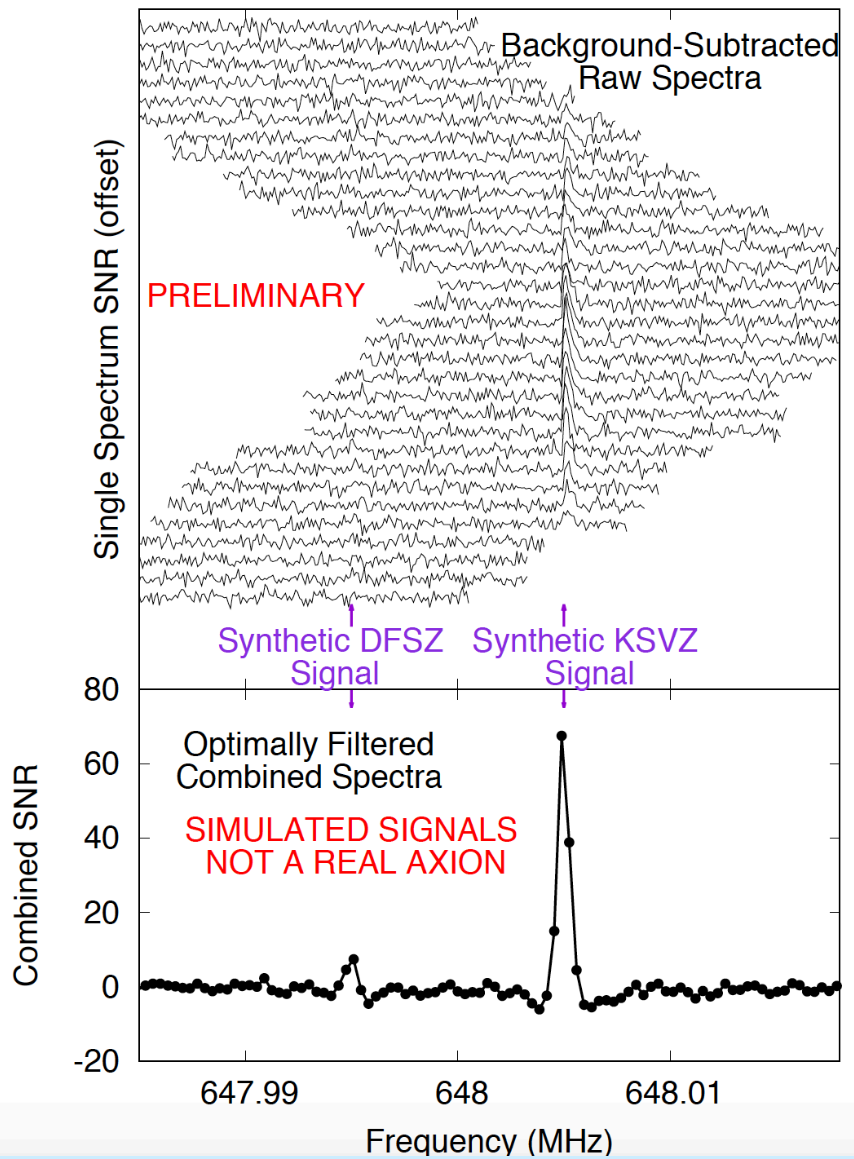
Combined power spectrum examined for signs of excess

Excess power can be statistical fluctuations, *synthetically injected signals*, RF interference, or axions

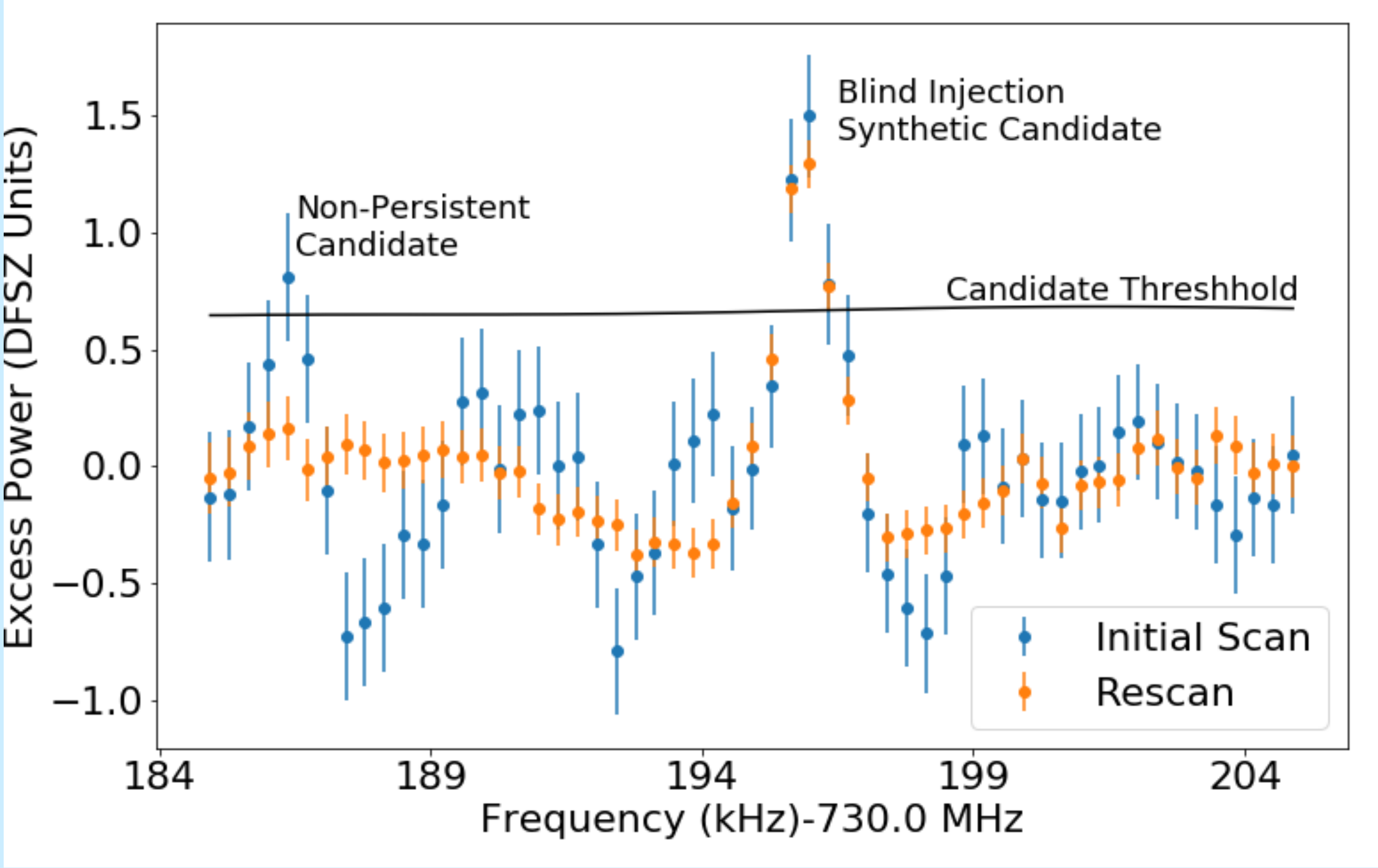
Excess power regions are rescanned to see if they persist

