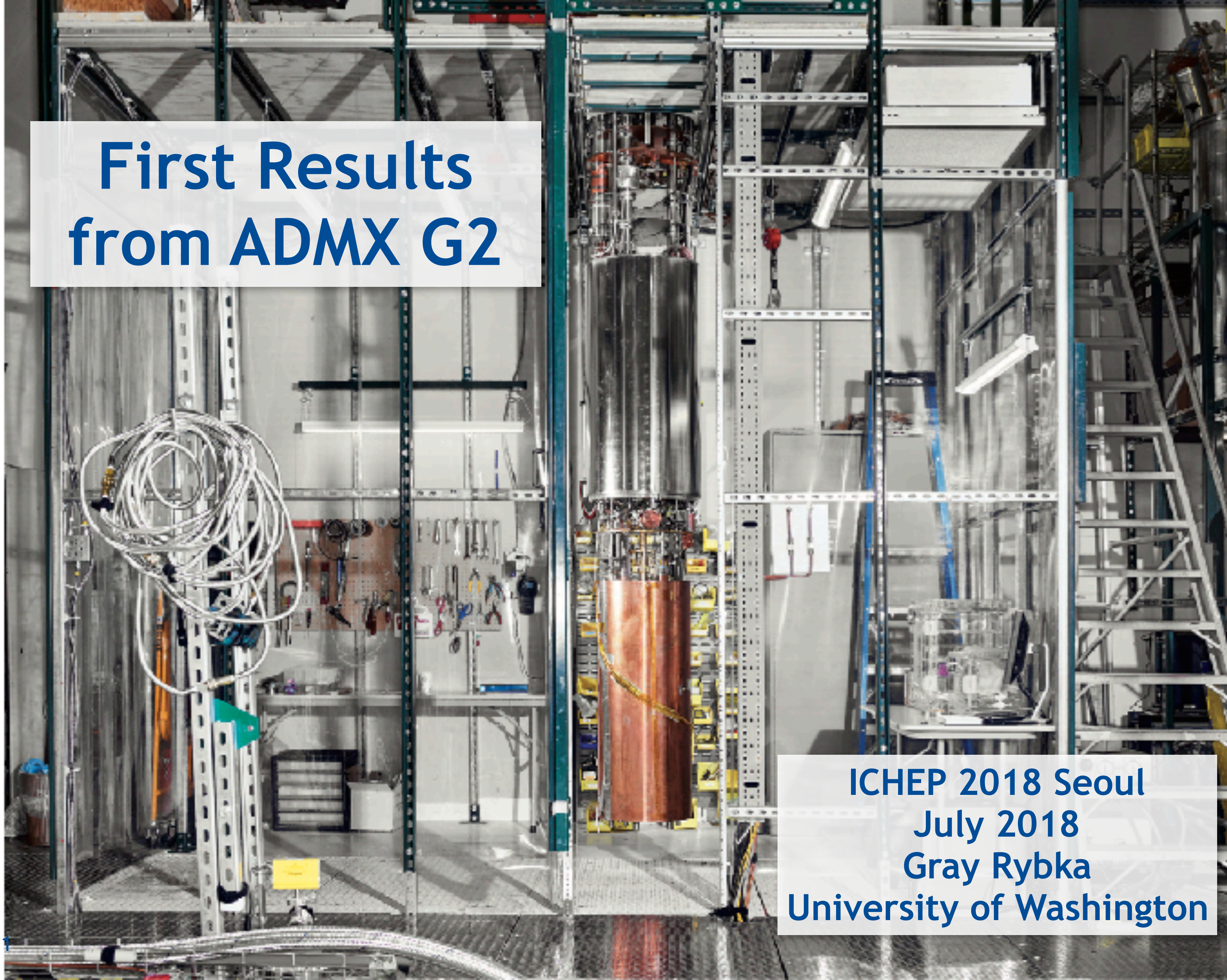
First Results from ADMX G2

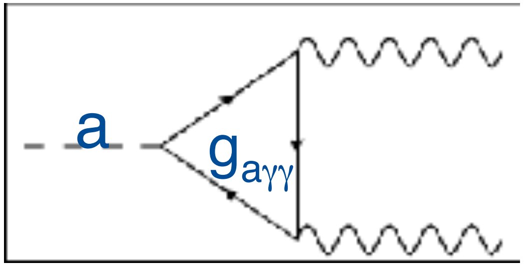


ICHEP 2018 Seoul
July 2018

Gray Rybka
University of Washington

The Axion

The QCD axion is a consequence of explaining the absence of neutron electric dipole moment and has the same quantum numbers as the π_0.

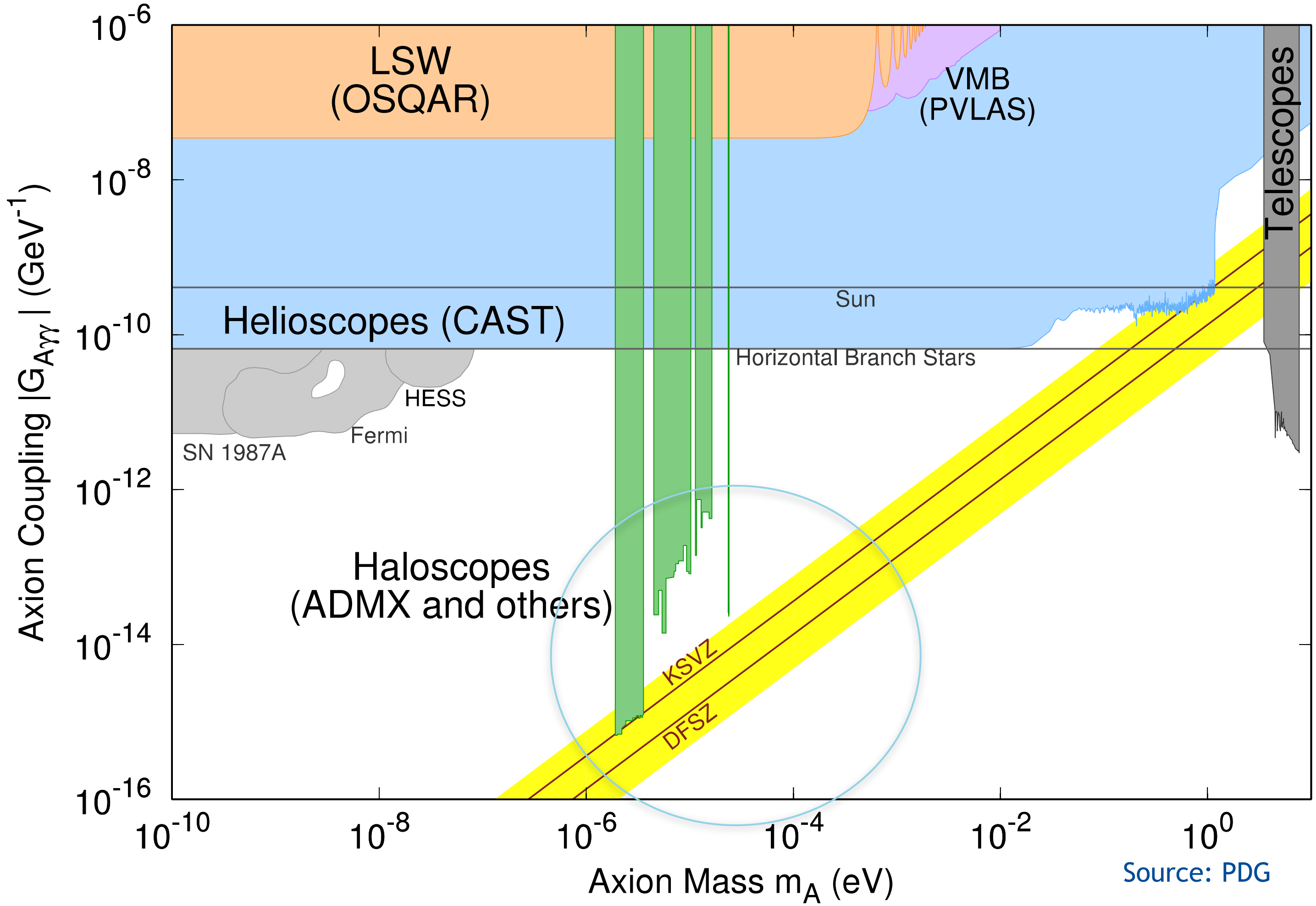


Axions are produced nonthermally in the early universe and can naturally account for all of the dark matter.

The benchmark QCD axion models vary only by a factor of 7 in axion-photon coupling.

Axion Landscape

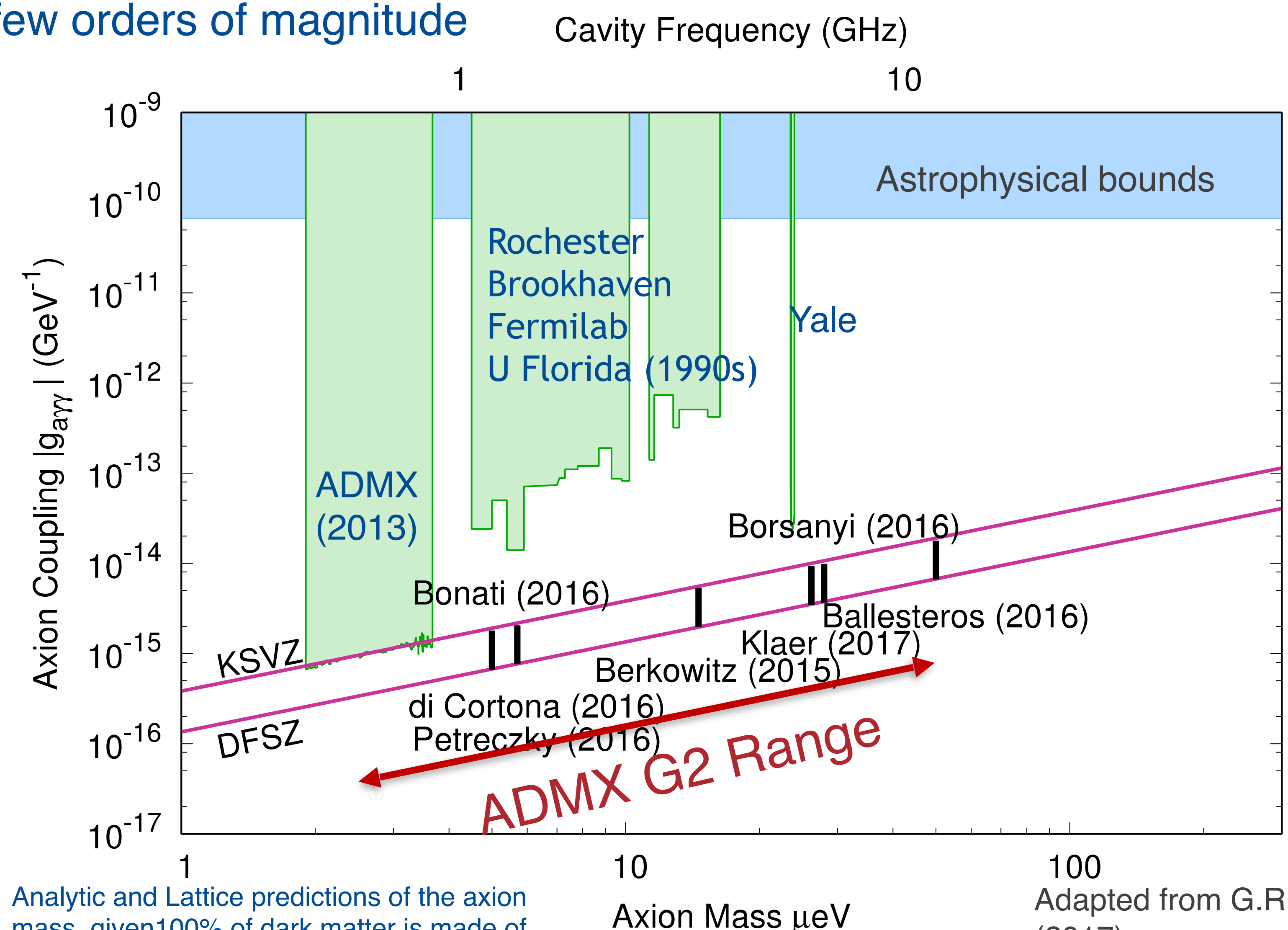
There are many experiments looking for axions with all sorts of masses, but we're interested in dark matter in particular.



