Precision Metrology with Photons, Phonons and Spins: Answering Major Unsolved Problems in Physics and Advancing Translational Science

Recent Limits on the Search for Axion Dark Matter

Prof. Michael Tobar

THE UNIVERSITY OF WESTERN AUSTRALIA

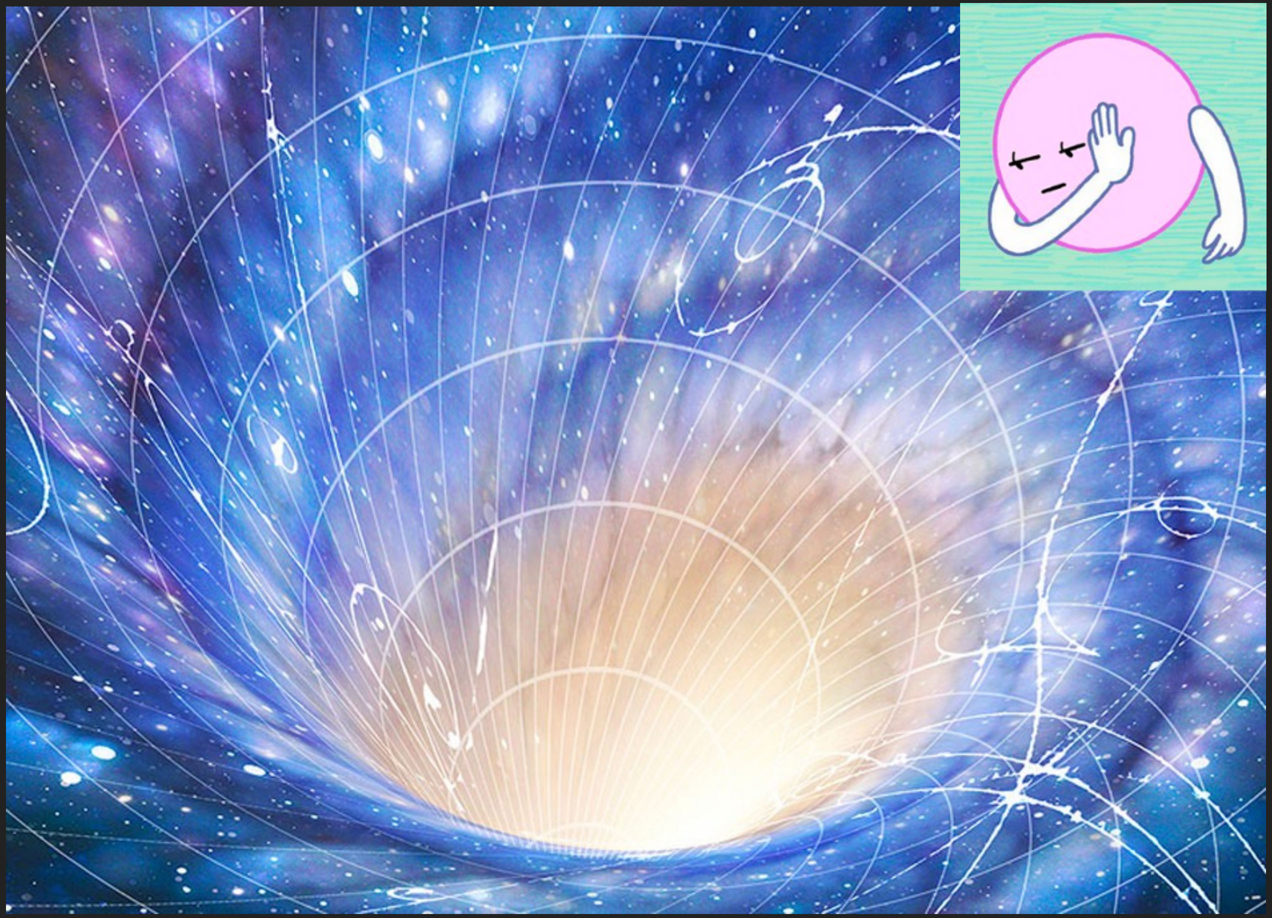
SEEK WISDOM

QDM

Quantum Technologies and Dark Matter Research Lab

ADMX

Axion Dark Matter eXperiment



ARC CENTRE OF EXCELLENCE FOR DARK MATTER

EQUS

Australian Research Council Centre of Excellence for Engineered Quantum Systems

Searches for Axions at UWA and ADMX

The QDM Lab: https://www.qdmlab.com/