Persistent candidates are subjected to a variety of confirmation tests.

Ultimately a B^2 dependence



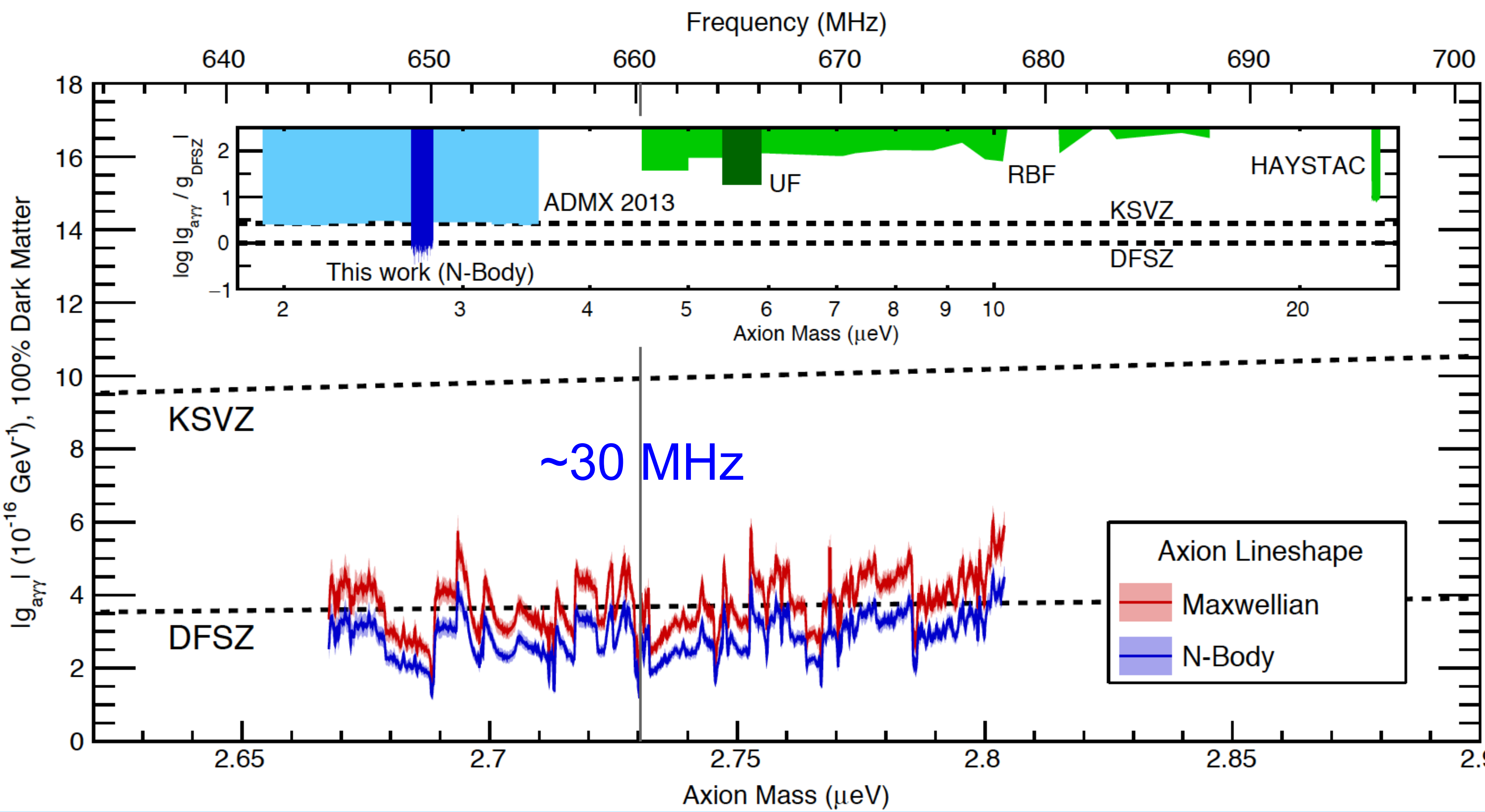
Synthetic Axion Signal



Axion-shaped RF signal are periodically injected into the cavity, blind to the analysis.
Most signals are unblinded at the time of rescan to verify our detection efficiency.
Some (like this one) are not unblinded until the decision to ramp the magnet down.
Note much more data is required over a rescan-frequency than during the initial scan.

