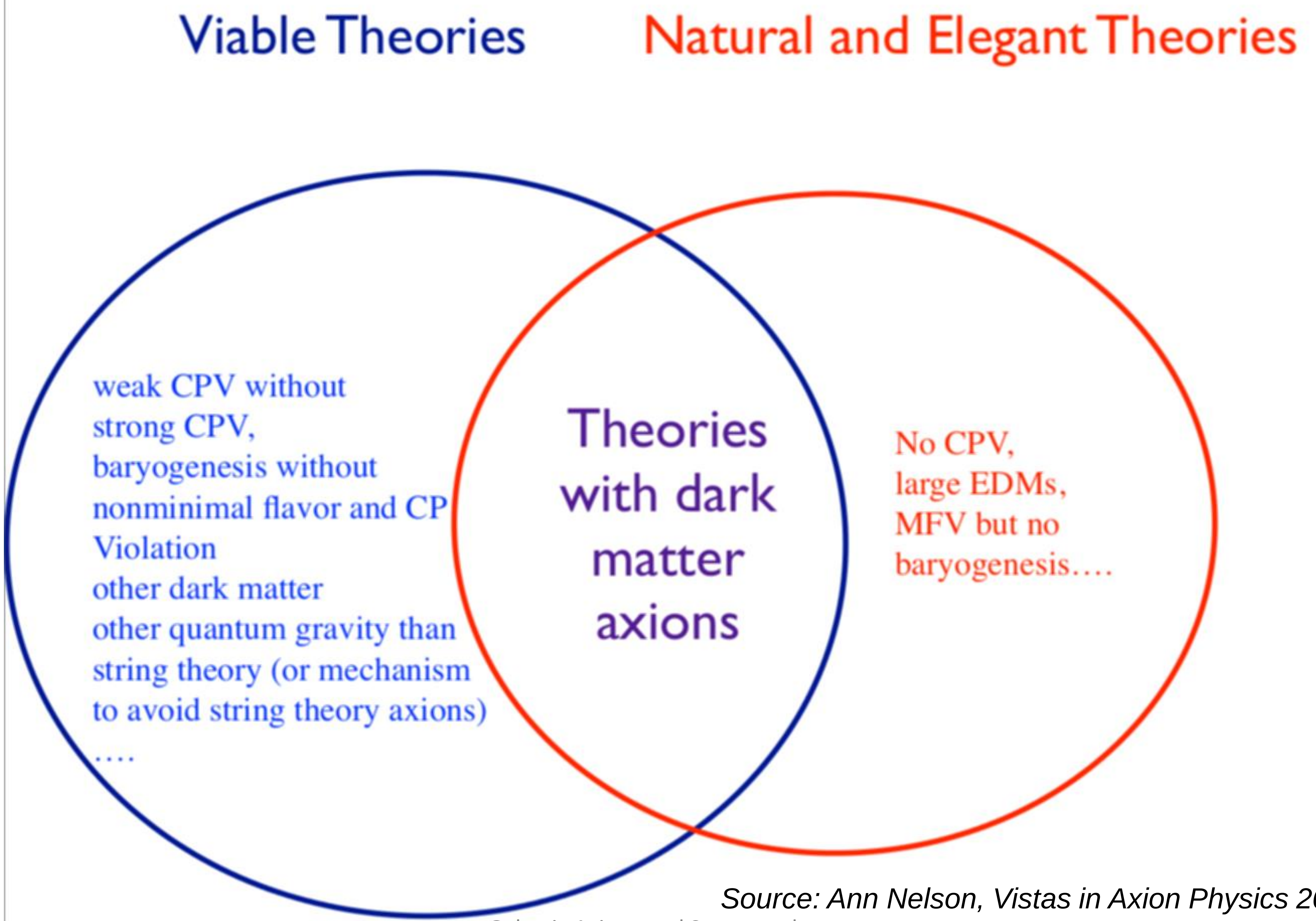
Recent Results from ADMX

Gray Rybka

University of Washington

Searching for Galactic Axions using Superconducting Devices with Quantum Efficiency – October 2021, Daejeon, Korea

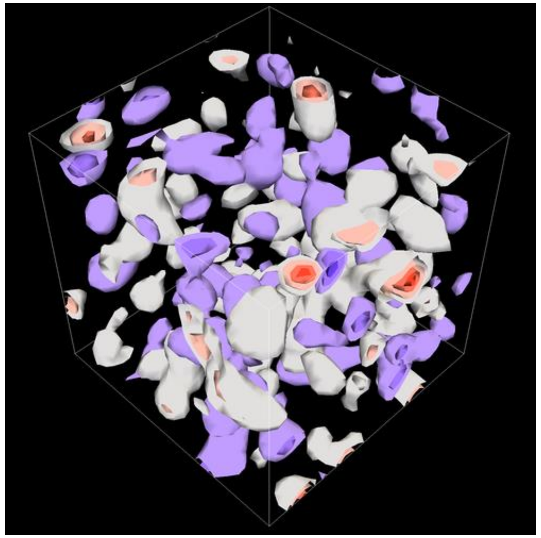
Why Axions?



Source: Ann Nelson, Vistas in Axion Physics 2012

The Axion: Motivation

- QCD is naturally CP violating from phenomena like QCD-instantons
- One naively expects a neutron electric dipole moment of 10^{-16} e cm
- But nEDM is measured to be below 3×10^{-26} e cm *(Baker, 2006)*
- The best explanation? New U(1) axial symmetry, that when broken, cancels CP violation in the strong sector *(Peccei, Quinn, 1977)*
- Consequence: New particle, called the axion *(Weinberg, Wilczek, 1978)*

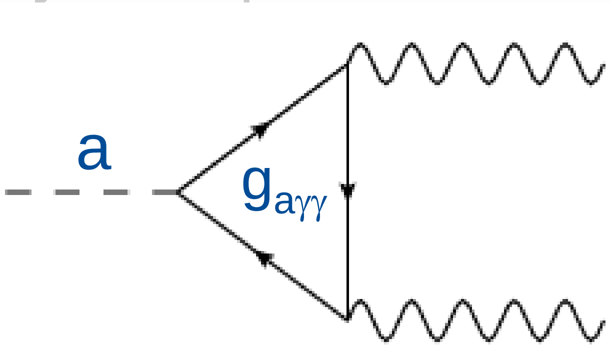


Lattice QCD simulation of QCD instantons

The Axion

The Axion has the same quantum numbers as, and mixes with, the $\pi_{0.}$

This gives a fairly clear picture of how the axion couplings scale with axio

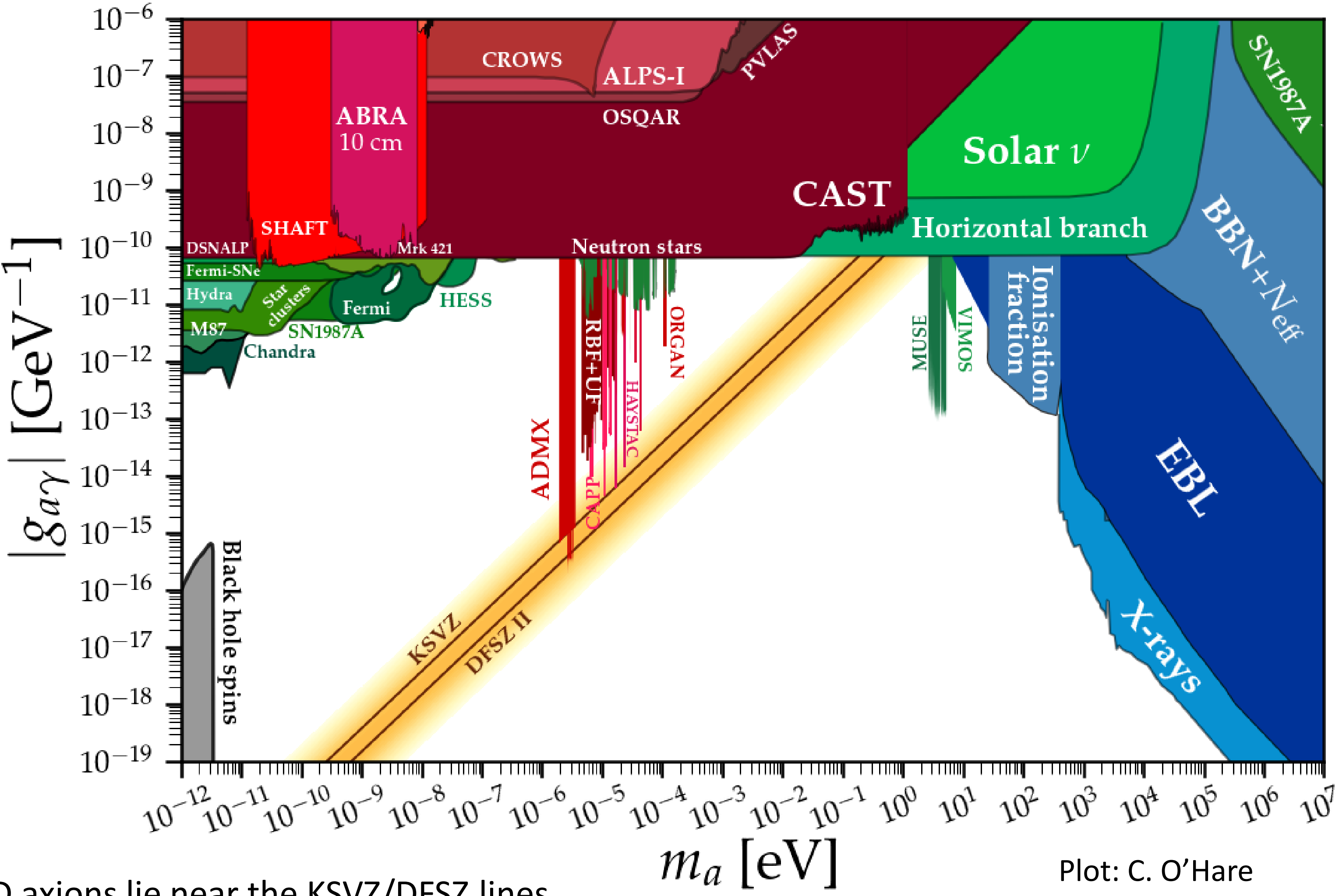


In particular the axion-photon coupling has very little model dependence. Benchmark models:

“KSVZ”: Ad hoc “hadronic” axion couplings.
“DFSZ”: Grand unification.