Source: PDG

Experimental Perspective on DM Axions

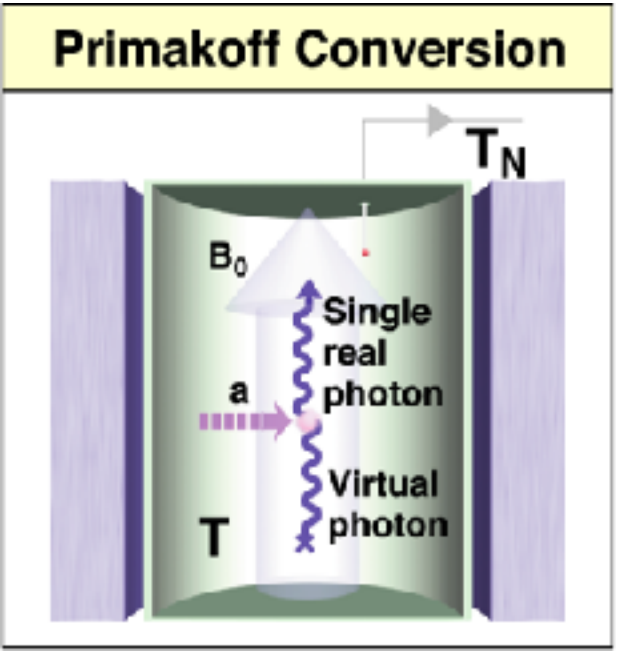
If you want axions to be most of the dark matter, the predictions fall within a few orders of magnitude



Analytic and Lattice predictions of the axion mass, given100% of dark matter is made of axions, post-inflationary

Adapted from G.R, J. Phys. G (2017)

Axion Haloscope: How to search for Dark Matter Axions



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

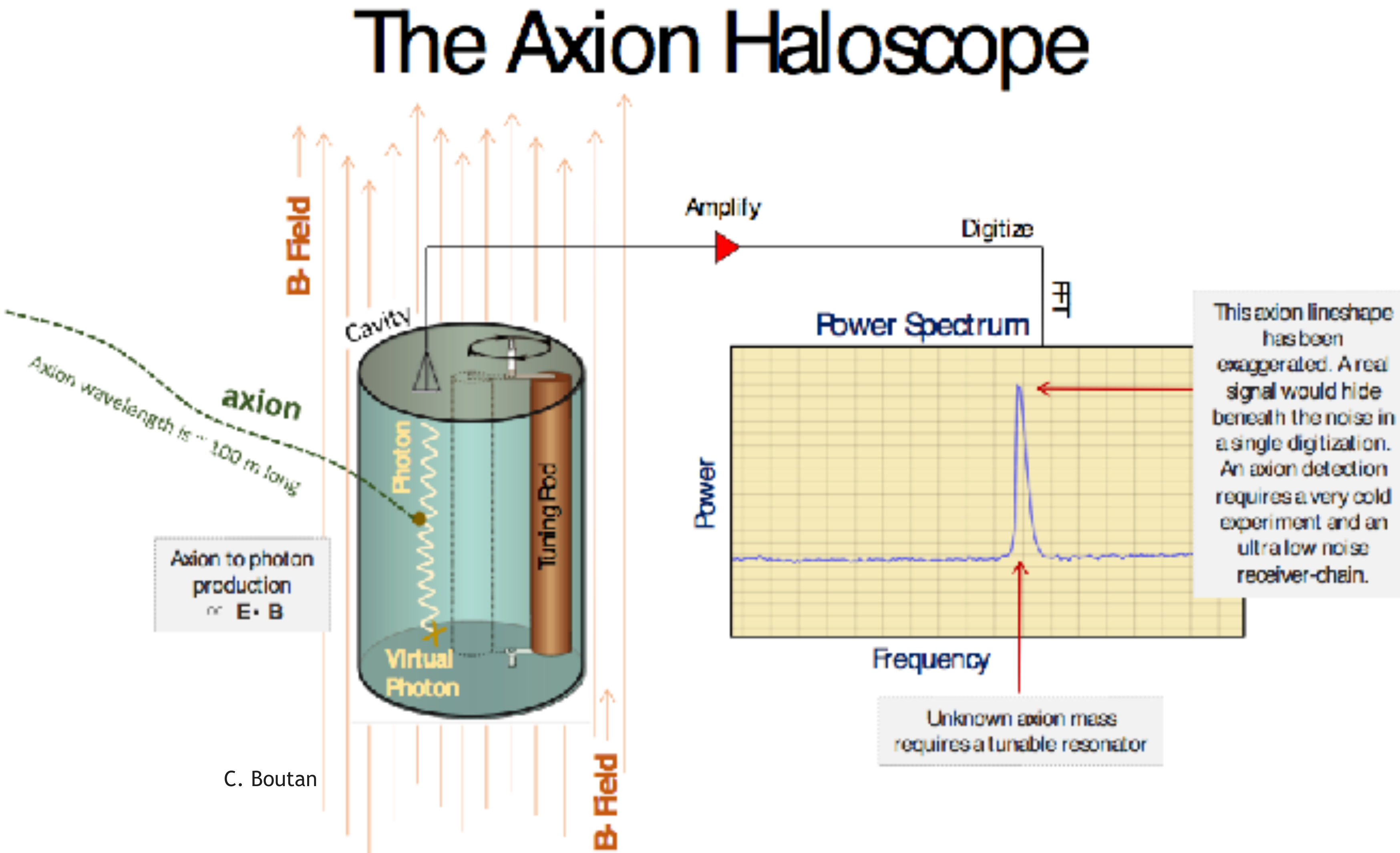
The conversion rate is enhanced if the photon's frequency corresponds to a cavity's resonant frequency.

Sikivie PRL 51:1415 (1983)

Signal Proportional to
Cavity Volume
Magnetic Field
Cavity Q

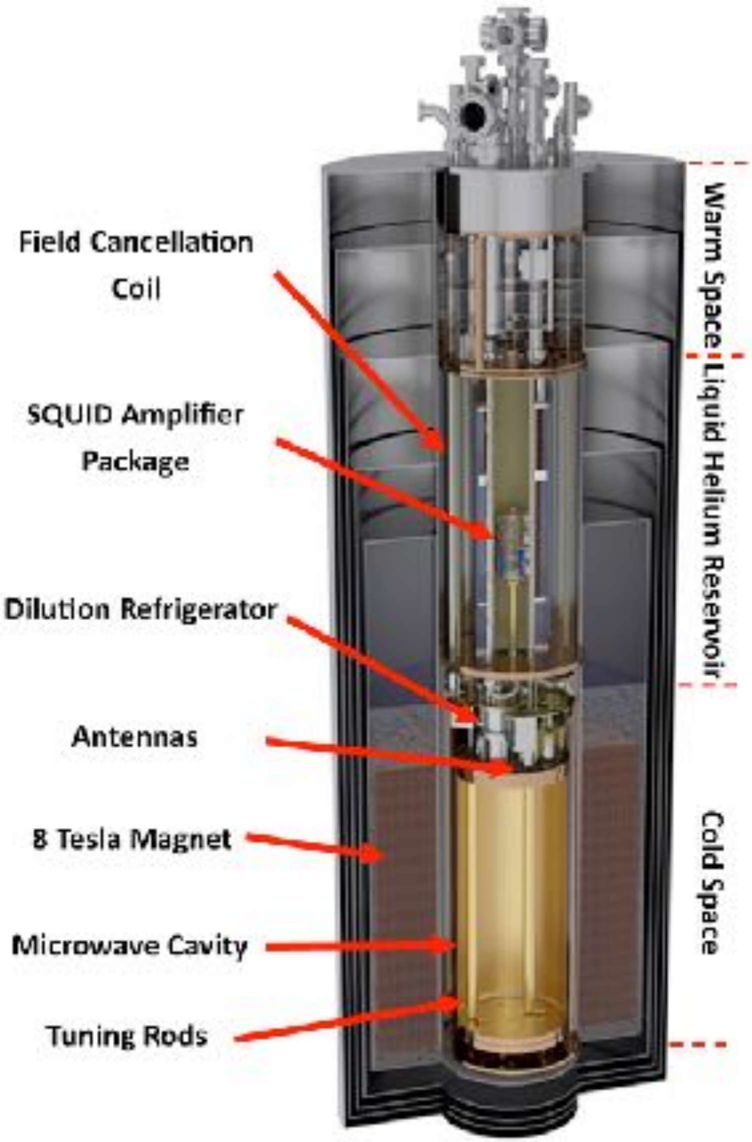
Noise Proportional to
Cavity Blackbody Radiation
Amplifier Noise

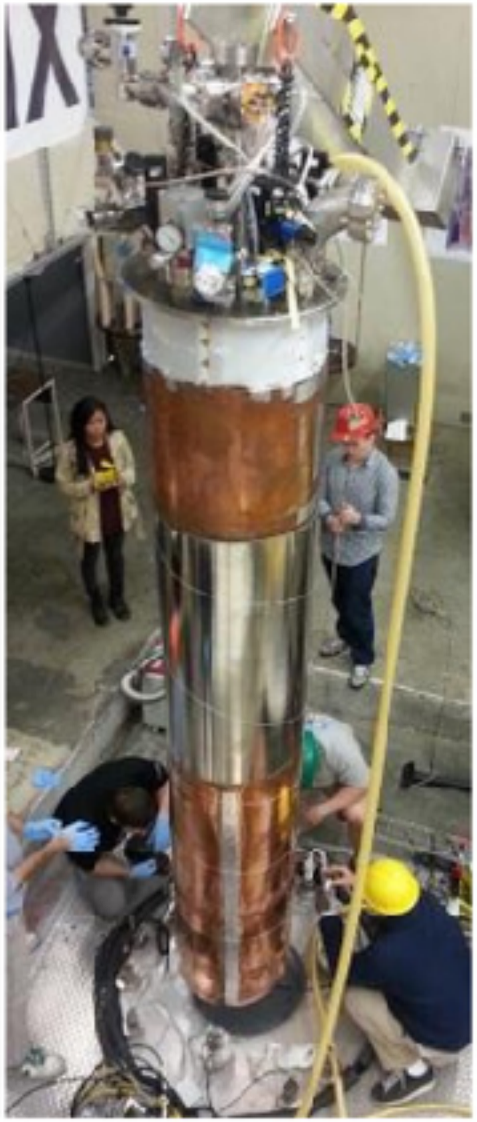
Principle of the Sikivie Axion Haloscope