First results Run 1A

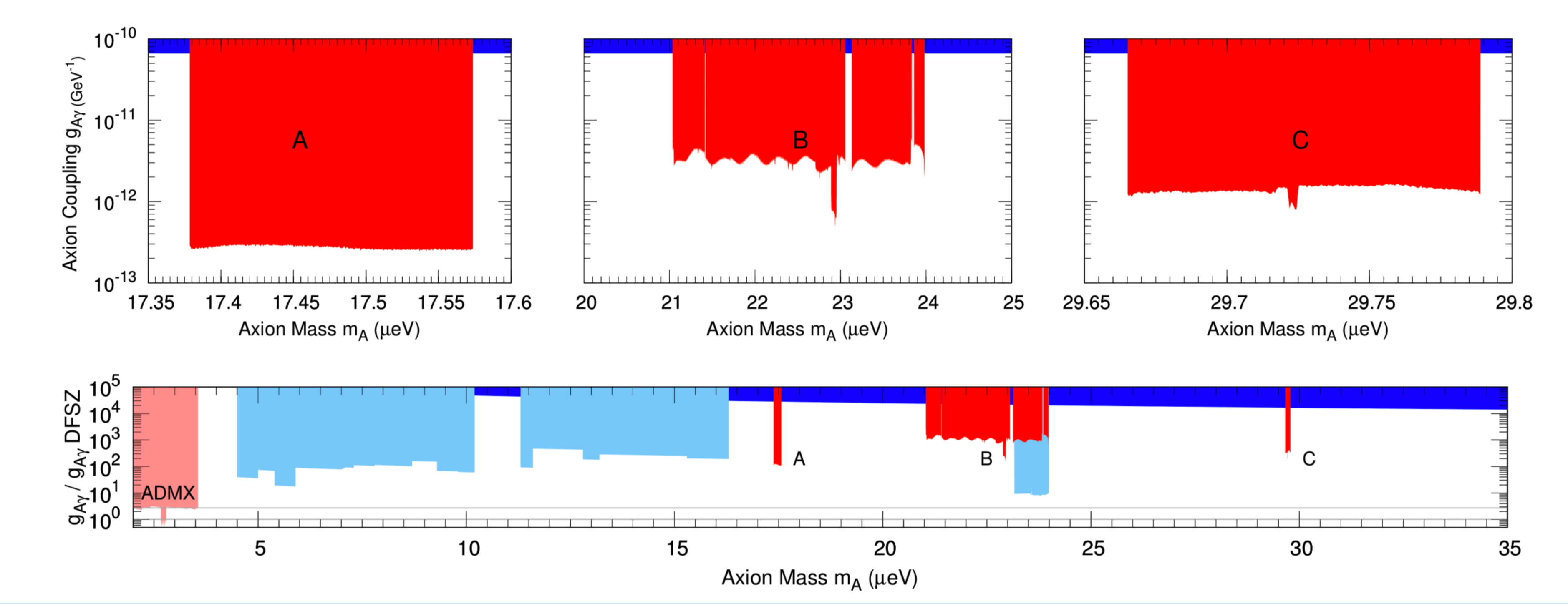
PHYSICAL REVIEW LETTERS 120, 151301 (2018)



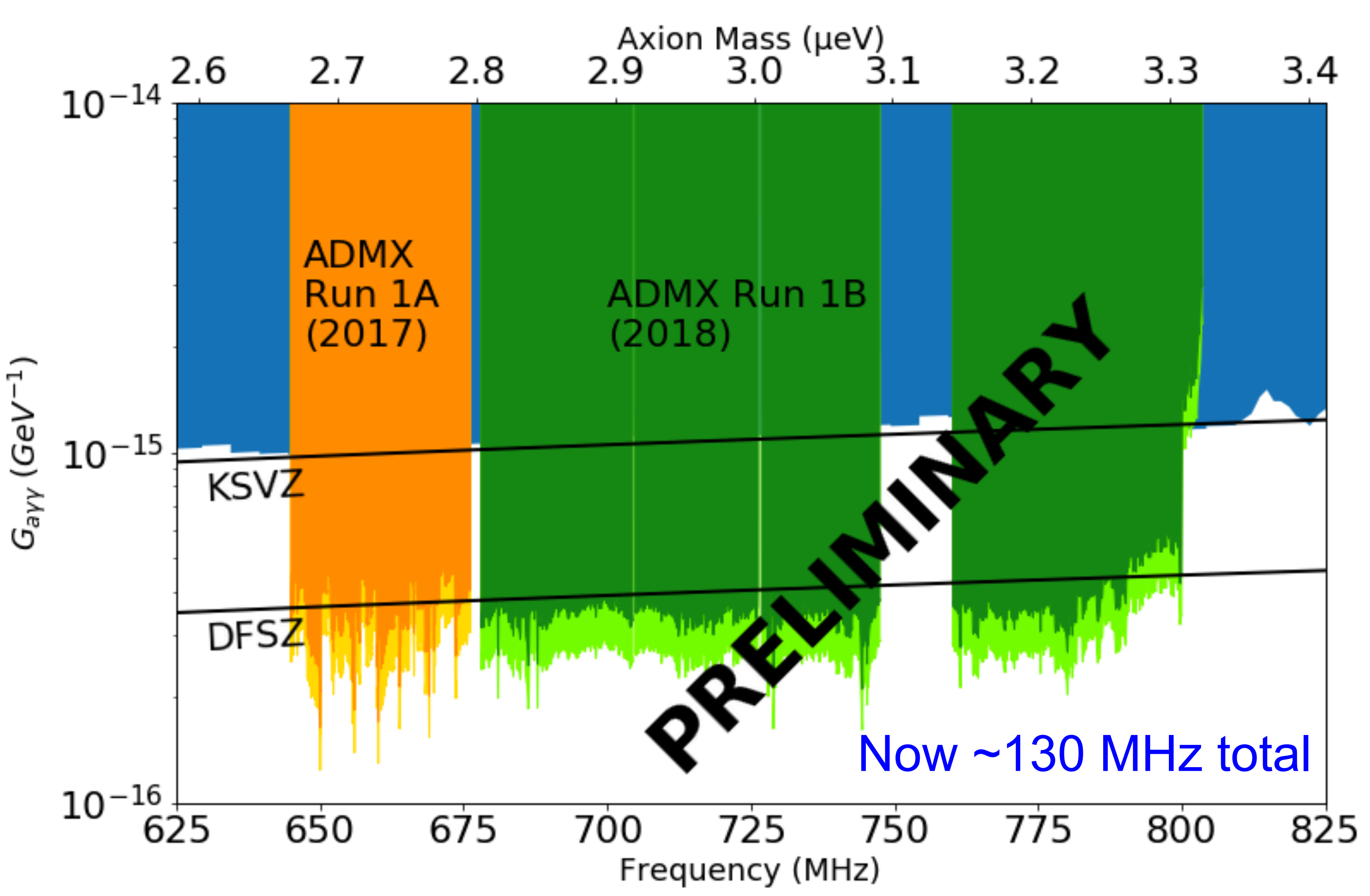
Results (Preliminary)!