QUANTUM TECHNOLOGIES AND DARK MATTER RESEARCH LAB

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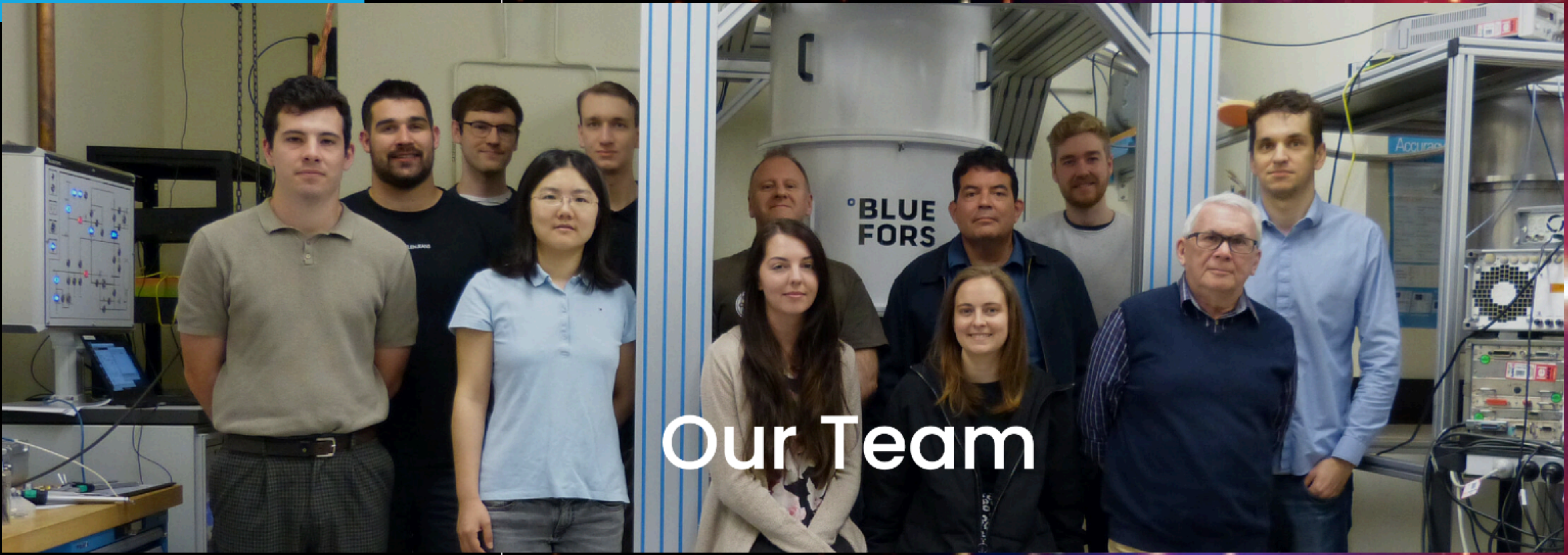

ACADEMIC
Michael Tobar
Eugene Ivanov
Maxim Goryachev

POSTDOCS
Ben McAllister
Cindy Zhao
Jeremy Bourhill

TECHNICIAN
Steven Osborne

ADJUNCT
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HDR/PHD STUDENTS
Graeme Flower
Catriona Thomson
William Campbell
Aaron Quiskamp
Elrina Hartman

UNDERGRAD STUDENTS
Bryn Roughan (MPE)
Robert Limina (MPE)
Campbell Millar (MPE)
Ishaan Goel (MPE)
Deepali Rajawat (MPE)
Miles Lockwood (Hons)
Aryan Gupta (BPhil)
Michael Hatzon (BPhil)
JoshGreen (BPhil)