C. Boutan

ADMX G2 Dark Matter Experiment: Design

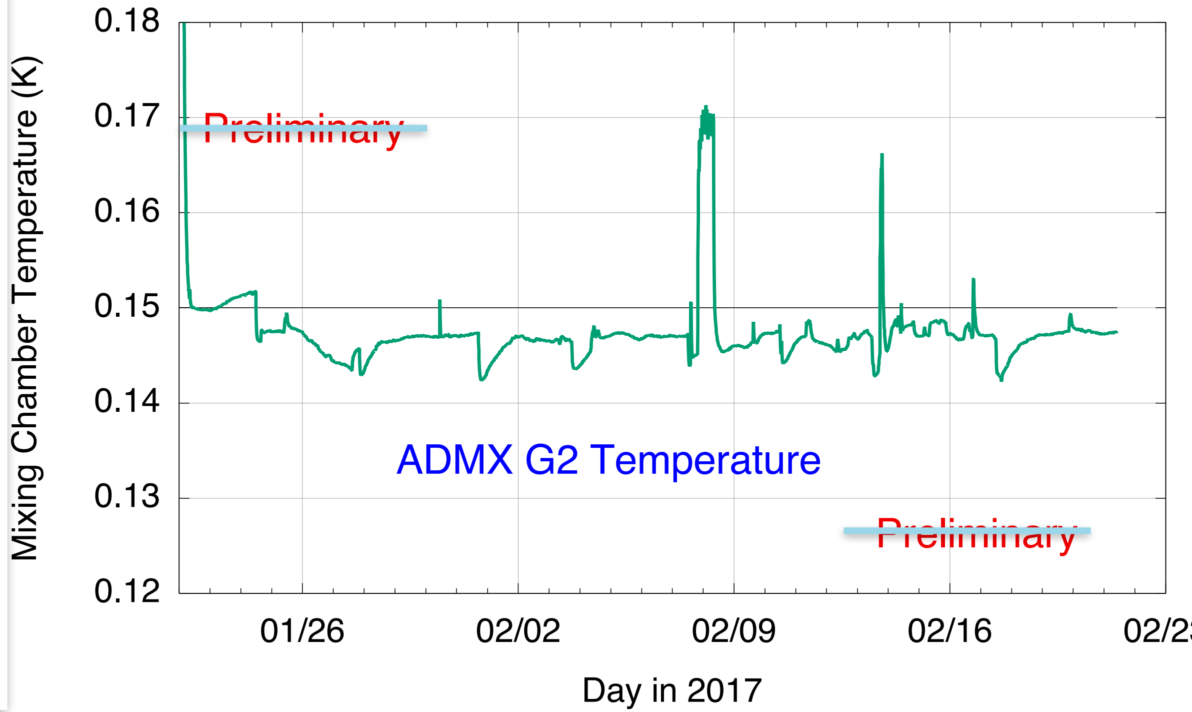




Cryogenics

Dilution Refrigerator installed above ADMX Cavity

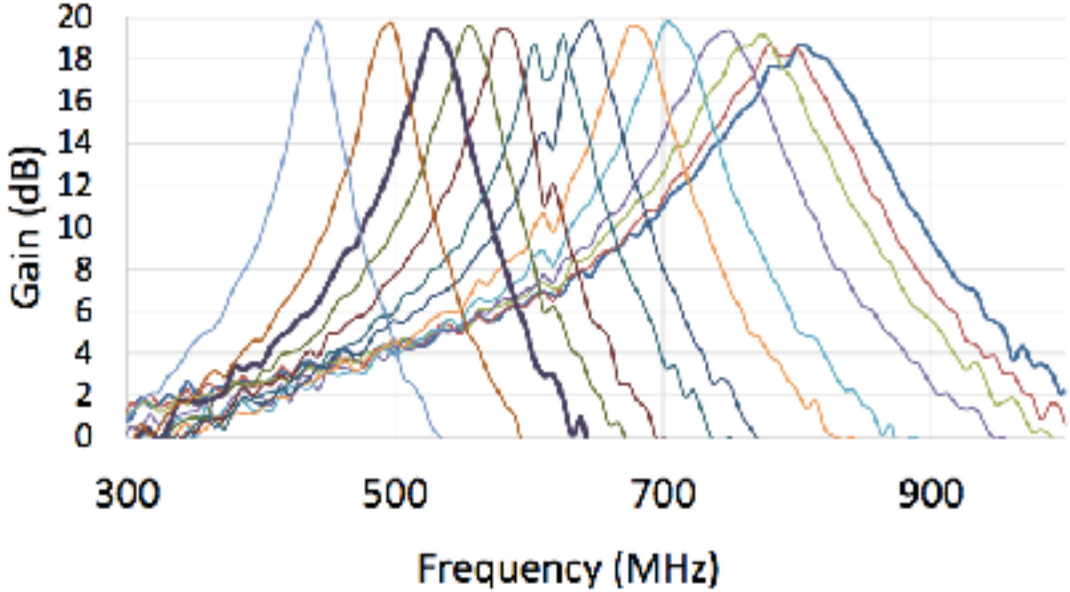
Cavity and electronics cooled with Dilution Refrigerator to minimize noise



Improvements in thermal engineering may allow us to reach lower temperatures

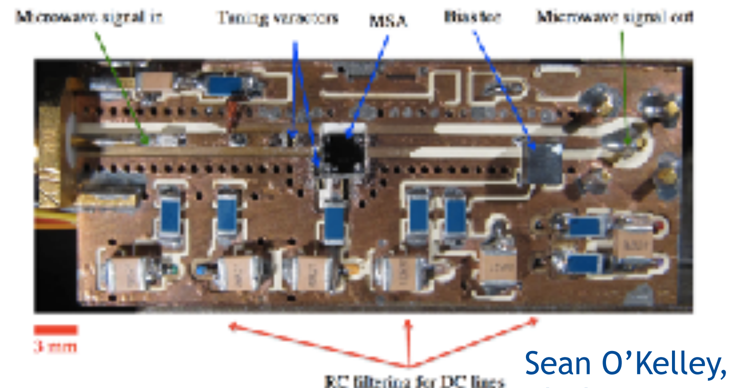
cs: Realization

MSA Varactor Tunability



Figures from 2nd Workshop of Microwave Cavities and Detectors for Axion Research

ADMX Tunable MSA



Sean O'Kelley, Clarke Group, UC Berkeley

Yanjie Qiu, Siddiqi Group, UC Berkeley

Experiment Operation Procedure

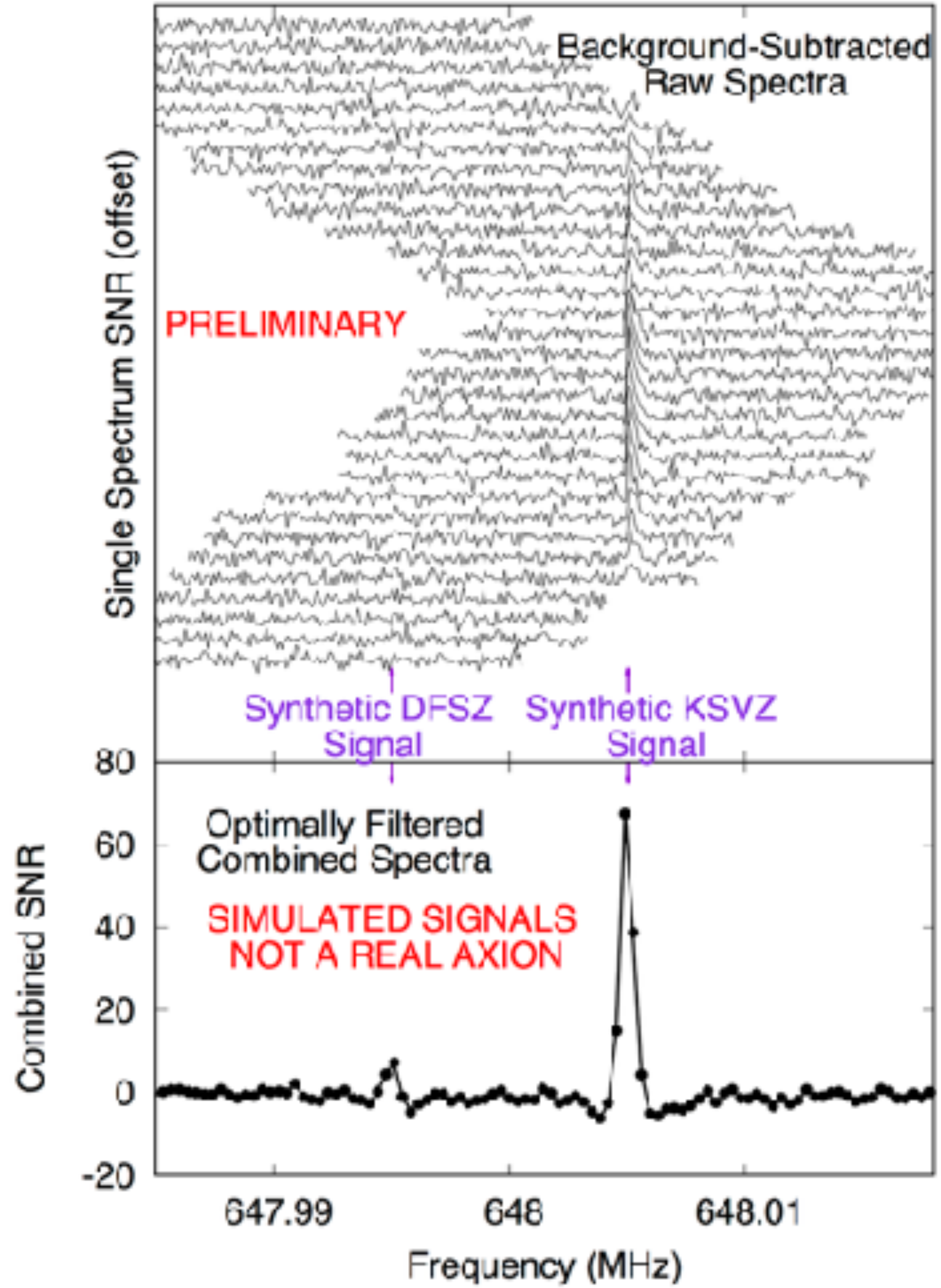
- The cavity frequency is scanned over a region until the desired SNR is achieved
- We then examine the combined power spectrum for signs of excess
- Excess power regions can be statistical fluctuations, synthetically injected signals, RF interference, or axions
- Excess power regions are rescanned to see if they persist
- Persistent candidates are subjected to a variety of confirmation tests: for example: magnet field changes or probing with other cavity modes.
- We do blind signal injection, so we always have candidates