Sidecar results at higher frequency.

Phys. Rev. Lett. 121 (2018) 261302

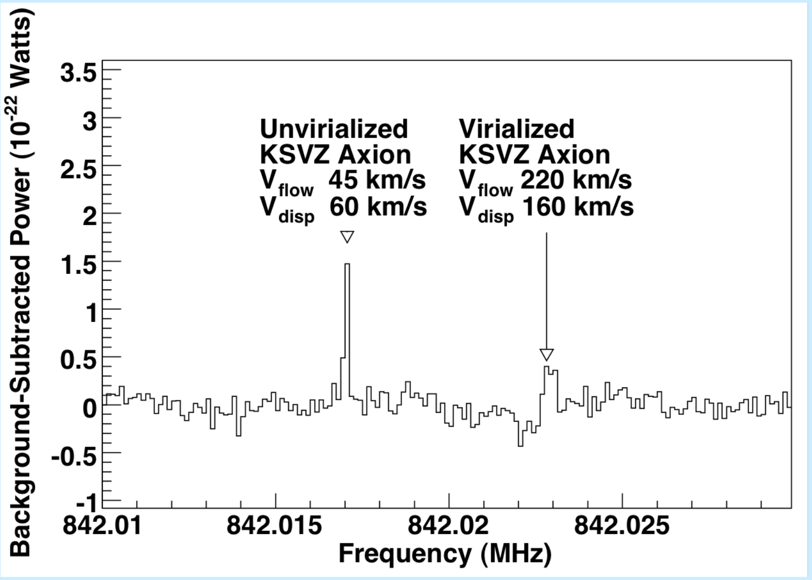


New Results Run 1B



After a persistent signal

ADMX AXION DARK MATTER EXPERIMENT



Confirmation (~minutes):

Does it behave as expected vs B^2

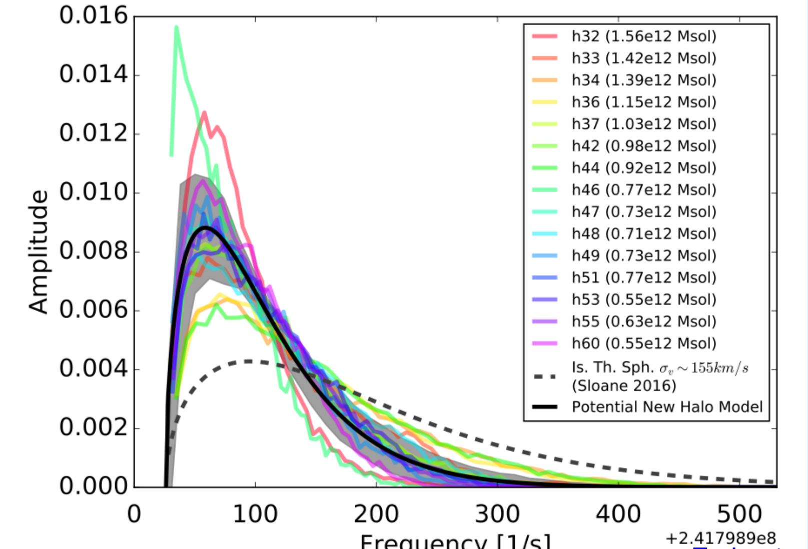
Rule out all other sources -> discovery!

Axion Astronomy

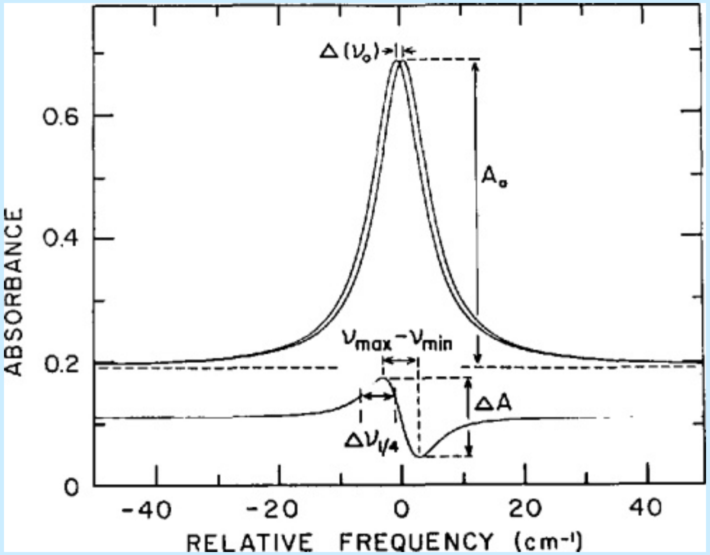
Velocity and broadening of the line

Look for structure like infalls etc.