“DFSZ” is so compelling that a search needs sensitivity to DFSZ axions in order to be credible. Unfortunately, DFSZ couplings are almost x10 weaker than KSVZ.

The Broad Landscape of Axion Like Particles (ALPs)

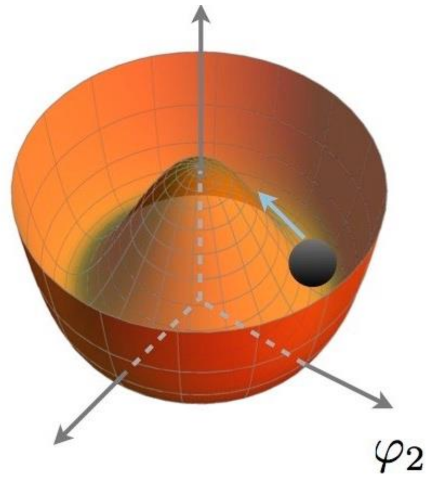


QCD axions lie near the KSVZ/DFSZ lines,
"ALPs" can be anywhere not excluded.

Plot: C. O'Hare
DOI 10.5281/zenodo.3932430

Axions as Dark Matter

As the Universe cools and the temperature falls below the Peccei-Quinn symmetry breaking scale, the axion field begins oscillating about the new minimum.



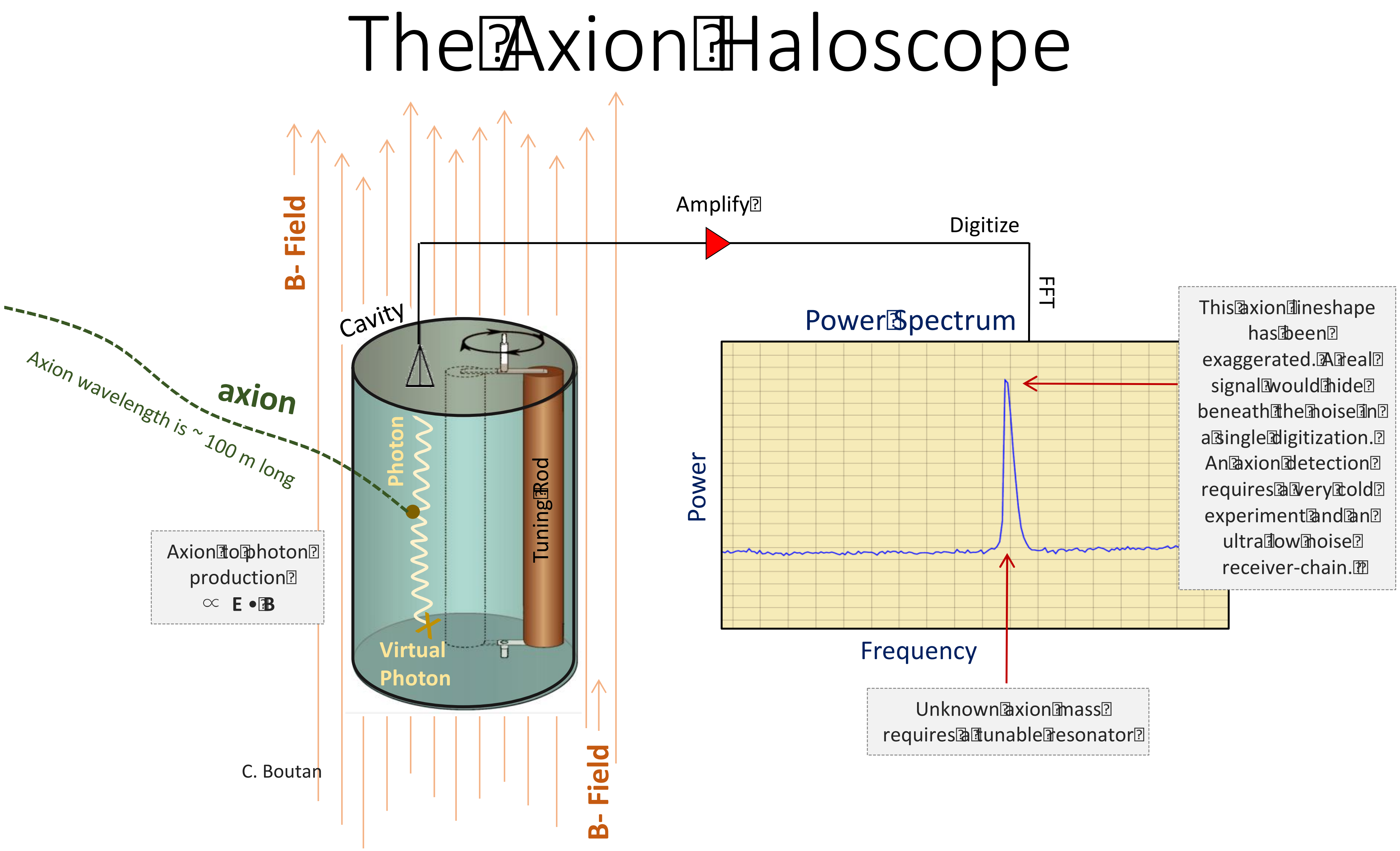
Oscillation about the QCD minimum – *Daniel Grin*

The energy stored in this minimum is Dark Matter, and can be estimated to be at the ueV scale. Uncertainties are due to:

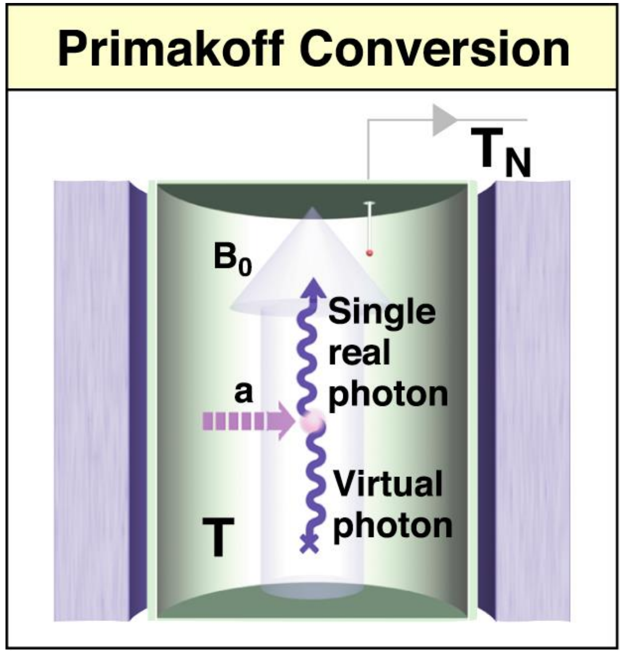
- Inflation scale (axion is a probe of inflation)
- Lattice QCD calculations of instantons
- Additional production mechanisms

This yields a range of axions 1-1000 ueV that could produce 100% dark matter.

Principle of the Sikivie Axion Haloscope



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	Noise Proportional to
Cavity Volume	Cavity Blackbody Radiation
Magnetic Field	Amplifier Noise
Cavity Q	

Key Components of an Axion Haloscope

- High Magnetic Fields
- Dilution Refrigeration
- High Q, Tunable Resonators
- **Ultra Low Noise Amplifiers**

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

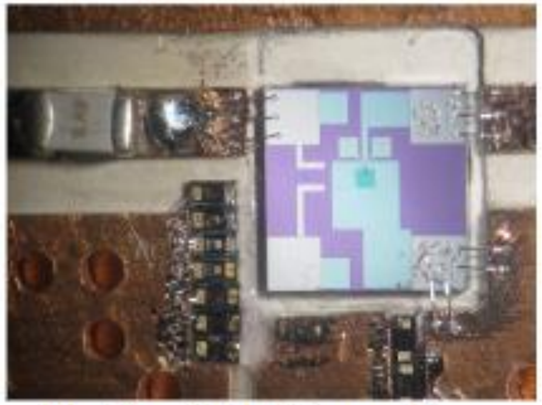
Collaborating Institutions:
UW, UFL, LLNL
FNAL, UCB, PNNL
LANL, WU, UWA,
Sheffield, IIT