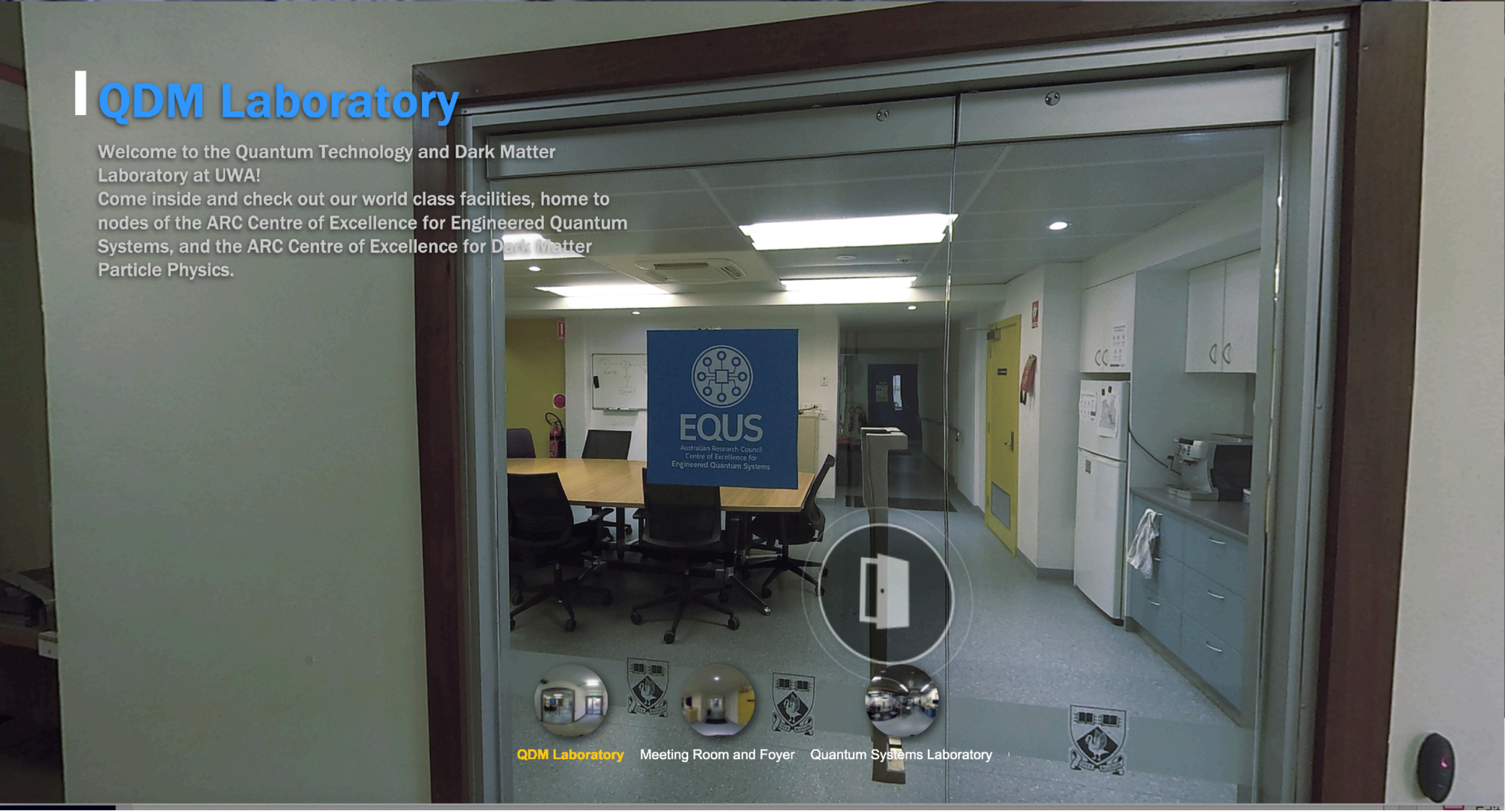
Welcome to the QDM Lab

Quantum Technologies and Dark Matter Research at the University of Western Australia

Research excellence in precision measurement and sensing, low temperature physics, hybrid quantum systems and laboratory tests of fundamental physics.

Learn More

Virtual Tour


QDM Laboratory
Welcome to the Quantum Technology and Dark Matter Laboratory at UWA!
Come inside and check out our world class facilities, home to nodes of the ARC Centre of Excellence for Engineered Quantum Systems, and the ARC Centre of Excellence for Dark Matter Particle Physics.
EQUS
Australian Research Council Centre of Excellence for Engineered Quantum Systems
QDM Laboratory
Meeting Room and Foyer
Quantum Systems Laboratory

Wave-like Dark Matter Candidates

Wave-like Definition: Mass < 1 eV

Broad Candidate Categories:

- Pseudo-scalar*
- Scalar
- Vector

Production: Athermal production (misalignment).

Detection: Coherent interaction of the wave with the detector. Resonant amplification often key.