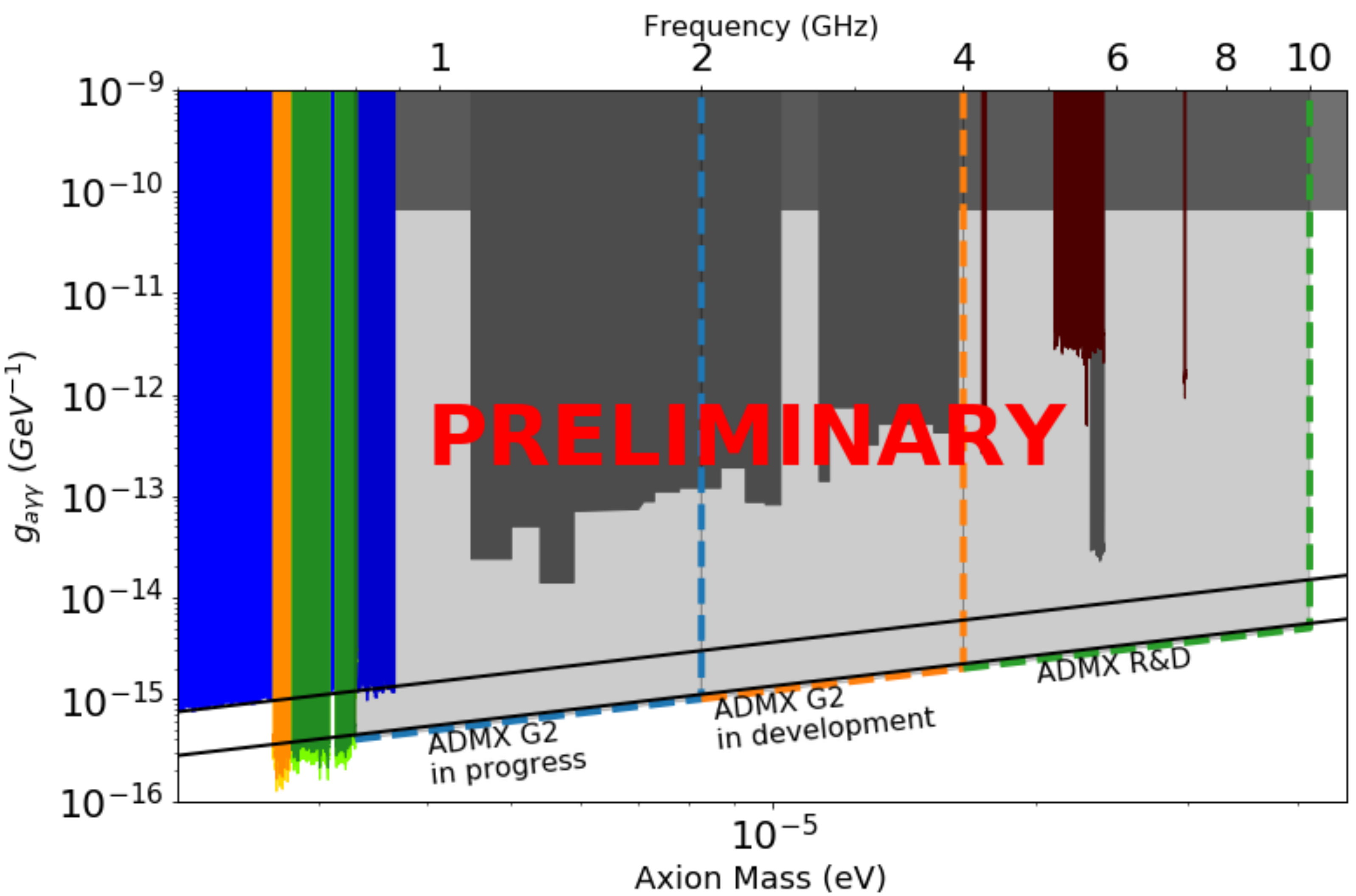
Annual modulation (~hr integration)



E.. Lentz, Ap. J (2017);