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

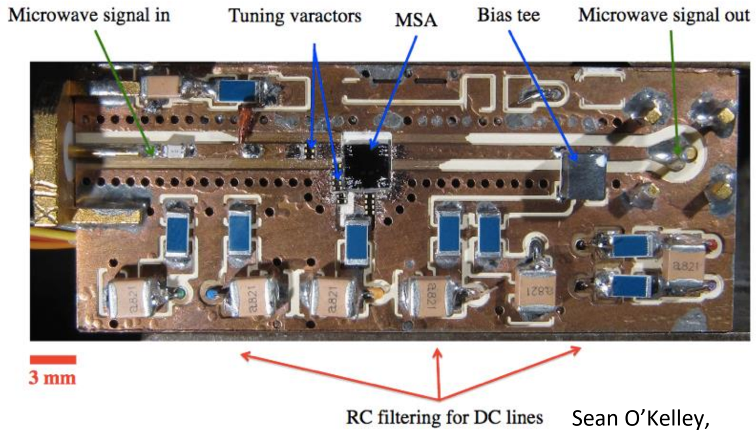
Reporting on Results from 2020-2021 Operation Period

Near-Quantum Amplifiers



Niobium SQUID amplifier
made by Sean O'Kelley
Clarke Lab, Berkeley

ADMX Tunable MSA



Sean O'Kelley,
Clarke Group,
UC Berkeley

- Enabling Technology!
- Superconducting Interference Device (SQUID) amplifiers
- Josephson Parametric Amplifiers (JPA)

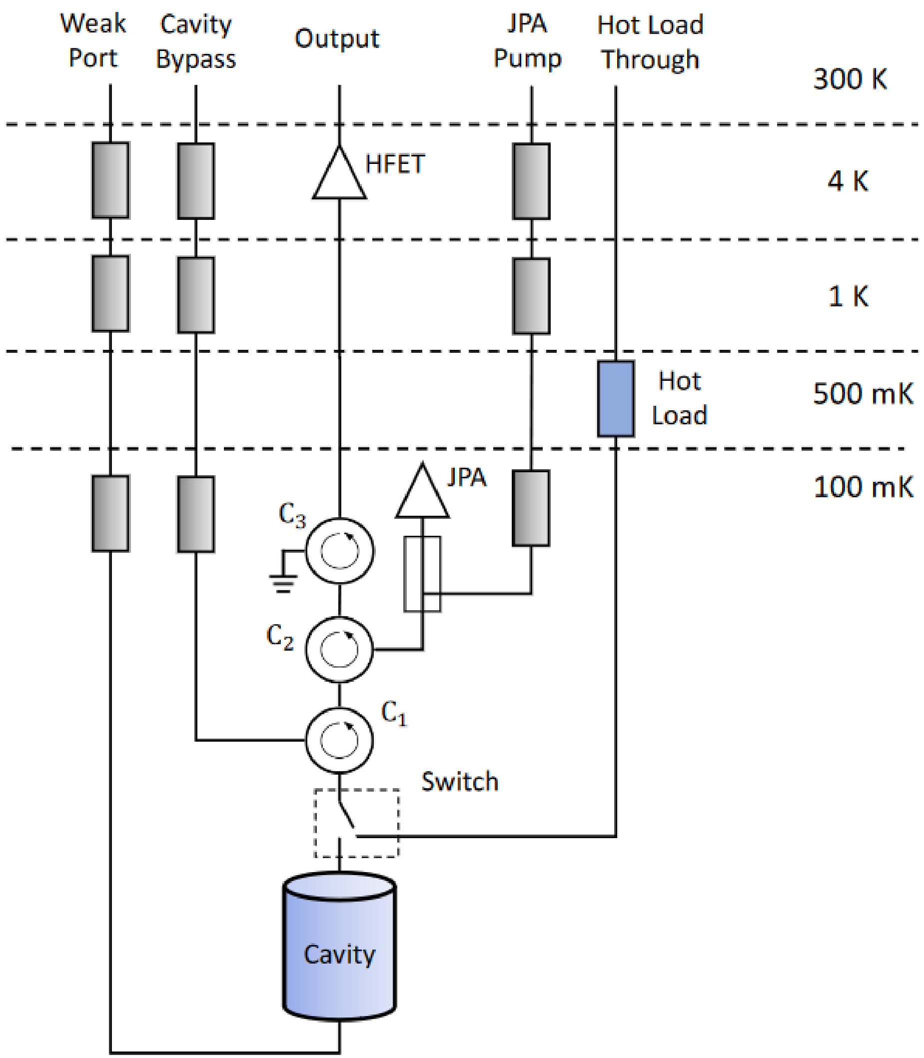
ADMX JPA

Yanjie Qiu,
Siddiqi Group,
UC Berkeley

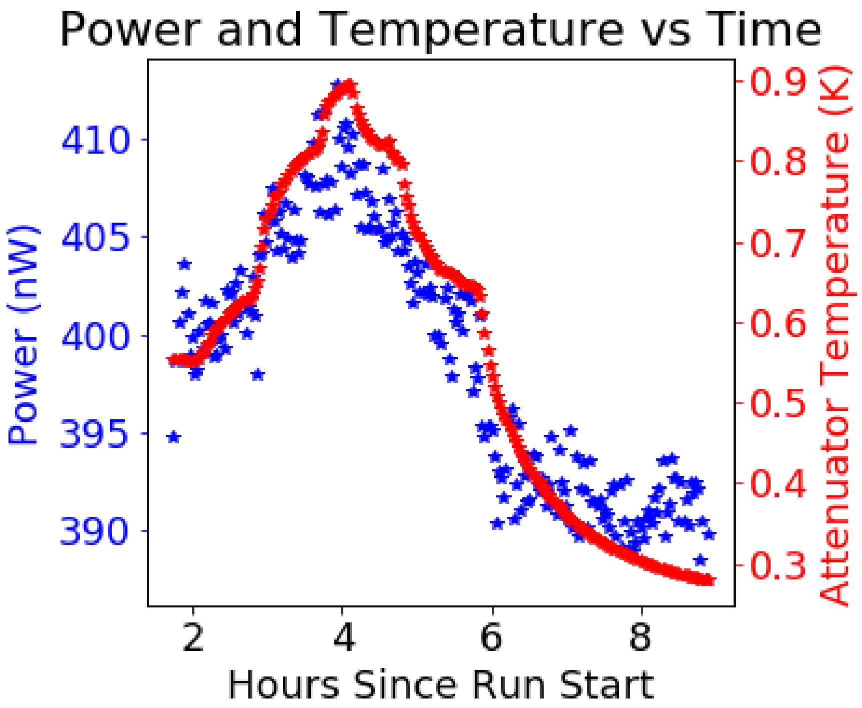
ADMX Cold Electronics

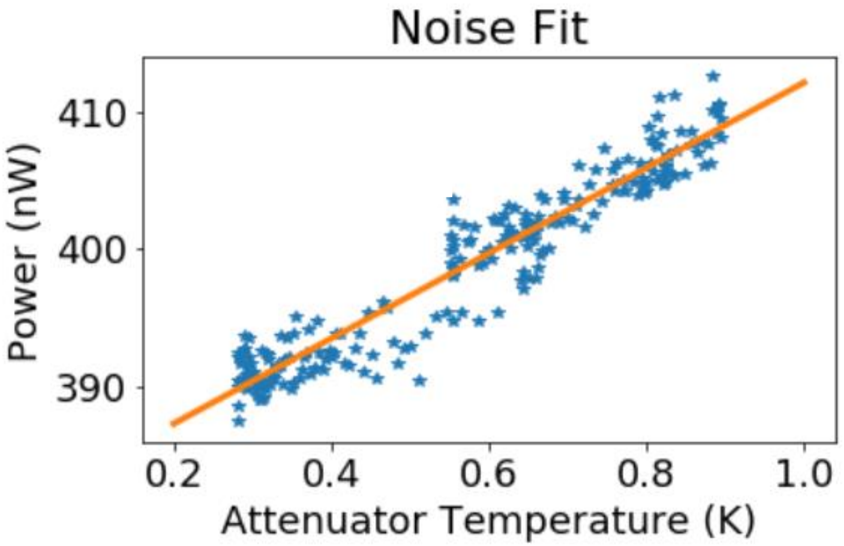
Primary signal path goes from cavity, through circulators, to JPA, through more circulators, and then through the HFET transistor amplifier to the output.