**The most famous candidate in this group is the QCD axion.*

Searching for Putative Wave-Like Dark Matter

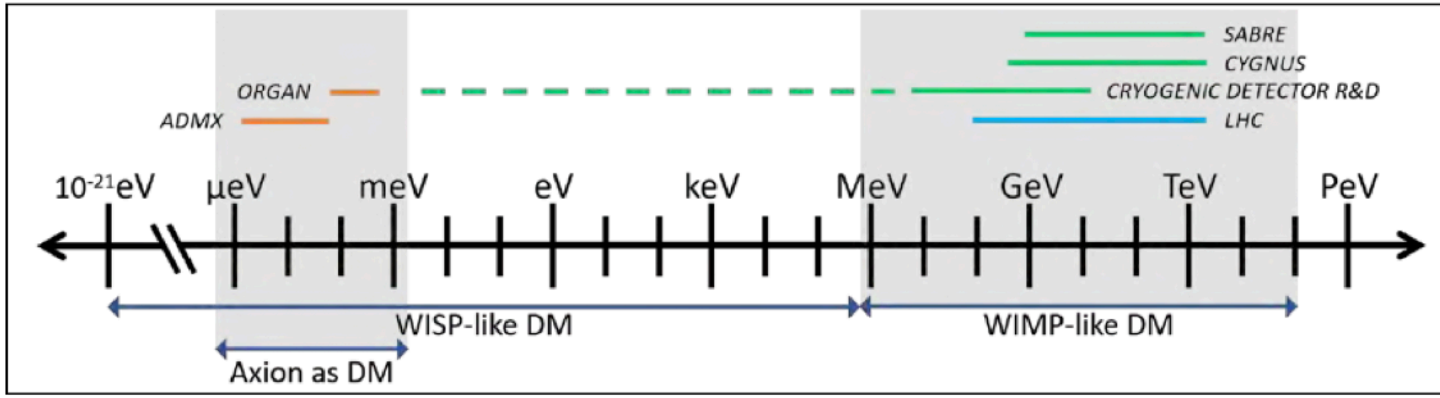
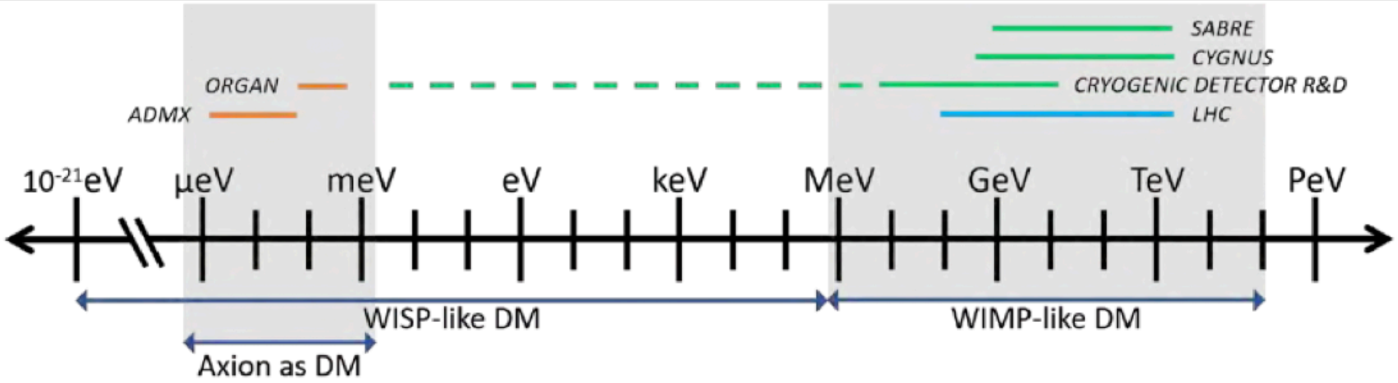


Figure 4: Dark matter mass ranges to be searched in Centre WIMP and WISP direct detection experiments and the LHC Program.

Searching for Putative Wave-Like Dark Matter



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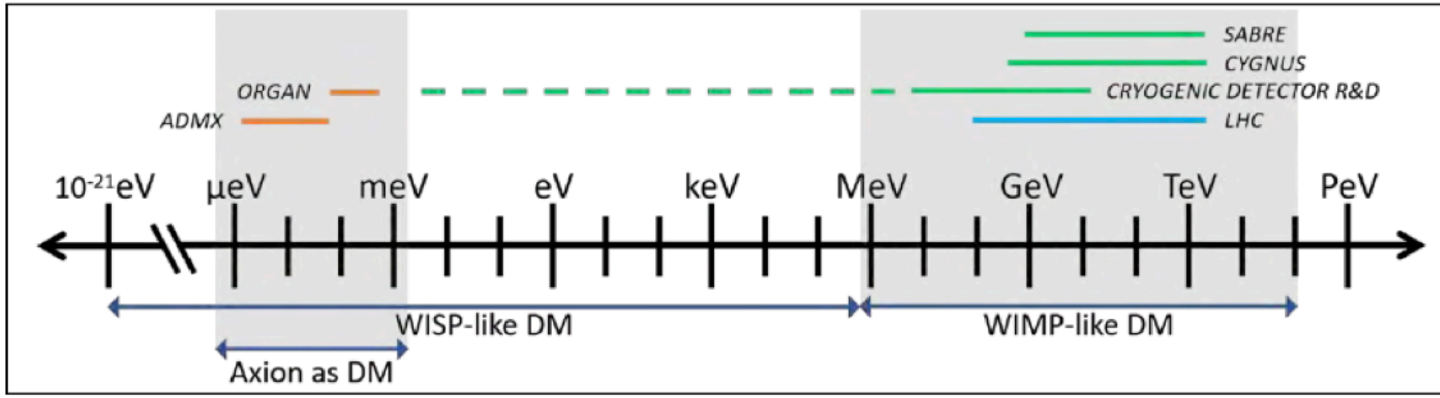