Analysis of Simulated Signals Injected into Real Data

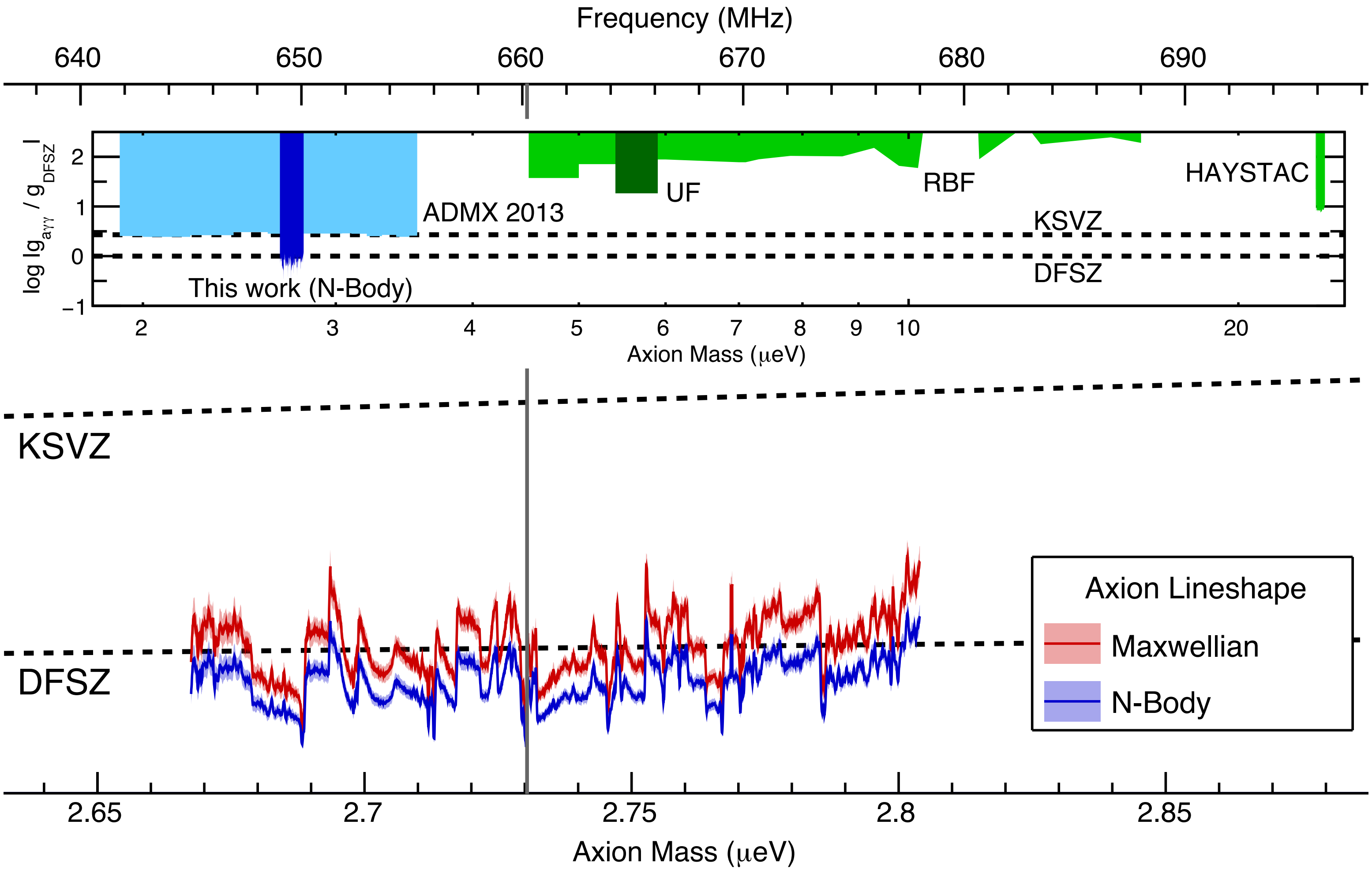
Synthetic signals are software-injected to evaluate analysis.

A KSVZ and DFSZ axion signal (N-body lineshape) are shown here.

Conclusion:
DFSZ axion signals should be very clear in analysis if present

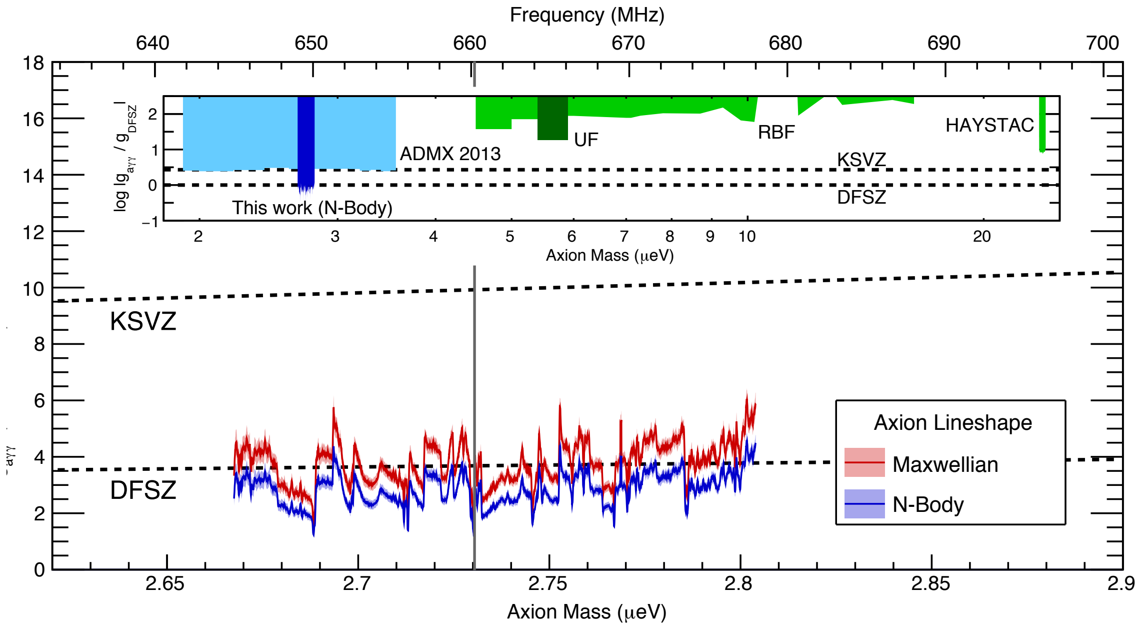


ADMX Exclusion Limits 2017



N. Du *et al.* (ADMX Collaboration), "Search for Invisible Axion Dark Matter with the Axion Dark Matter Experiment," [Phys. Rev. Lett. **120**, 151301 (2018)].

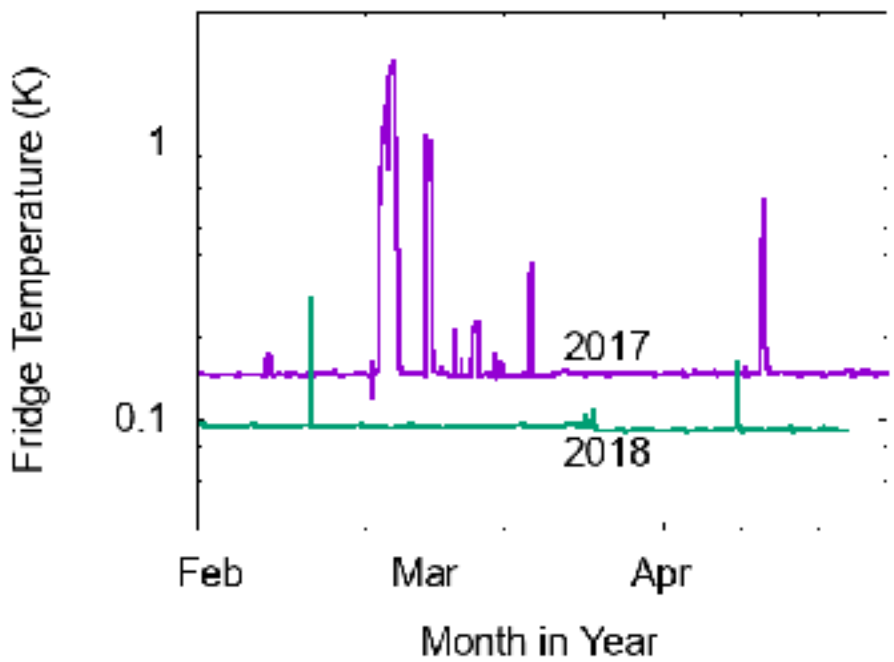
ADMX Exclusion Limits 2017



We didn't find an axion over this narrow range. More importantly, we could have. This is the first exploration into the plausible DFSZ coupling in the prime mass range for Dark Matter. A discovery could come at any time.

2018 Operations: Cryogenics

Temperature for example weeks, 2017 vs 2018

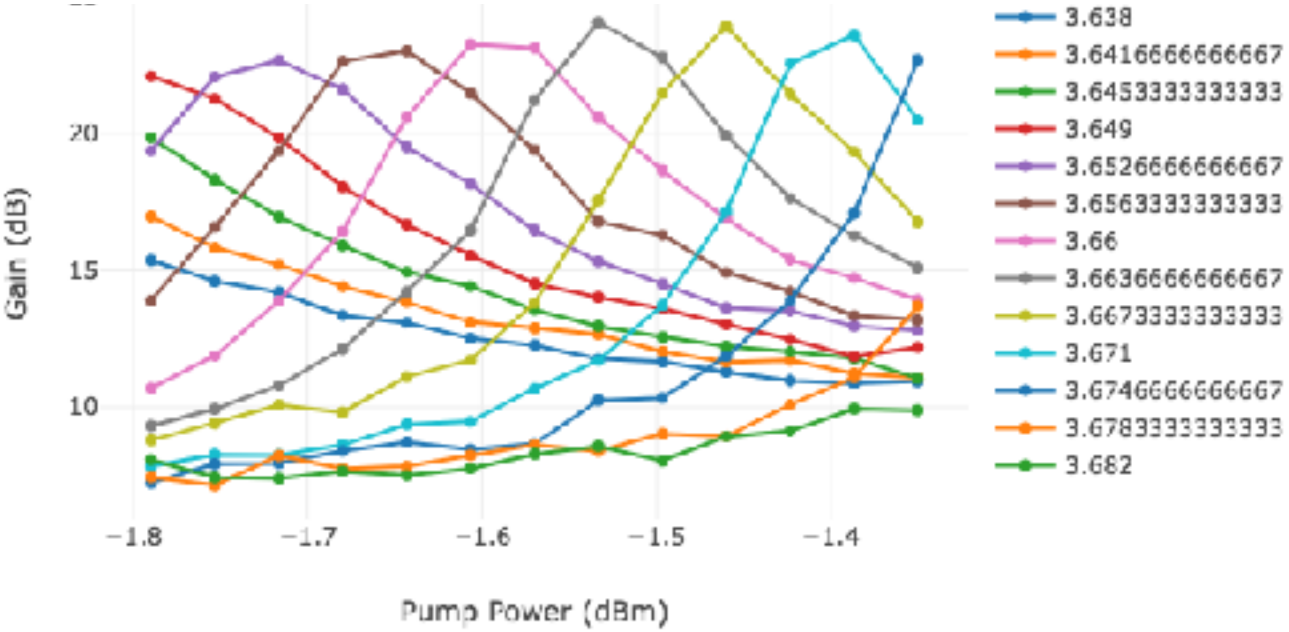


We've been taking data in our 2018 run at significantly lower temperature. Expect great things!