Note many calibration lines. *Your noise is only as good as your calibration!*

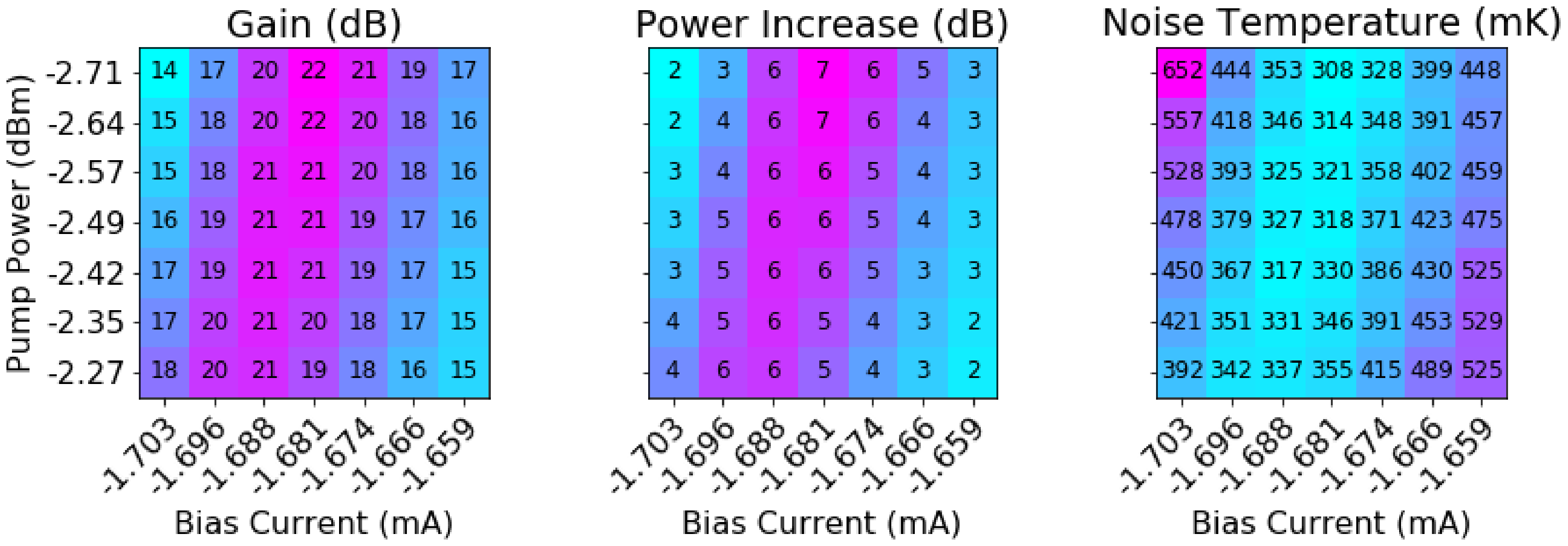


Primary Calibration: System Noise Temperature Determination
1) Tie 2nd Stage Amplifier noise power to temperature sensor

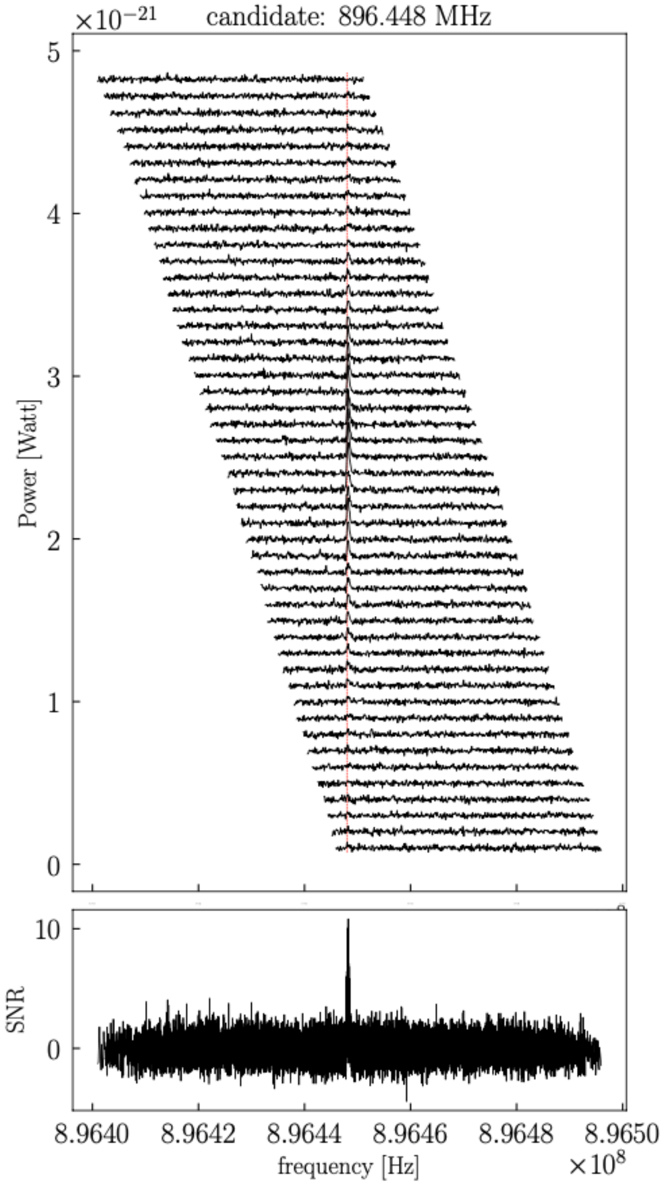




System Noise Determination
2) Add in Signal-to-Noise Improvement of Quantum Amplifiers



ADMX Operations



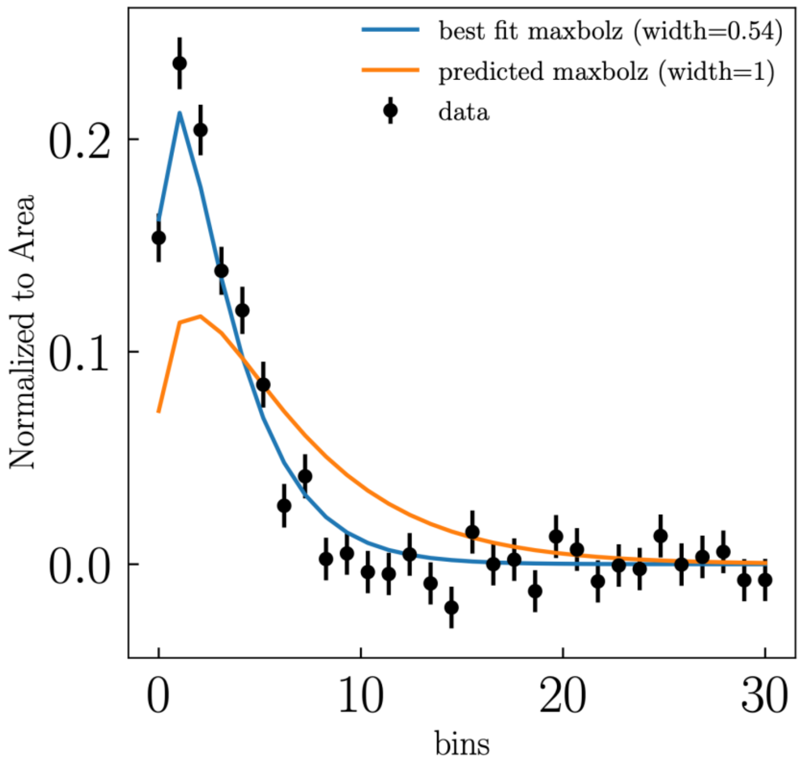
The cavity is tuned every 100 seconds, during which power spectra are taken. Overlapping power spectra are examined for the characteristic axion signal shape appearing on-resonance.

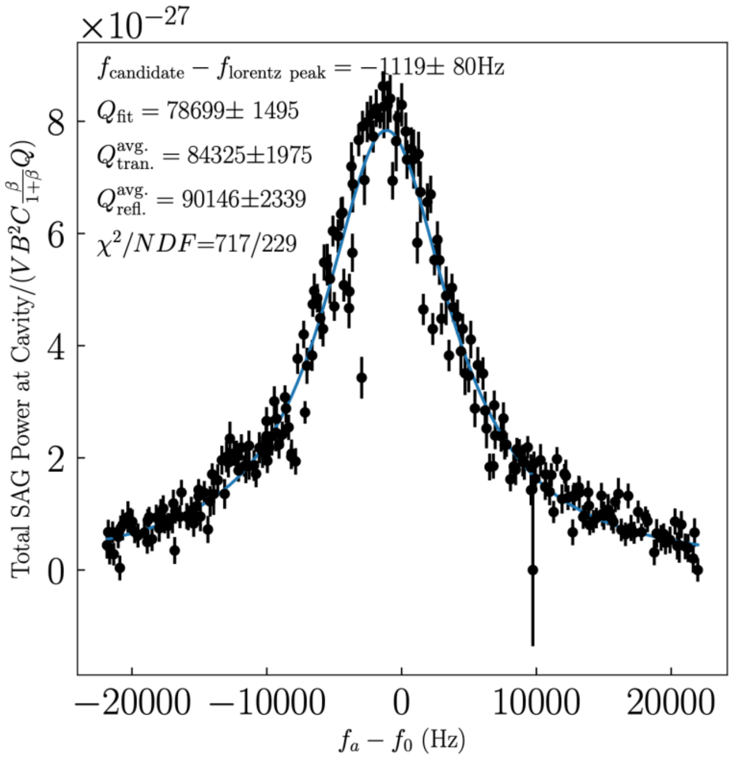
Here, the "synthetic signal" team within the ADMX collaboration has injected a blind axion-like signals directly into the cavity without warning.

The analysis team finds them, reports them to the detection committee and proceeds with the checks to see if the signal is a real axion.

Here is one from 2021. Exercising the detection procedure gives us confidence we will find the real signal when we come across it.