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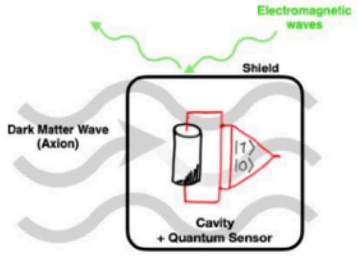
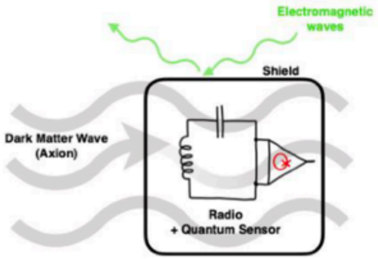
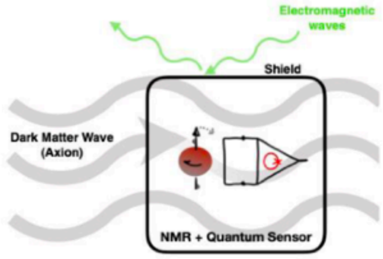
Wave like Dark Matter surrounds



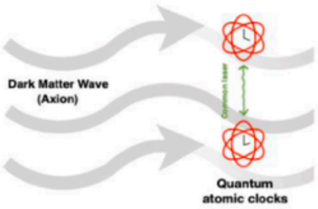
Microwave Cavity



Lumped Element

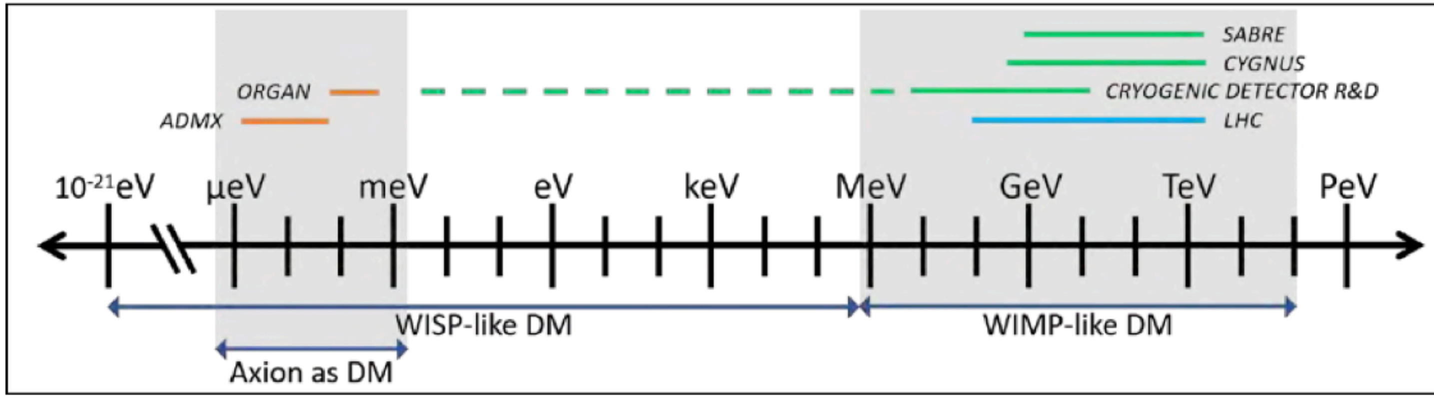


Magnetic Resonance