2018 Operations: Electronics

Yanjie Qiu,
Siddiqi Group,
UC Berkeley

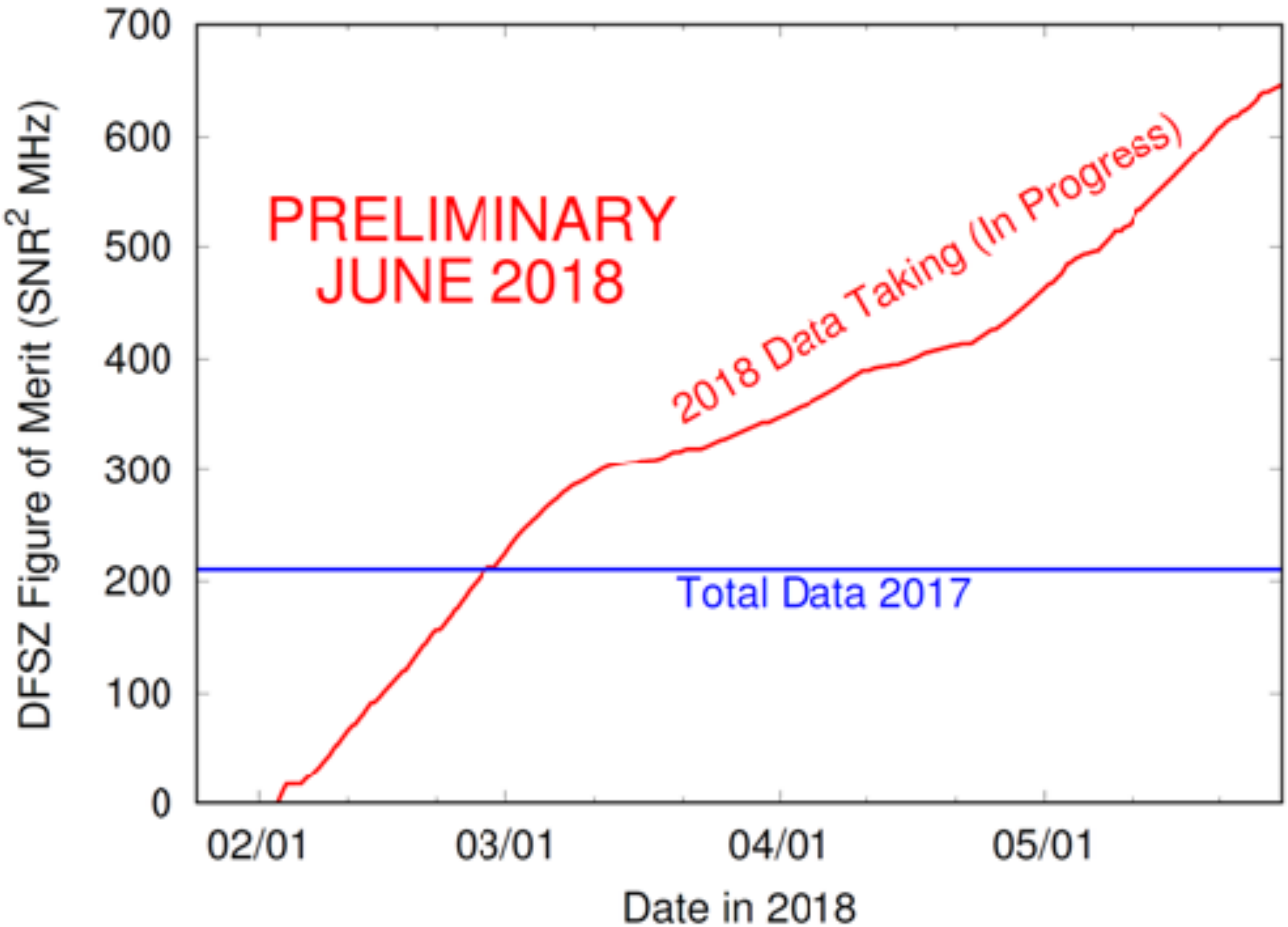
Gain Tuning Curves of Operating ADMX JPA



2018 Operations use a Josephson Parametric Amplifier in place of the Microstrip Squid Amplifier

2018 Operations: Data

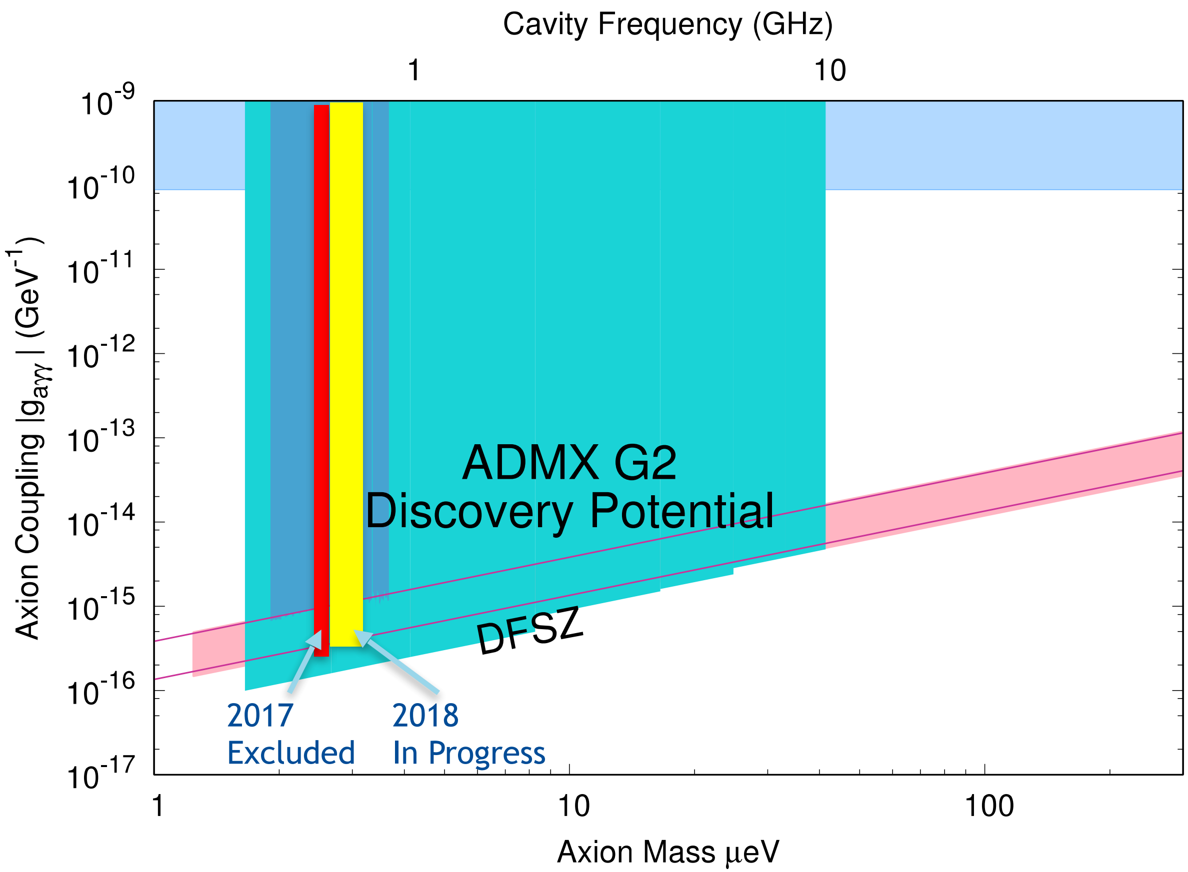
We have already taken three times as much data in 2018 as we did in 2017 (and the run is not over yet!)



ADMX G2 – Discovery Potential

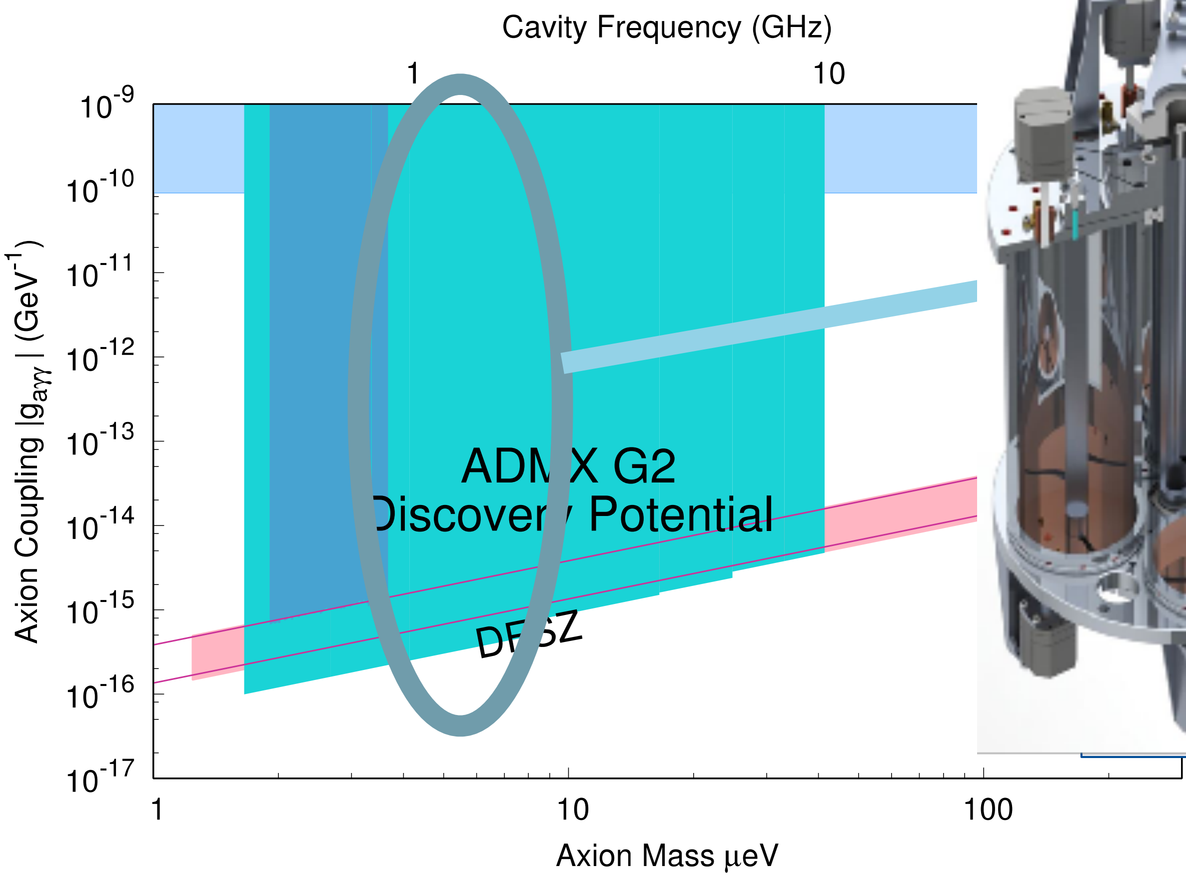
ADMX G2 targets the entire 1-10 GHz region over 6 years