Blind-Injection Synthetic Signal Detection



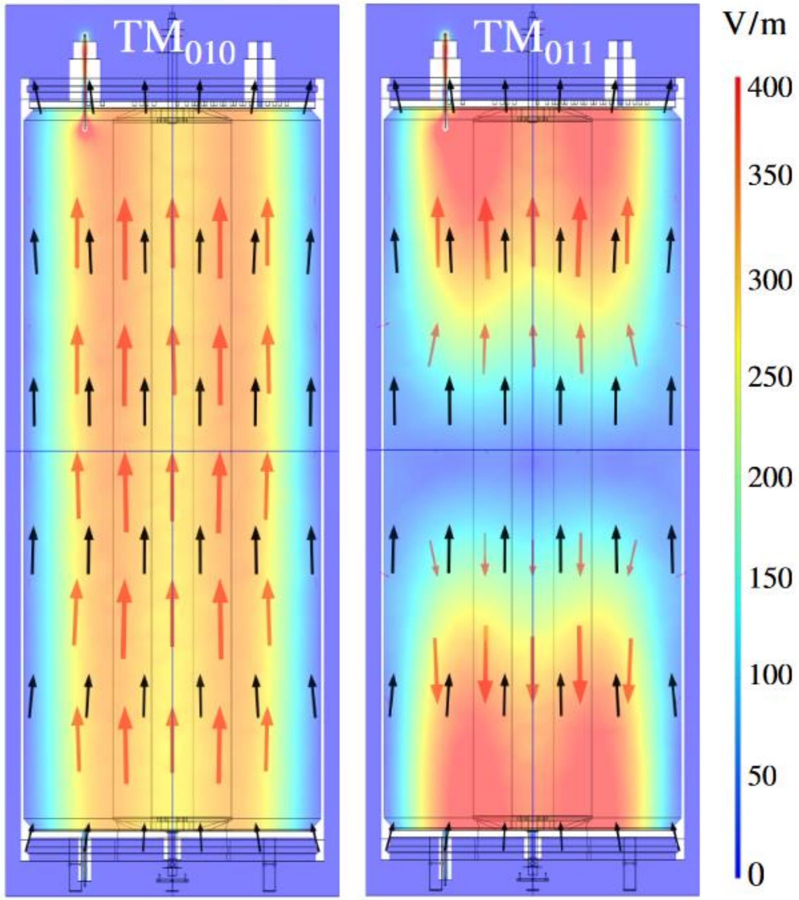


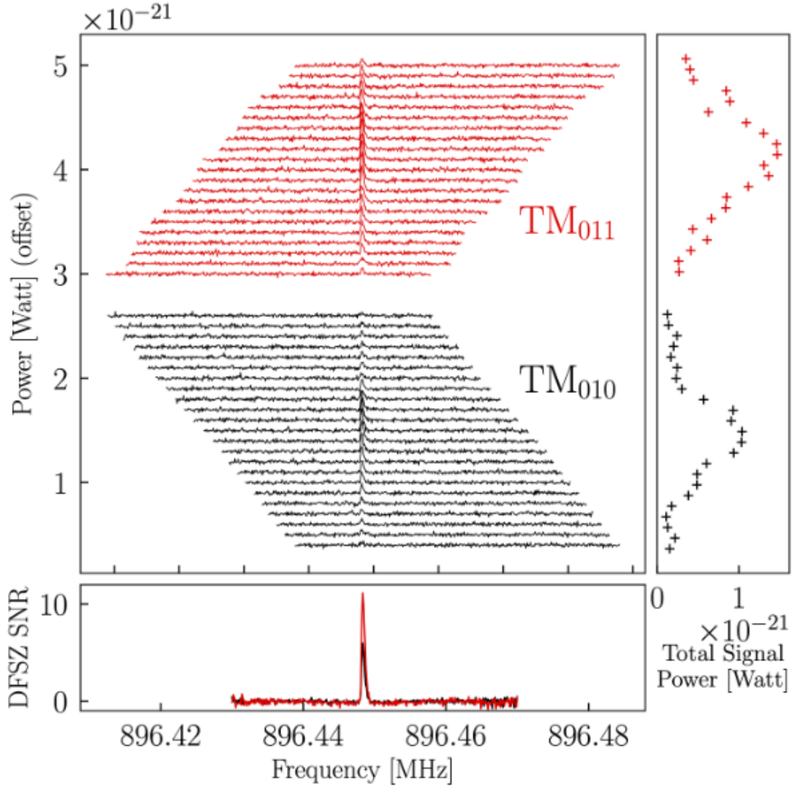
This signal sure looked like an axion. But before we began ramping the magnet down to be sure, we wanted to try looking at it from another mode.

The lineshape was consistent with cosmological predictions

The signal was clearly coming from inside the cavity

Axions Couple to TM010 modes, not TM011

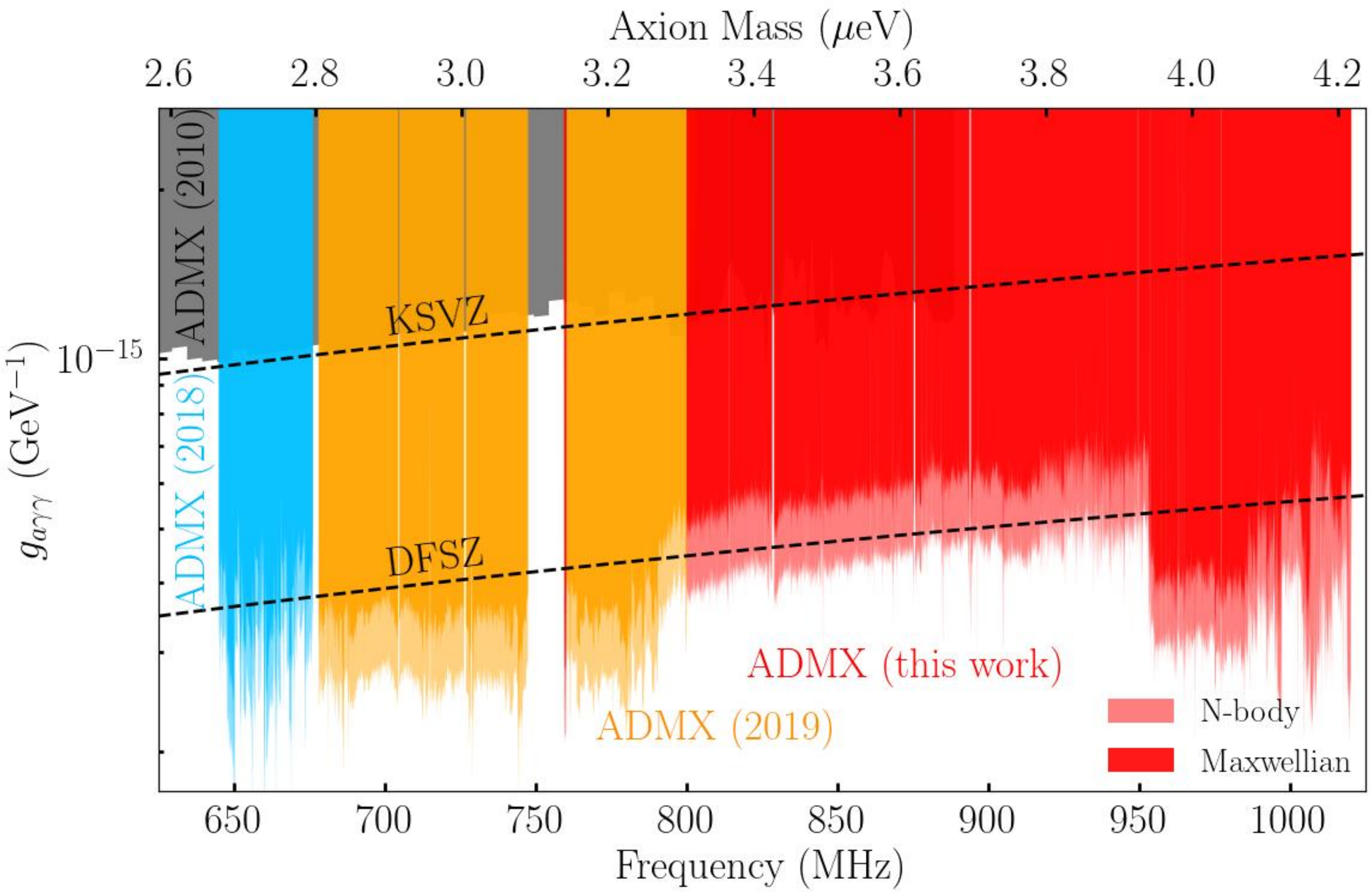




Overlap of axion field (black) and E&M mode field (red)

This signal appeared in both modes, and was thus clearly not an axion.