Atom Interferometry

Searching for Putative Wave-Like Dark Matter



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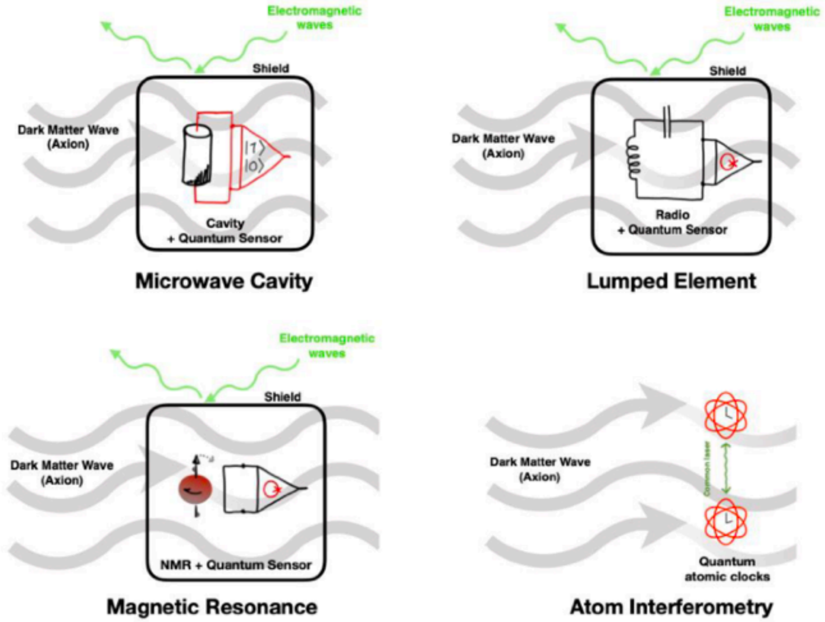

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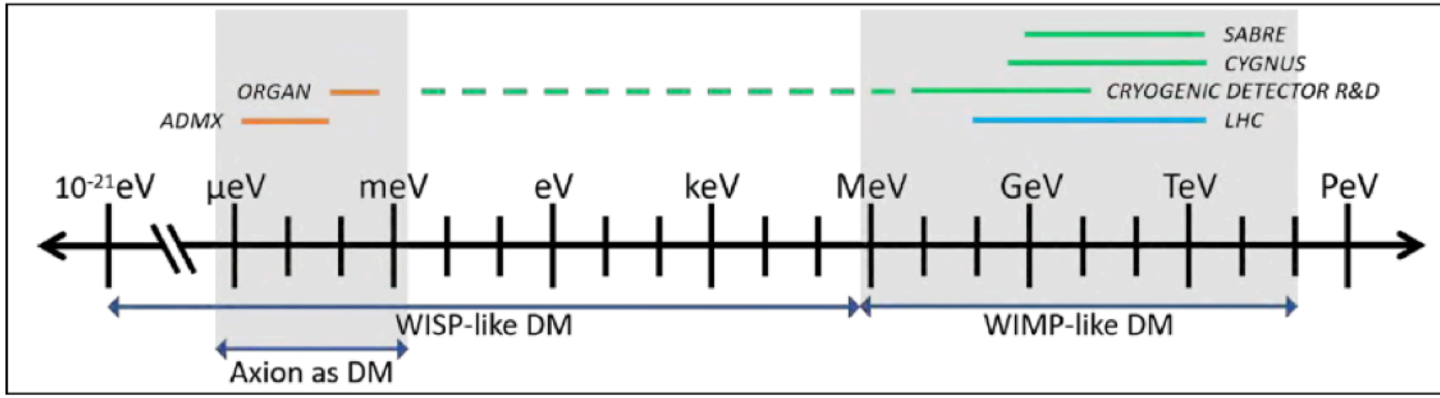

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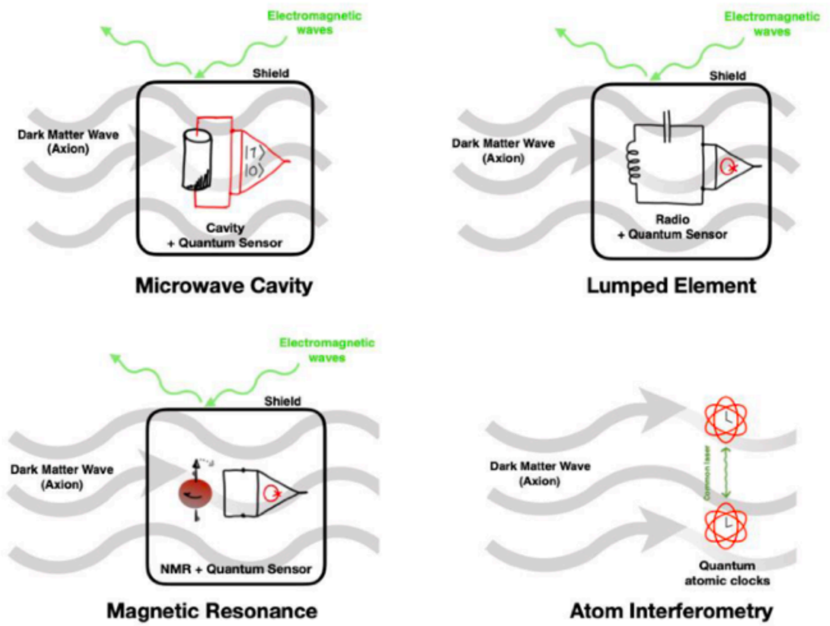