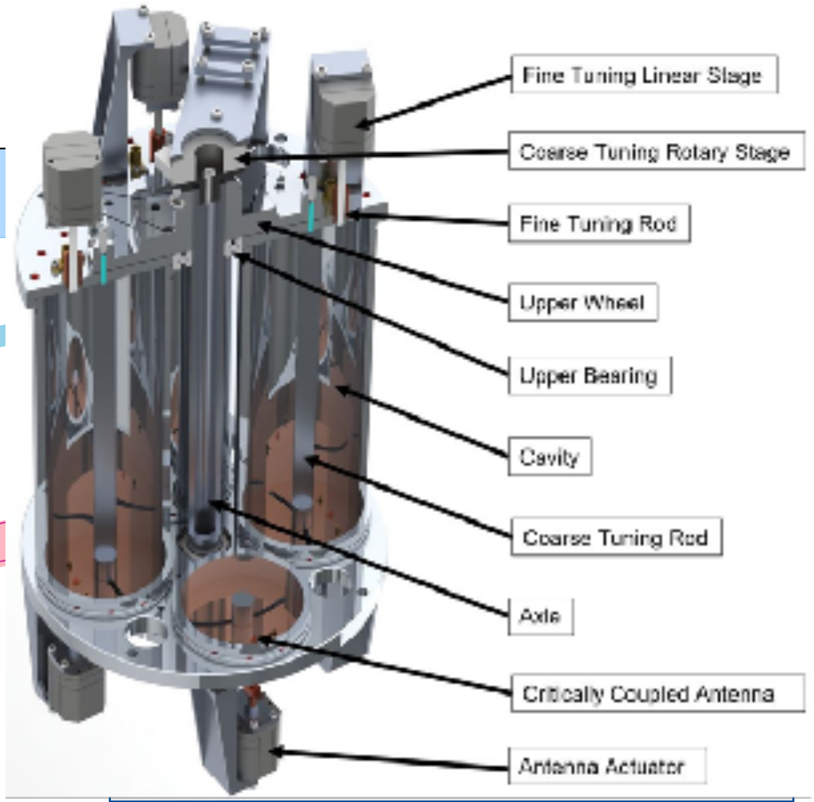
Reaching higher frequencies requires new hardware, but no new R&D



ADMX G2 – Multicavity Systems

Maintain detection volume at higher frequencies

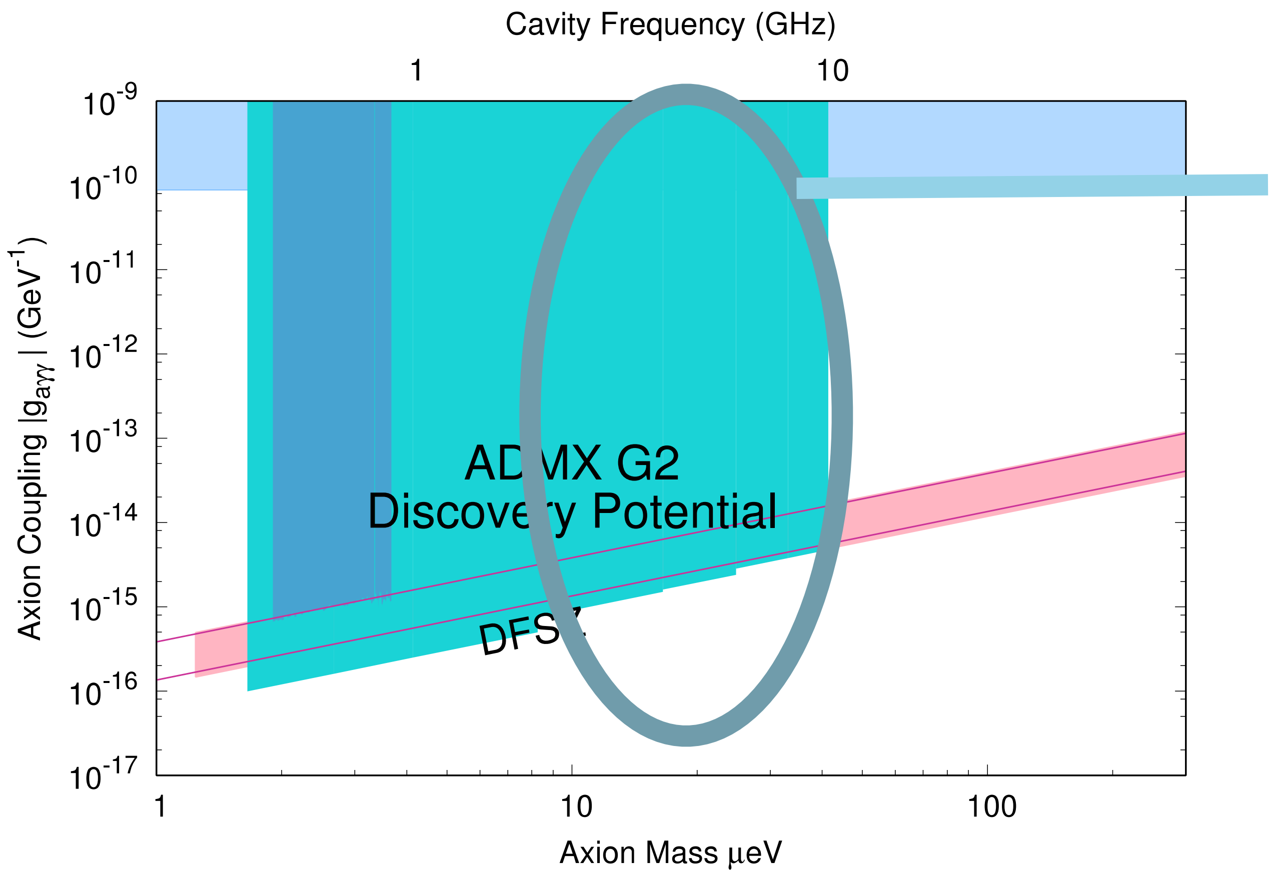




Multicavity system 1-2 GHz

Prototype fabricated, in testing

ADMX G2 Multicavity Systems 2



Multicavity systems for 2-4 designs being finalized.

4-8 GHz resonators in design. Note, DFSZ at 10 GHz will require extra run time

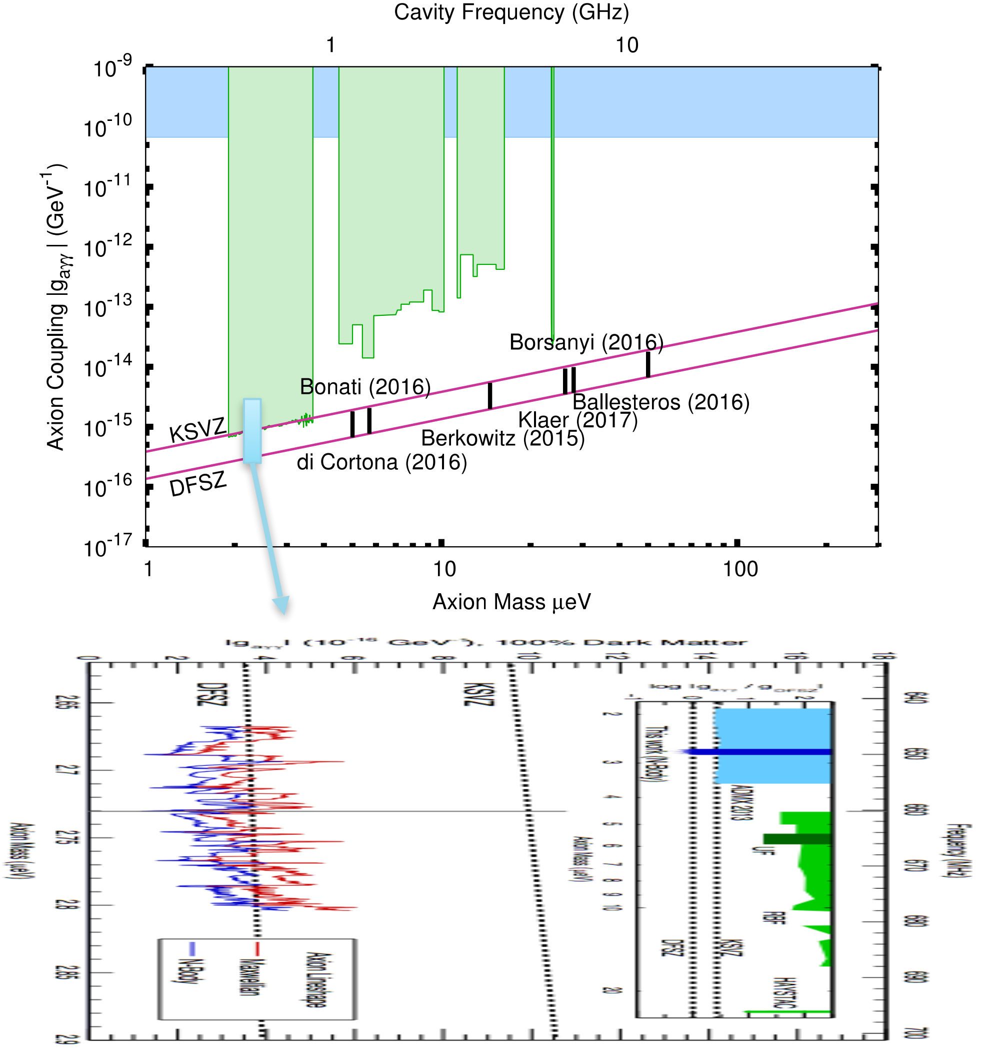
Conclusions

ADMX Gen 2 has operated with sensitivity to the DFSZ axion around 2.7 ueV

ADMX Gen 2 is the first and only experiment with DFSZ sensitivity in the ideal dark matter axion mass range

We are scanning up in mass right now, and have plans to scan to 40 ueV

Discovery could come at any time!