ADMX 2021 Exclusion

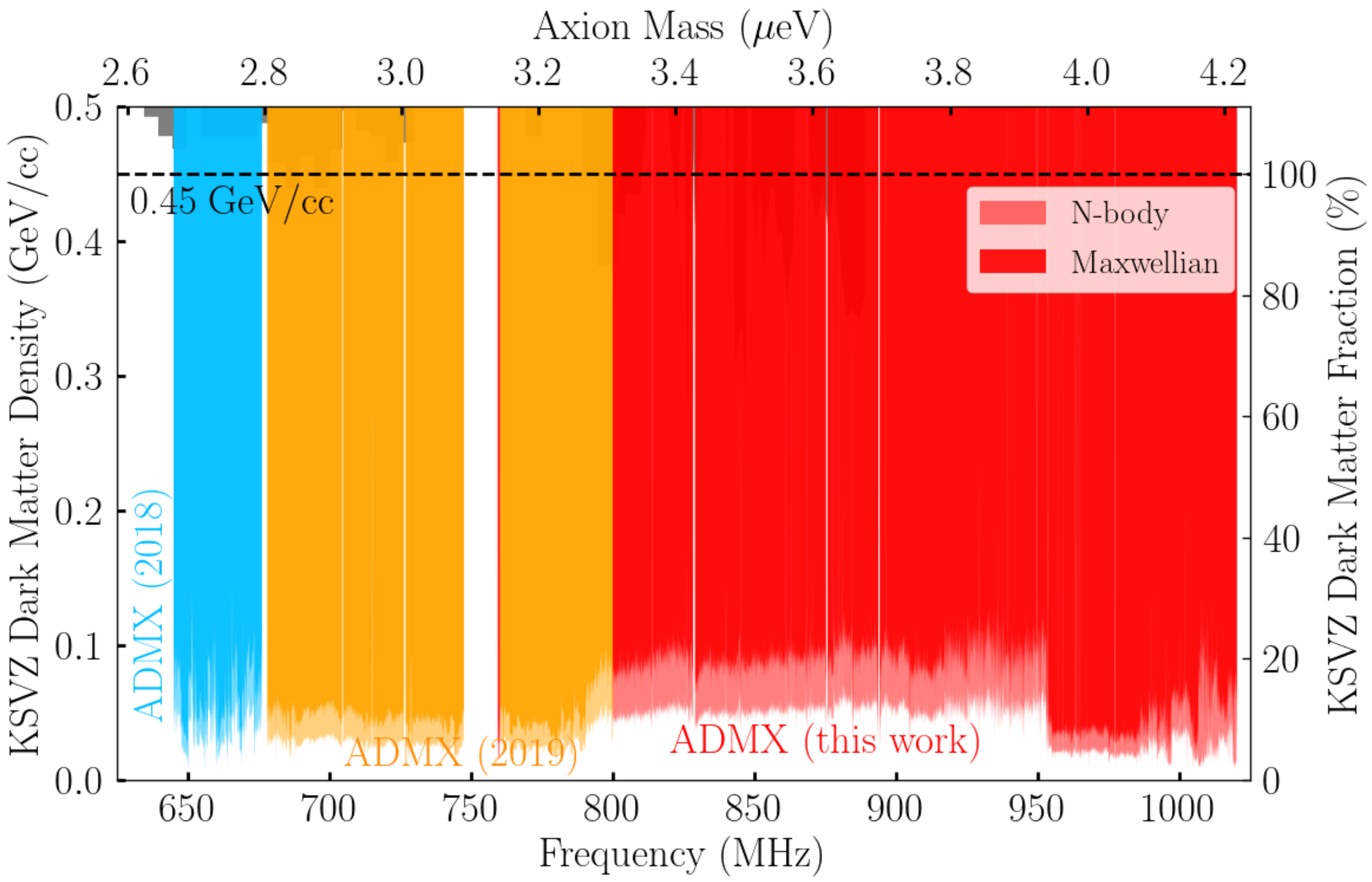


As we found no axion signals, we can exclude an even wider mass range.

https://arxiv.org/abs/2110.06096

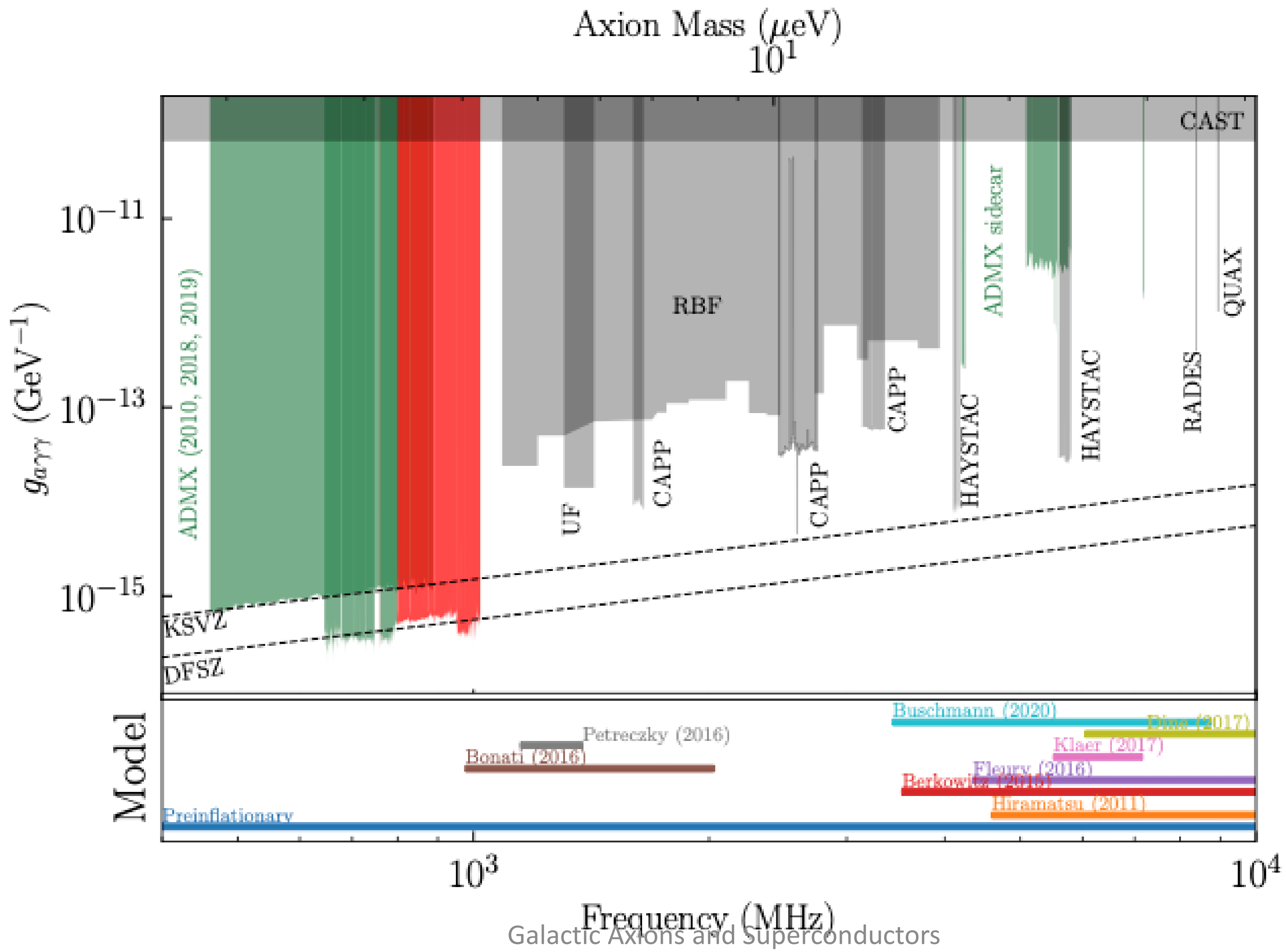
The end of 2021 will be dedicated to pushing limits to DFSZ

ADMX 2021 Exclusion – KSVZ Dark Matter Density

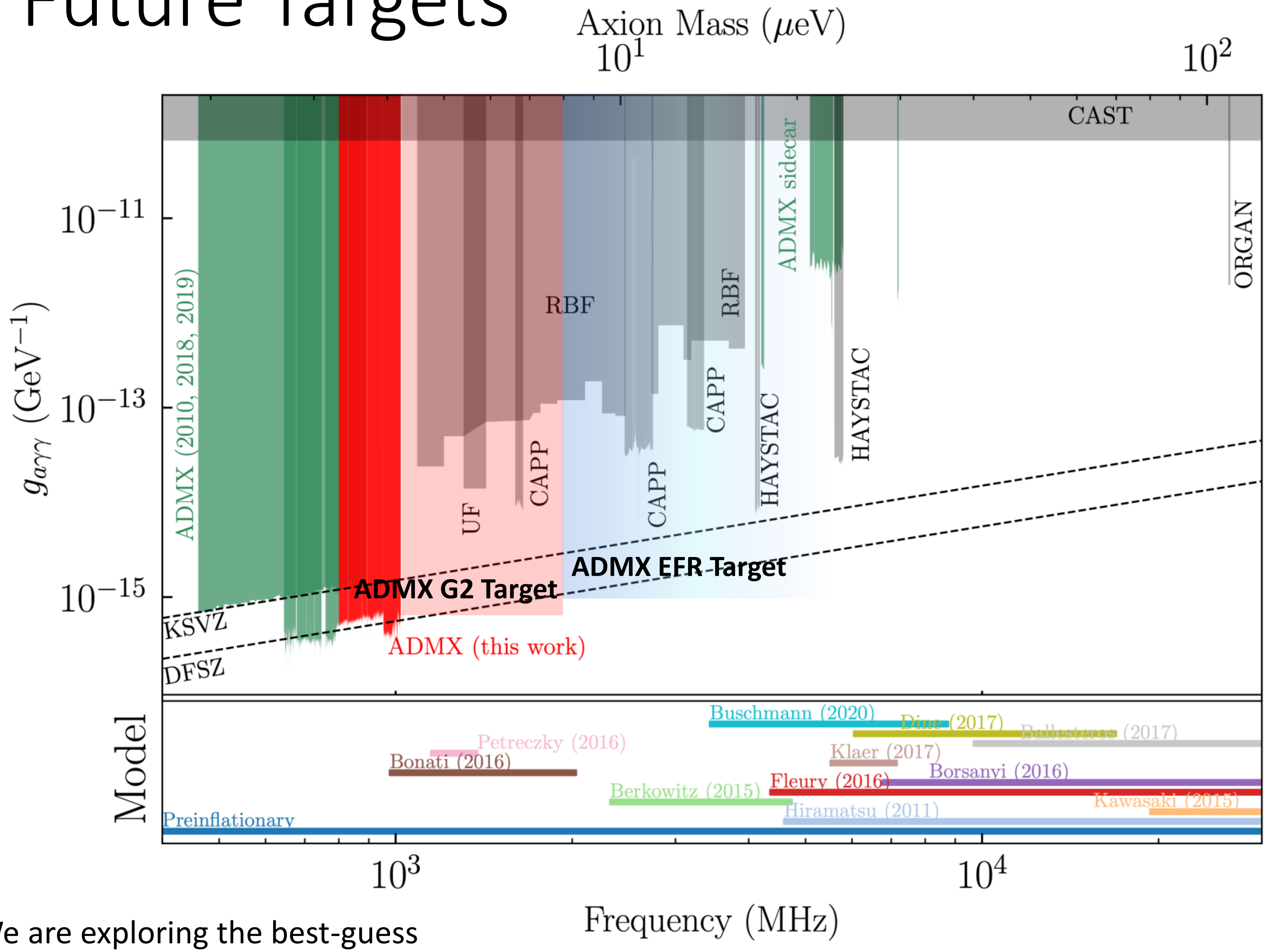


One can also assume an axion model (KSVZ in this case) and ask what local dark matter density we can exclude