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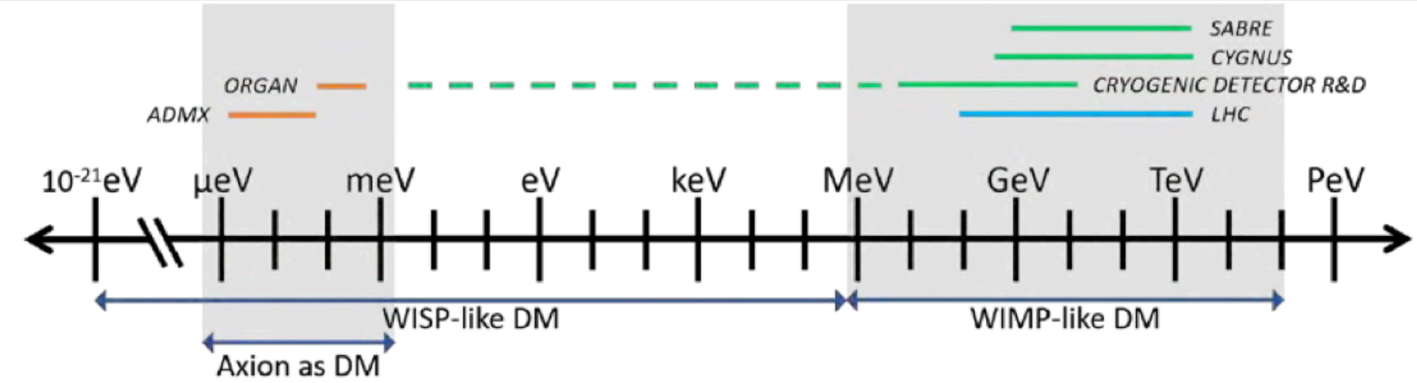

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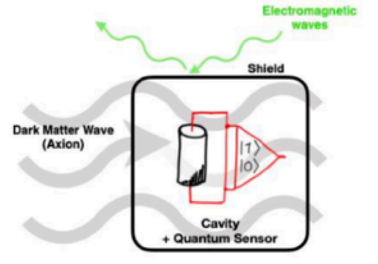

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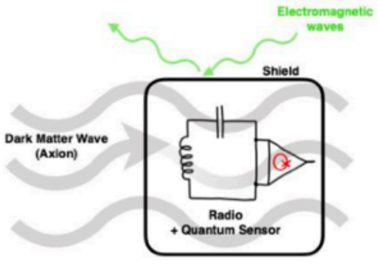

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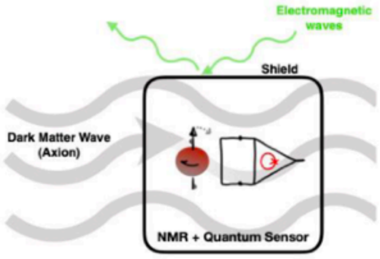

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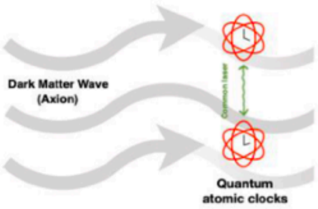

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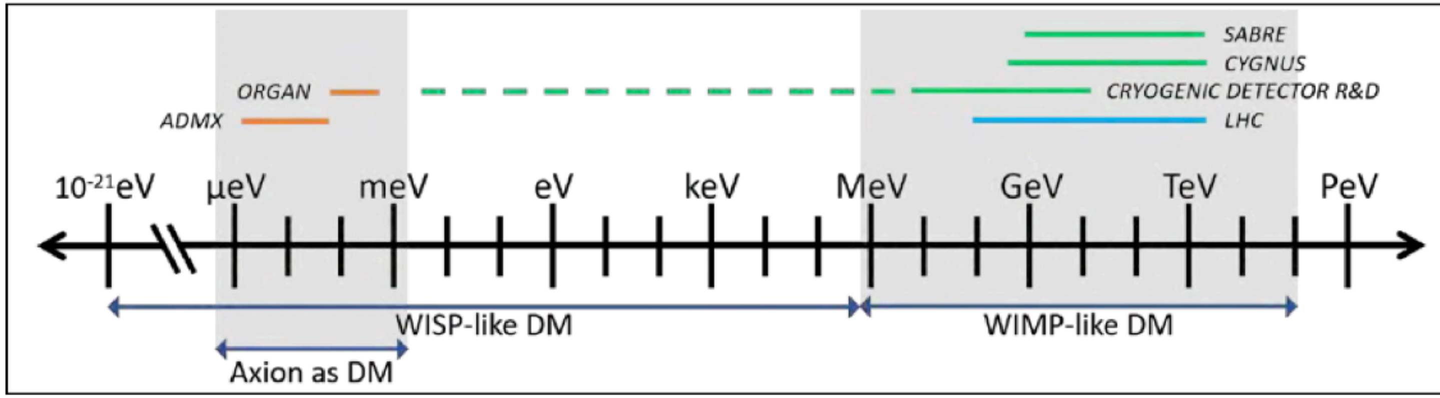