ADMX "G2" Dark Matter Search: Find Dark Matter Axions

ADMX collaboration meeting, April 2018

Collaborating Institutions:
UW, UFL, LLNL
FNAL, UCB, PNNL
LANL, NRAO, WU, Sheffield

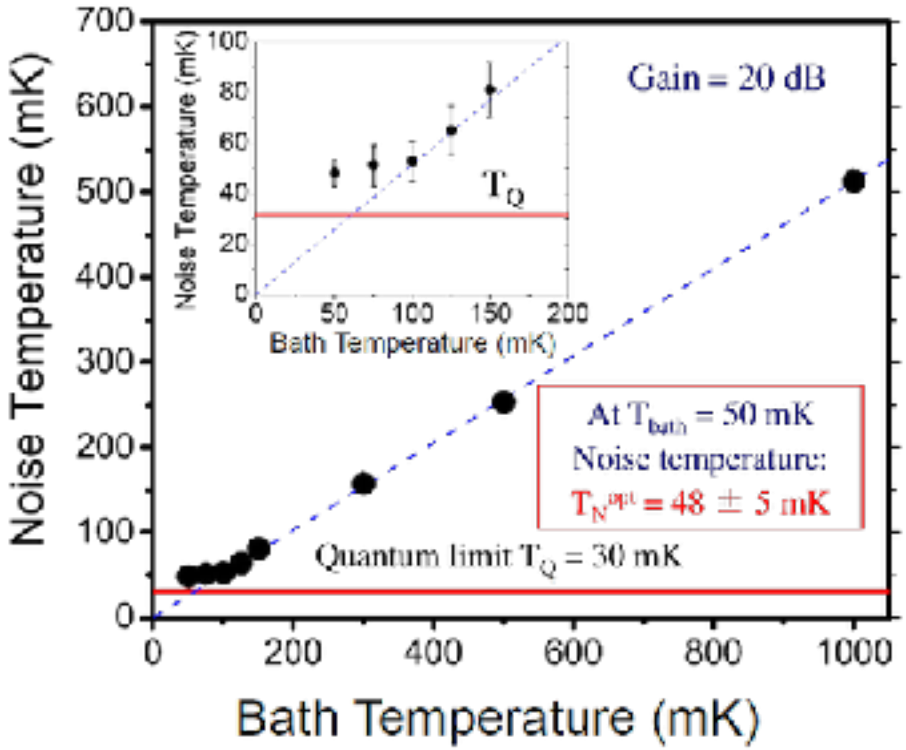
The ADMX collaboration gratefully acknowledges support from the US Dept. of Energy, High Energy Physics DE-SC0011665 & DE-SC0010280 & DE-AC52-07NA27344

Also support from LLNL and PNNL LDRD programs
and R&D support the Heising-Simons institute

BACKUP SLIDES FOLLOW

Quantum Electronics: Noise Limit

- Quantum mechanics forces a linear amplifier to contribute at least a half photon per resolution bandwidth to the noise
- We have amplifiers that operate near this limit



Clarke Group, UC Berkeley

Key Element: System Noise

Injection of swept power & fake axions

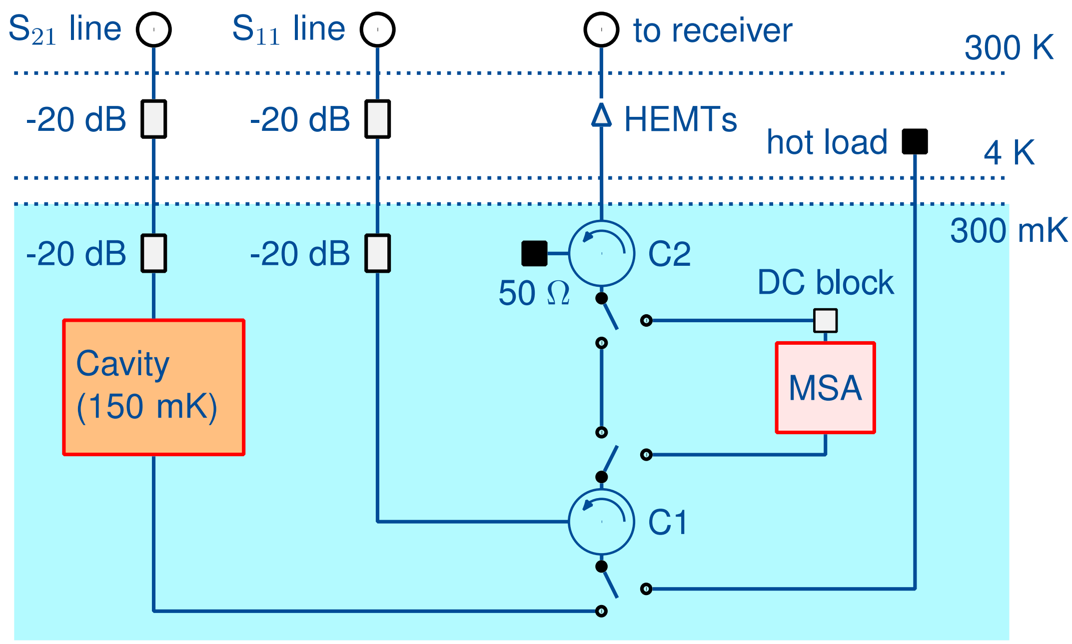
Reflection to look at antenna coupling

Hot / Cold load:
Measure system noise temperature

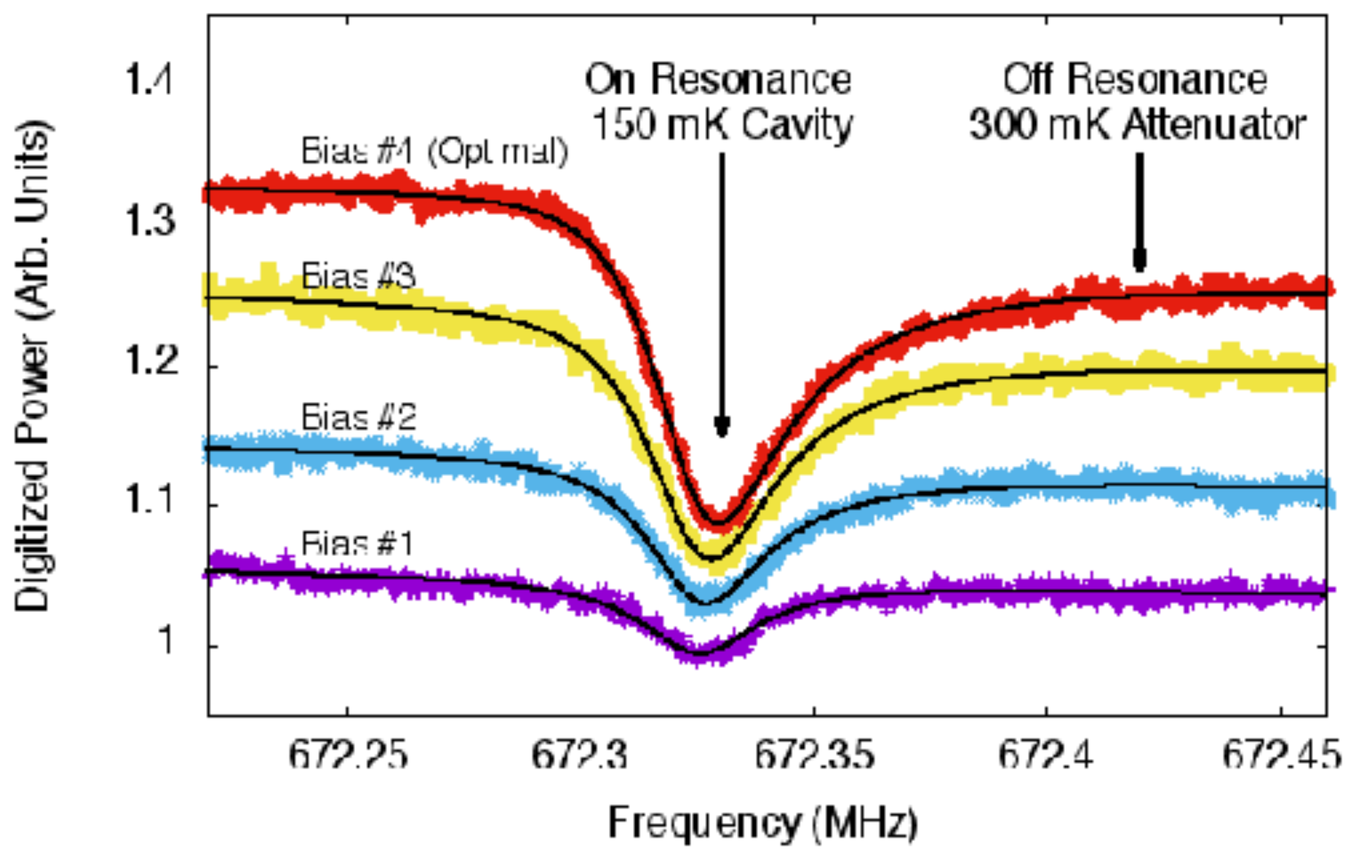
SQUID at $T_{physical}$~ 300 mK
Cavity at $T_{physical}$~ 150 mK

Total system noise ~ 0.5 K*

*includes attenuation + post-amplifier contributions.