ADMX 2021 Exclusion - Context

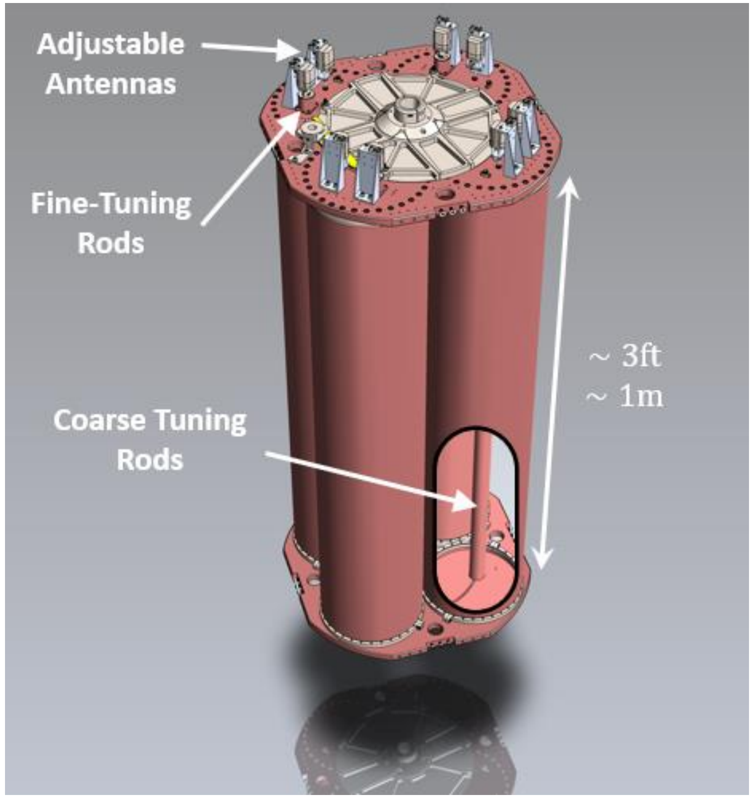


ADMX Future Targets



We are exploring the best-guess axion dark matter mass range

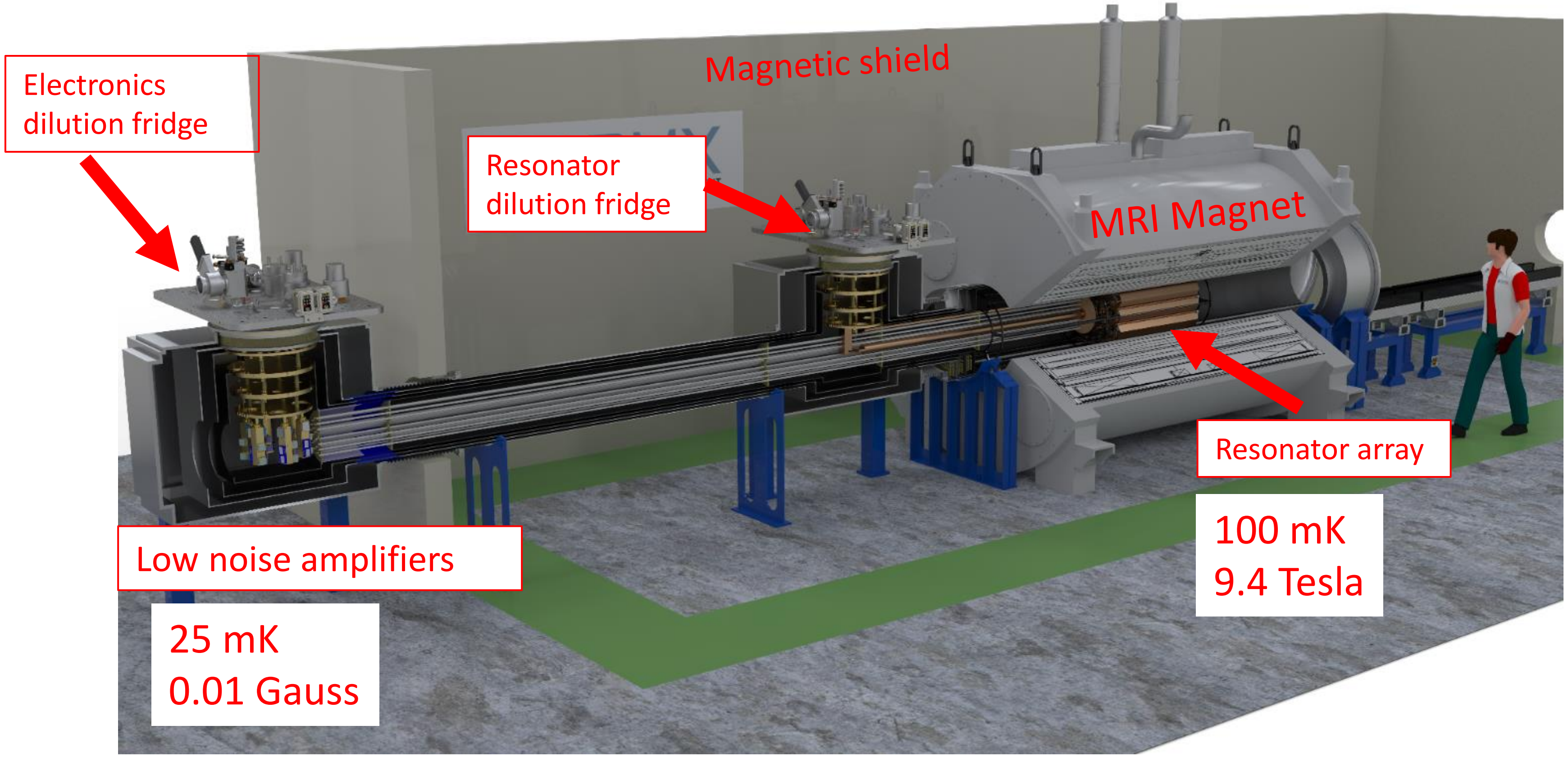
Next Steps: Multicavity Arrays



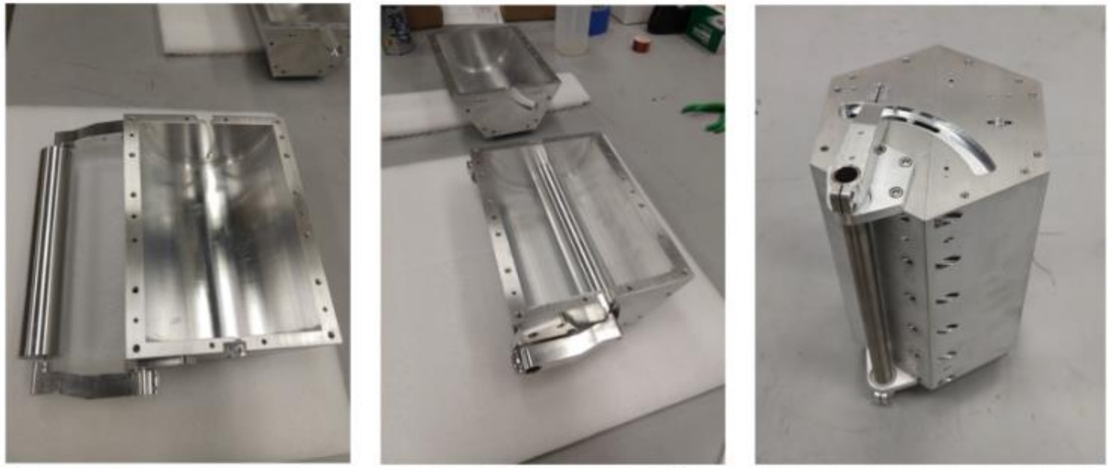
Our 4-cavity arrays up to 2 GHz are constructed and under testing

ADMX- EFR Conceptual Design

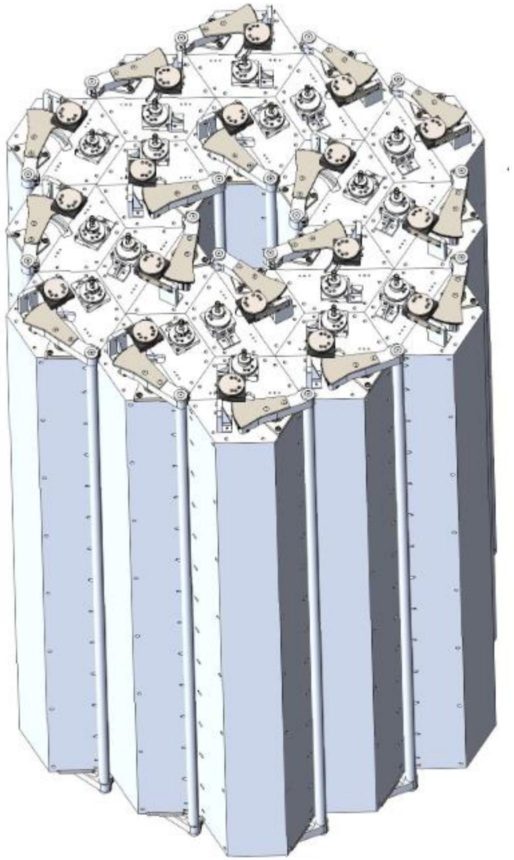
To reach higher than 2 GHz at DFSZ sensitivity, we are designing an entirely new system with a much larger magnet: ADMX- Extended Frequency Range