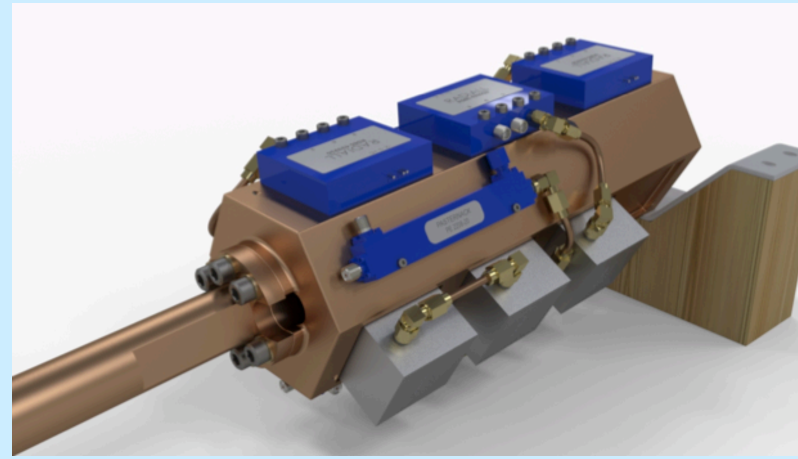


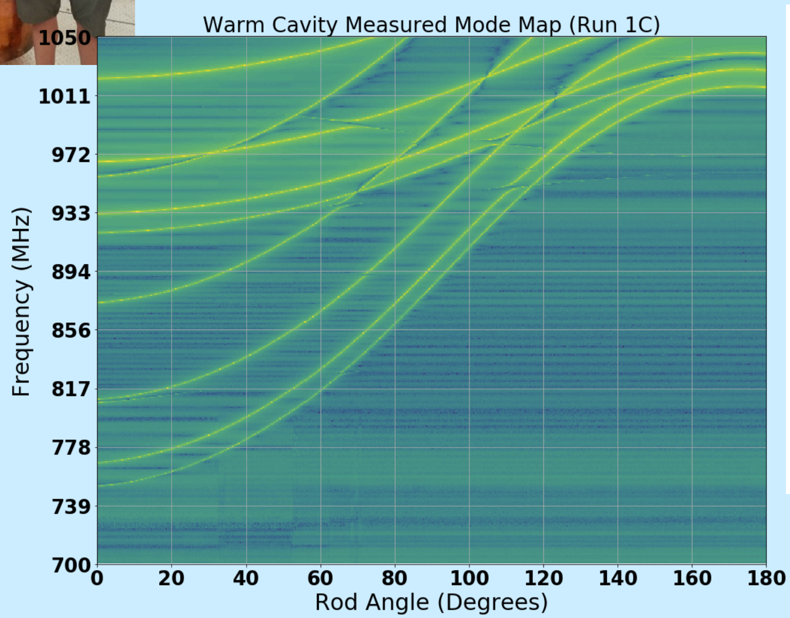
Moving to higher frequencies

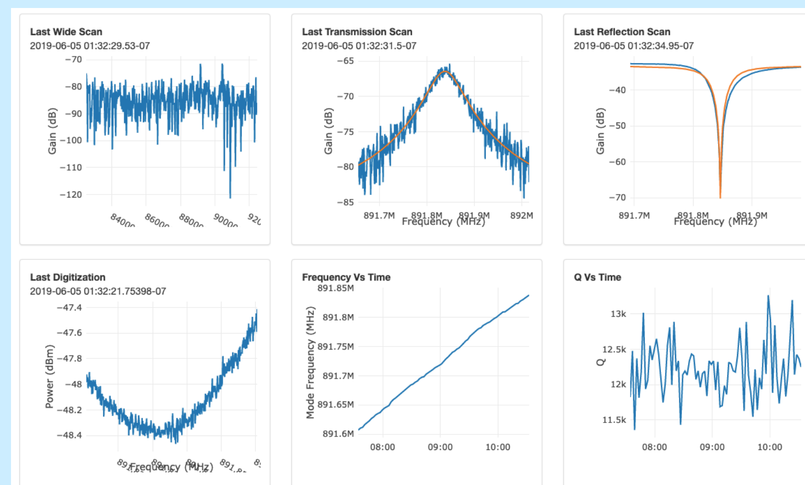


Run 1C to 1GHz (in progress)