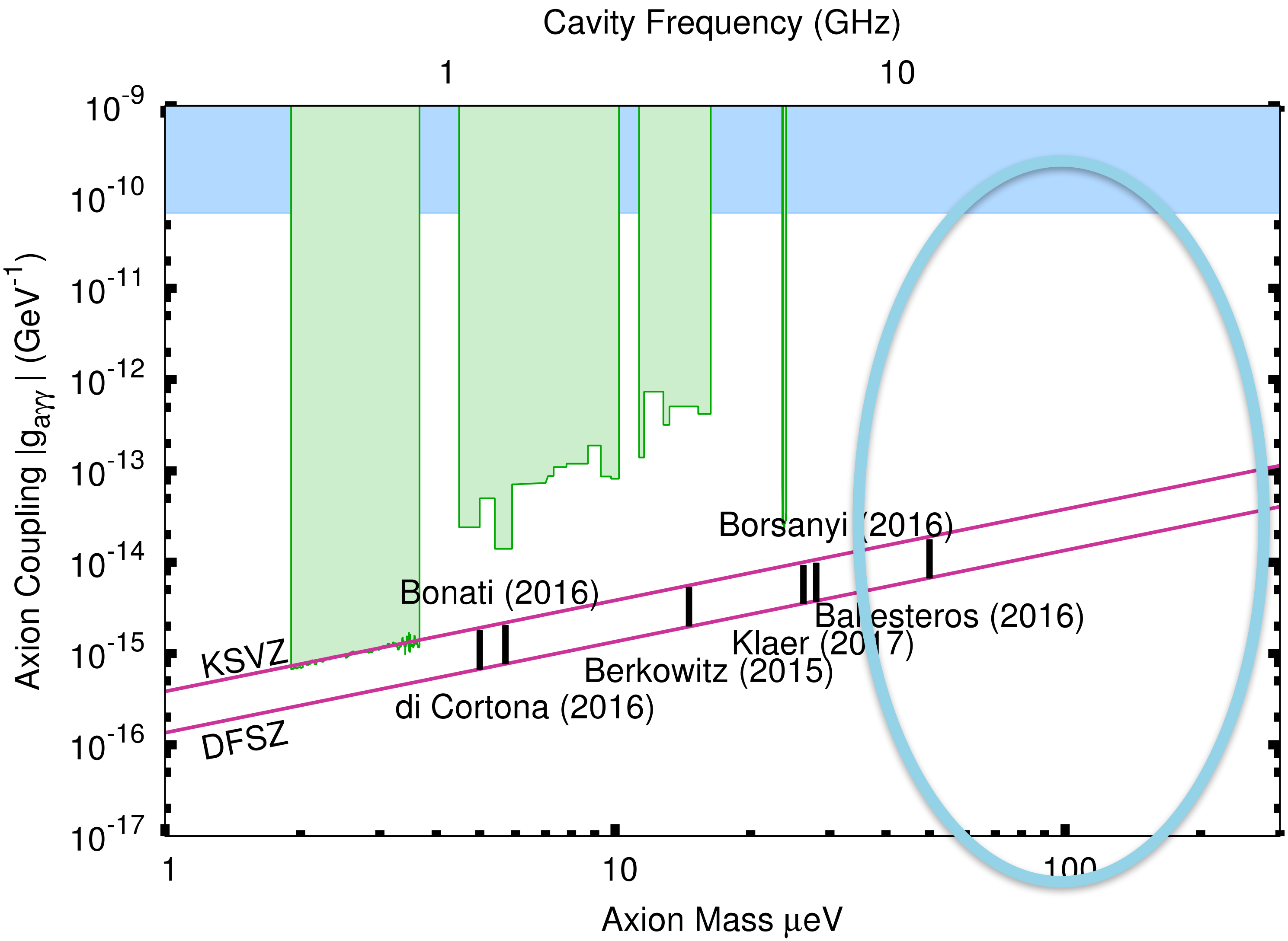
Example Cavity Noise Measurement
Multiple MSA Biases



You might have an axion if the signal…

- can’t be seen in the room outside of the magnetic field
- persists all the time
- follows the lorentzian lineshape of the cavity
- is suppressed in non TM010 modes
- scales with the B^2 of the magnet
- has a tiny daily and annual frequency modulation

R&D For Next-Generation Axion Experiments



We're going to need bigger magnets, more sophisticated cavities and detectors

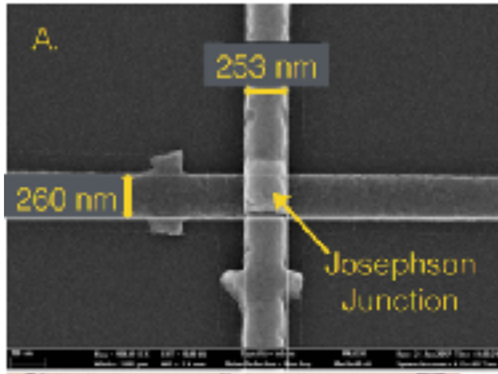
High Frequency Axion R&D: Detectors

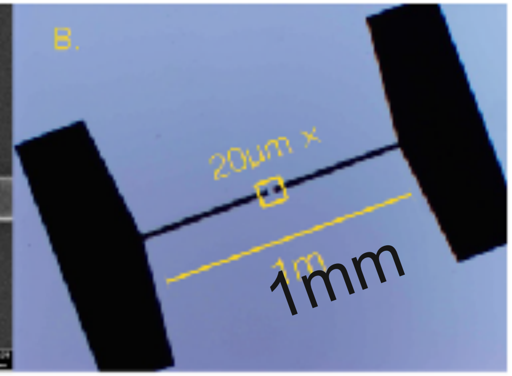
A.S. Chou, D.Bowring, David Schuster (UC), Akash Dixit, Ankur Agrawal

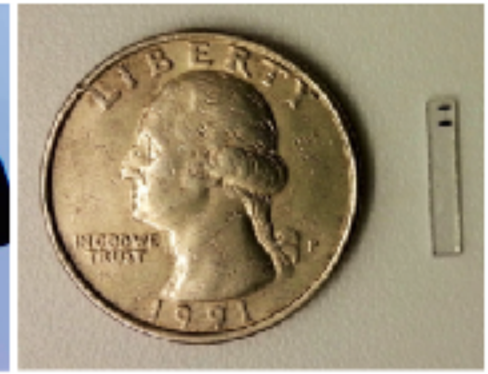
Funded by

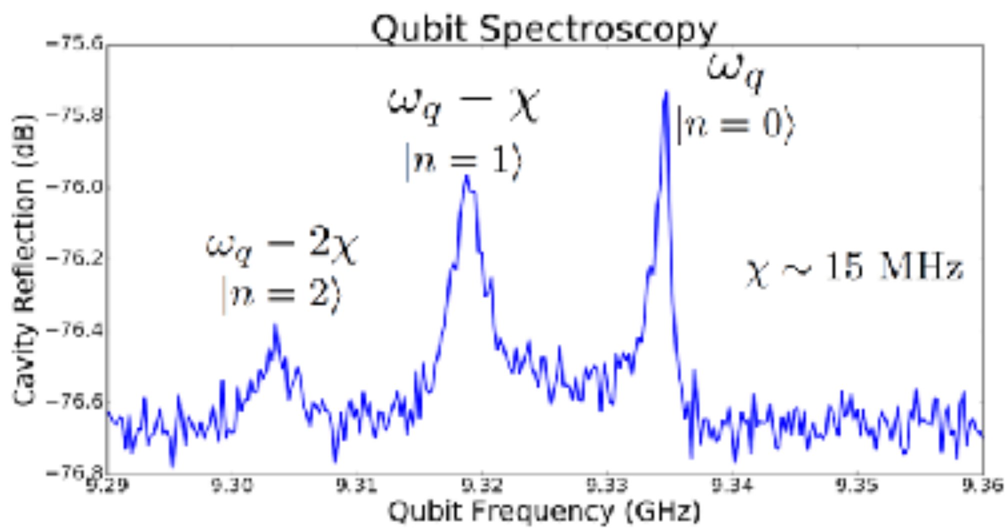
HEISING-SIMONS FOUNDATION

FNAL LDRD



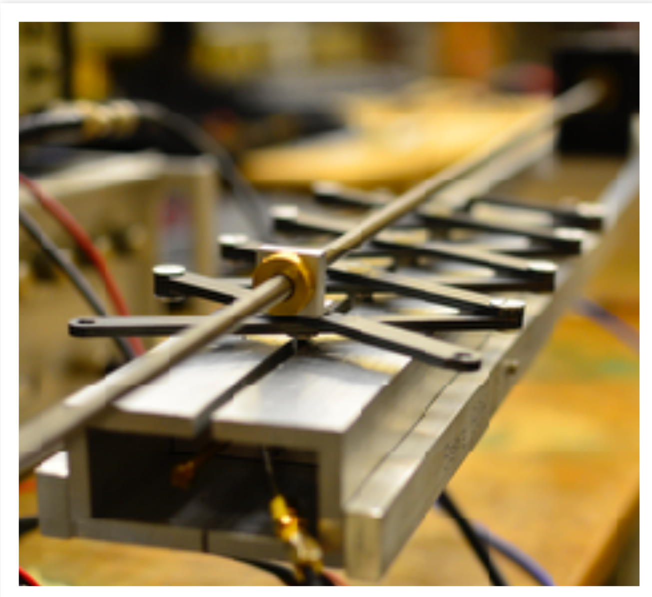




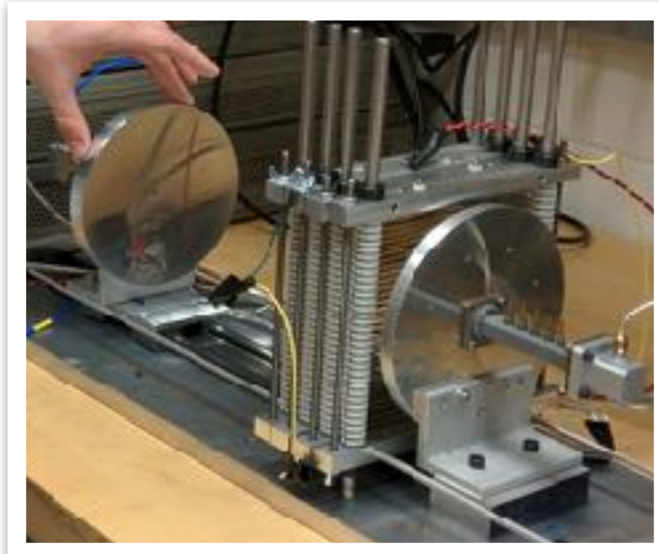


Photon-amplitude-to-qubit-frequency transduction enabled by the nonlinearity of the anharmonic qubit oscillator

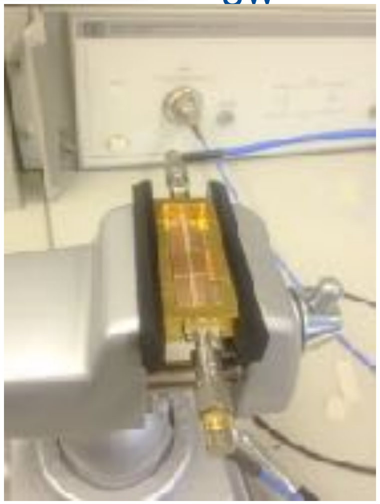
High Frequency Axion R&D: Resonators



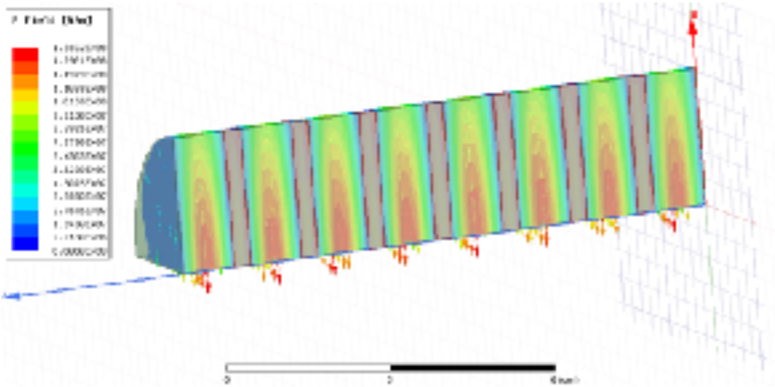
“Electric Tiger” multiwavelength resonator prototype - UW



“Orpheus” open-resonator prototype - UW



Dielectric tuned cavity - FNAL



Open Resonator E&M Simulation - UW