ADMX EFR Multicavity Concept – 4 GHz



Tuning rod is mounted to arms outside of array | **Tuning rod swung into position** | **Array with fully assembled tuning system**



Side Note: JTWPAs

- A travelling wave design allows a much broader region of gain than other amplifiers
- This may open up trainsient searches, or multiplexing multiple resonant systems

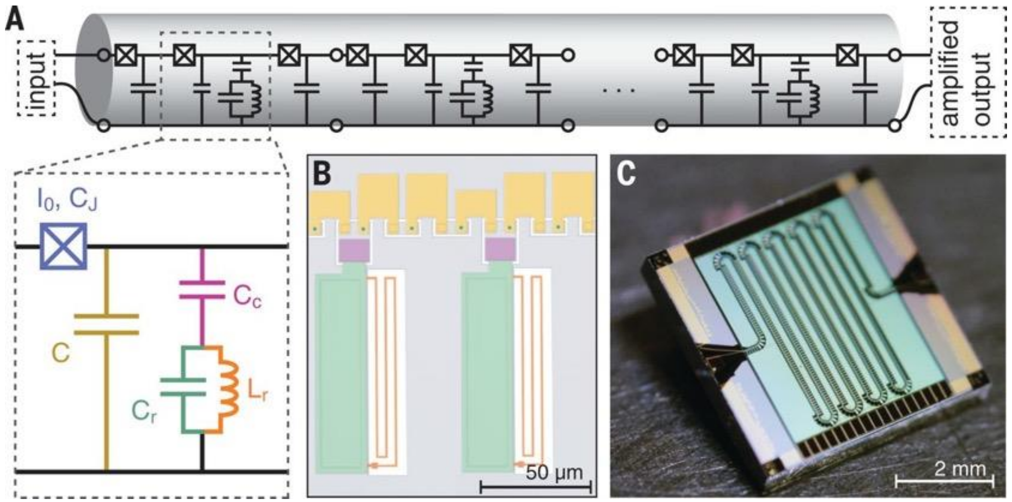
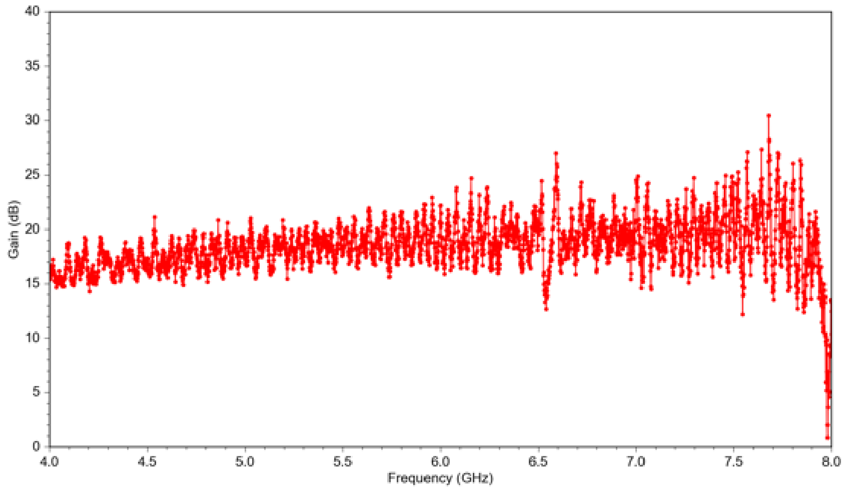
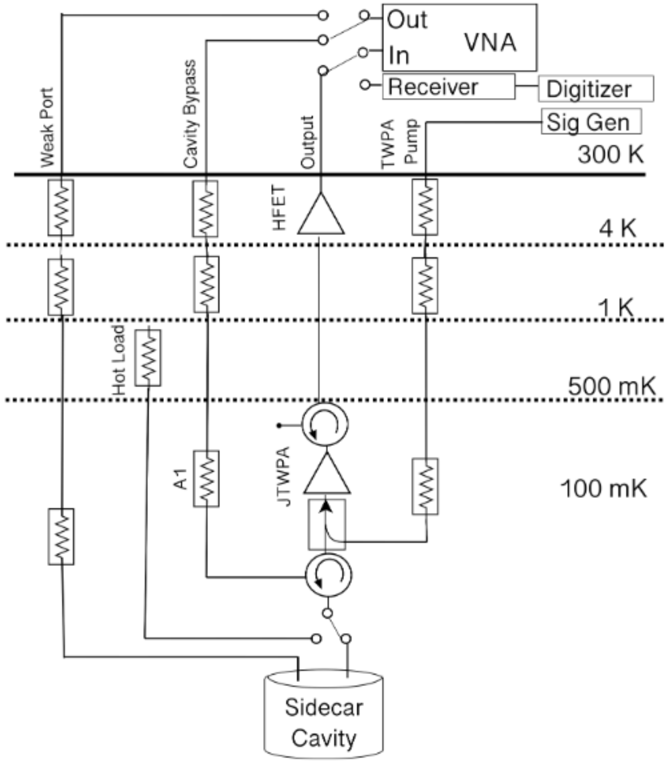
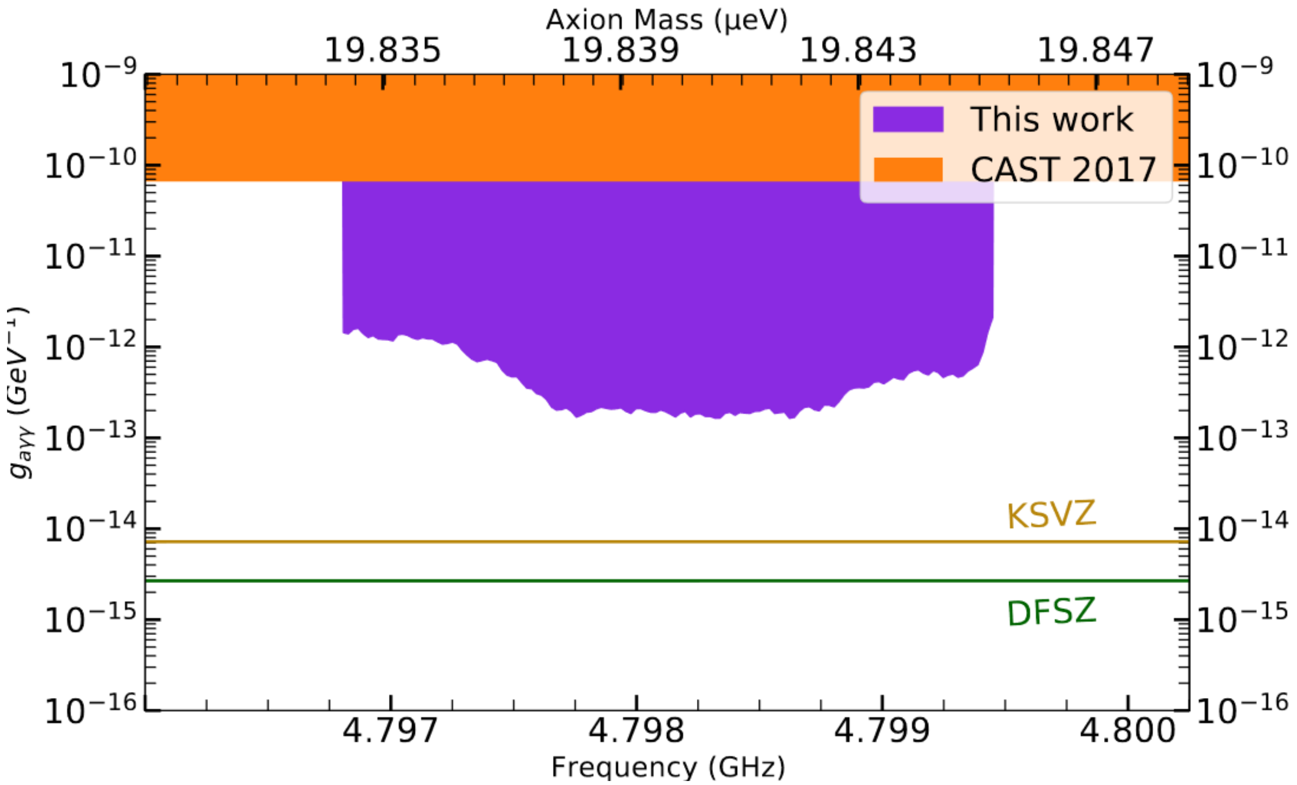


Image courtesy N. Woollett



Demonstration of JTWPA in ADMX Sidecar





Bartram et al. https://arxiv.org/abs/2110.10262

Conclusions

ADMX is the only haloscope searching for dark matter axions with DFSZ sensitivity

We have beyond-KSVZ results that double the previously reported frequency coverage, and is in the process of extending sensitivity all the way to DFSZ

ADMX has concrete designs to reach 4 GHz and beyond

We are also exploring new quantum limited amplifier designs to enable innovative axion searches