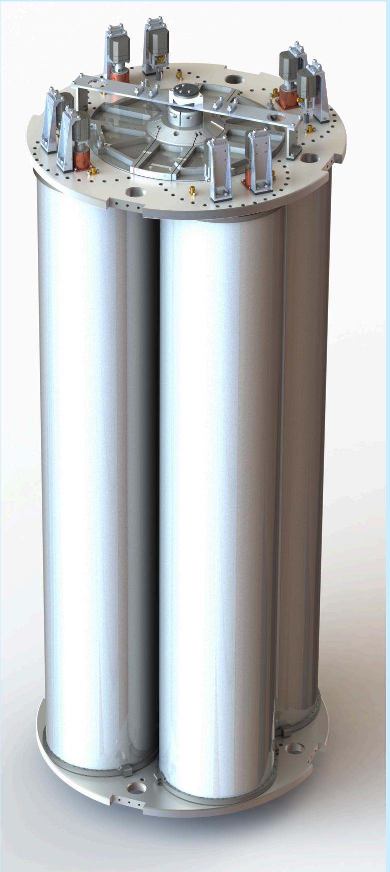
ADMX AXION DARK MATTER EXPERIMENT

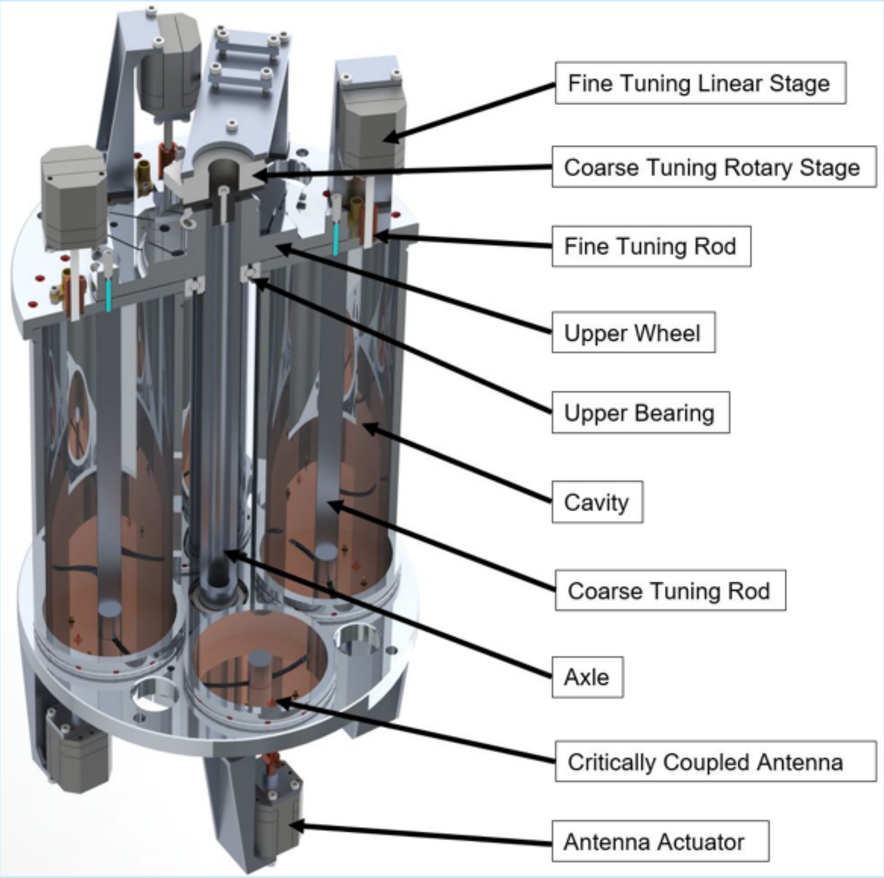


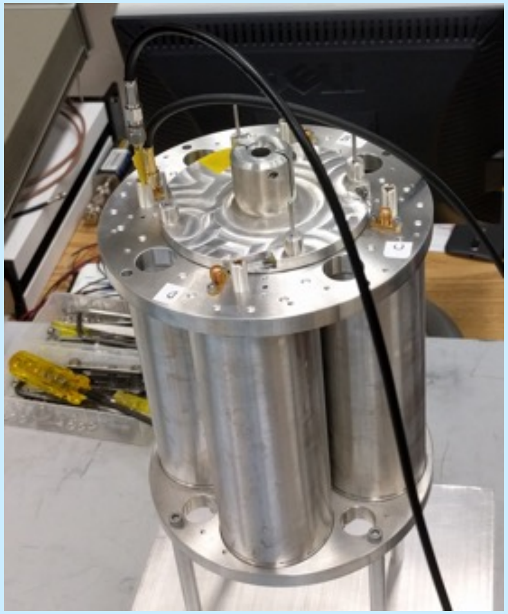




Gen2 takes us to 2GHz



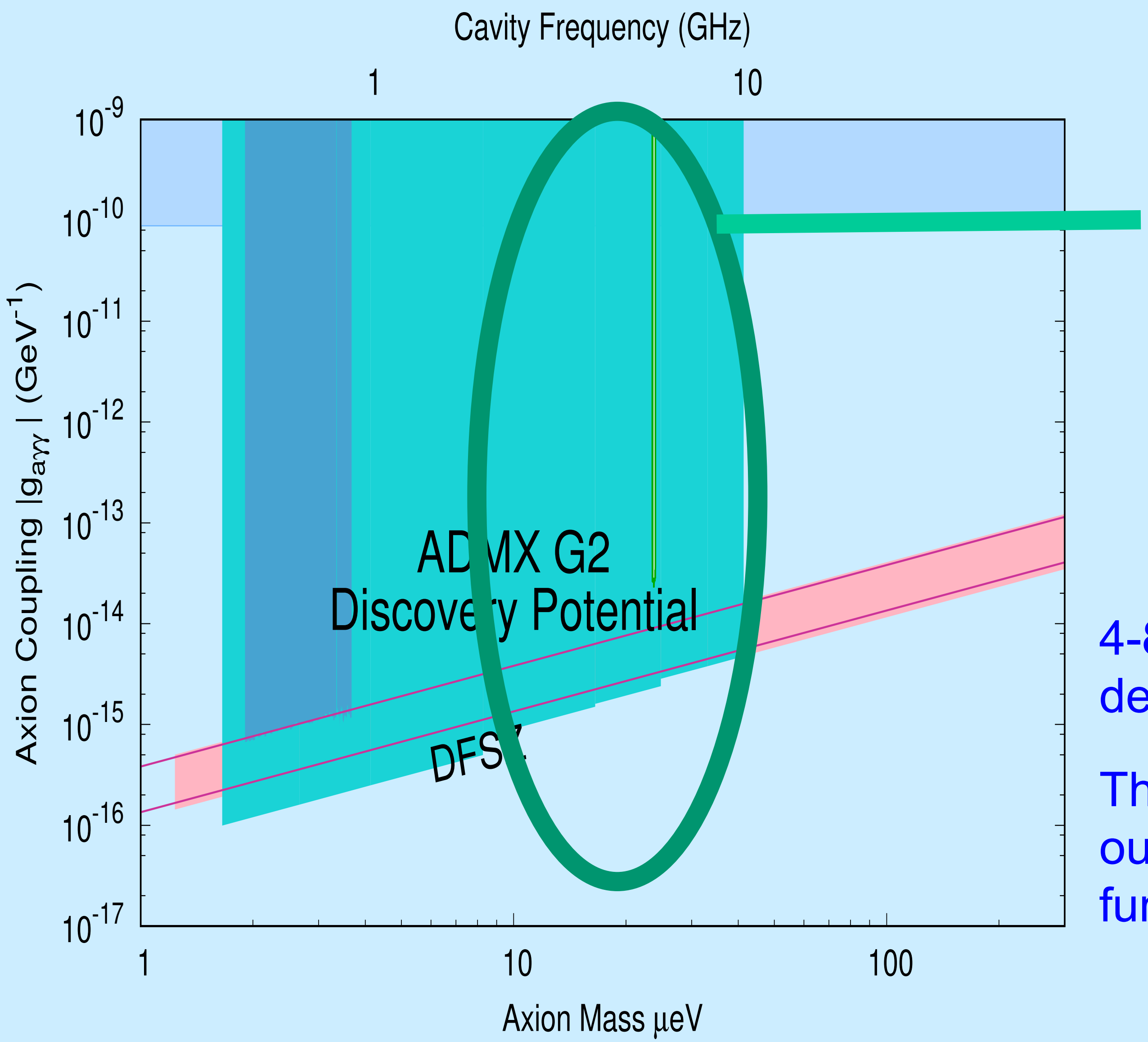


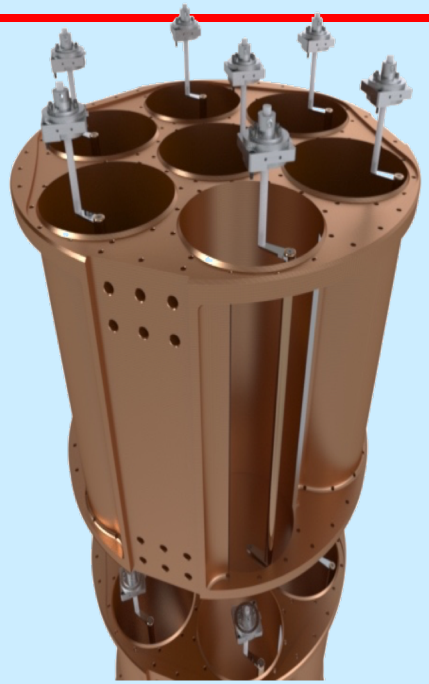


Prototype 1-2 GHz prototype fabricated, tested

Run 2A to utilize a 4 cavity array with either sapphire or metal tuning rods to cover to 2GHz

ADMX, next steps
multicavity systems, new magnet?



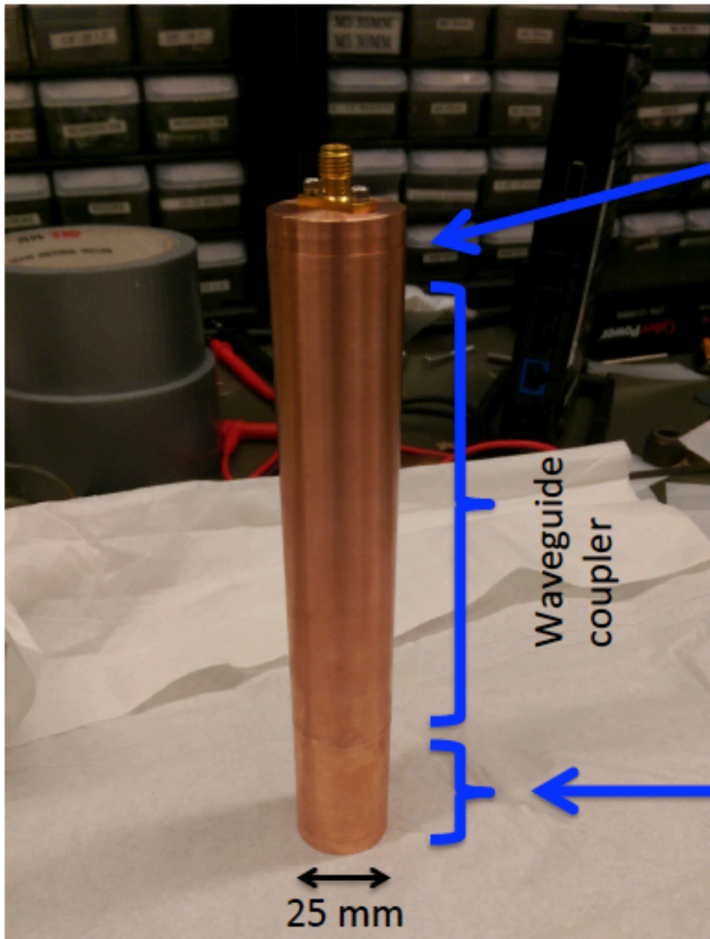


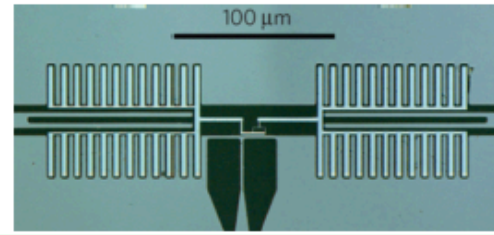
4-8 GHz resonators in design.

This would be beyond our currently approved funding.

Beyond 10 GHz: Quantum Computing Technology

Prototype for 10 GHz axion QND detector





Superconducting qubit in field-free bucking coil region acts as an amplitude→frequency transducer for QND measurements.

Qubit frequency shifts by 10 MHz per photon deposited in axion cavity. **Successful "spin-flip" of qubit confirms presence of cavity photon.**

Axion scattering cavity dipped into high B-field region

Akash Dixit, Aaron Chou, David Schuster (UC),

Conclusions

ADMX for the first time has the necessary components to probe the QCD axion that would solve the strong-CP problem and could account for most of the dark matter in the universe

ADMX is now taking data at DSFZ sensitivity. None found yet!

ADMX is part of the DOE gen 2 dark matter program. Current funding cycle allows probe up to about 2 GHz. Work with multiple cavities to cover 2-4 GHz and perhaps up to 10 GHz

Above 10 GHz, new technologies such as those enabled by quantum computing and high field magnets may result in a definitive yes-no program on the existence of the axion

Nature may have a different surprise associated with dark matter. There are new developments in applying new tool-sets and creativity towards new experiments

Thank you to sponsors

ADMX
AXION DARK MATTER EXPERIMENT

Institutions

Berkeley UNIVERSITY OF CALIFORNIA

UF UNIVERSITY of FLORIDA

Fermilab

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

The University Of Sheffield.

UNIVERSITY OF WASHINGTON 1861

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The ADMX collaboration gratefully acknowledges support from the US Dept. of Energy, High Energy Physics DE-SC0011665 & DE-SC0010280 & DE-AC52-07NA27344.

Also support from FNAL, LLNL and PNNL LDRD programs and R&D support from the Heising-Simons Foundation.