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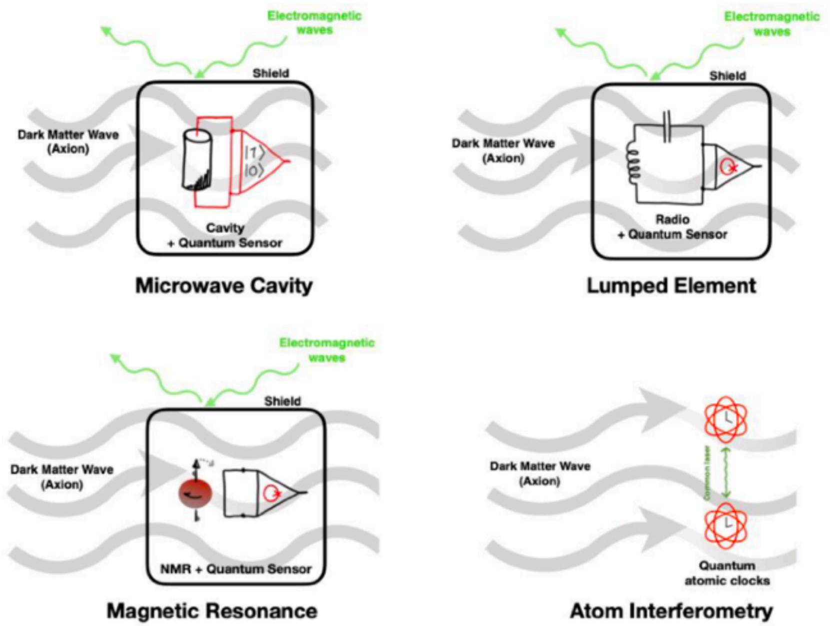

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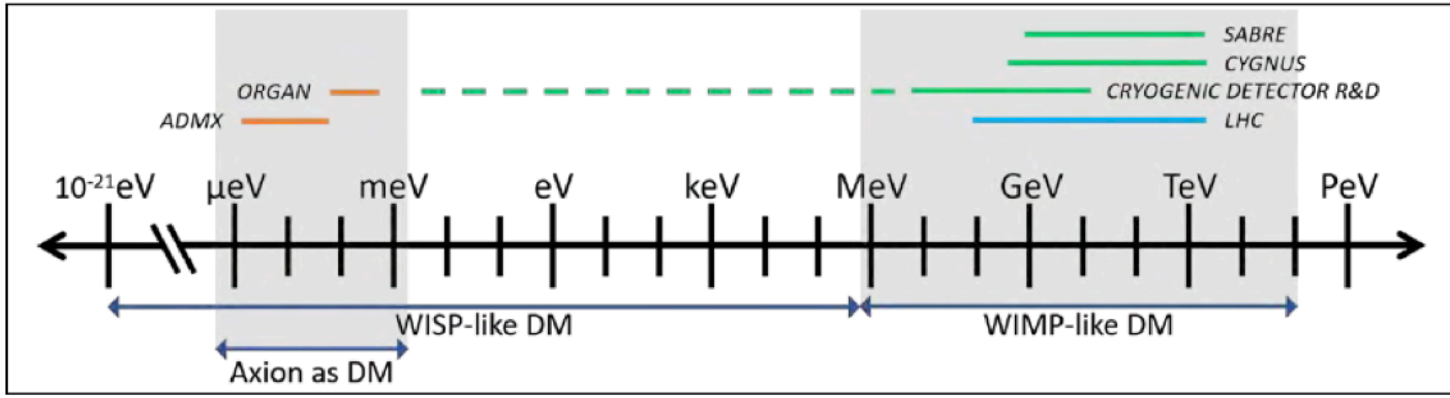

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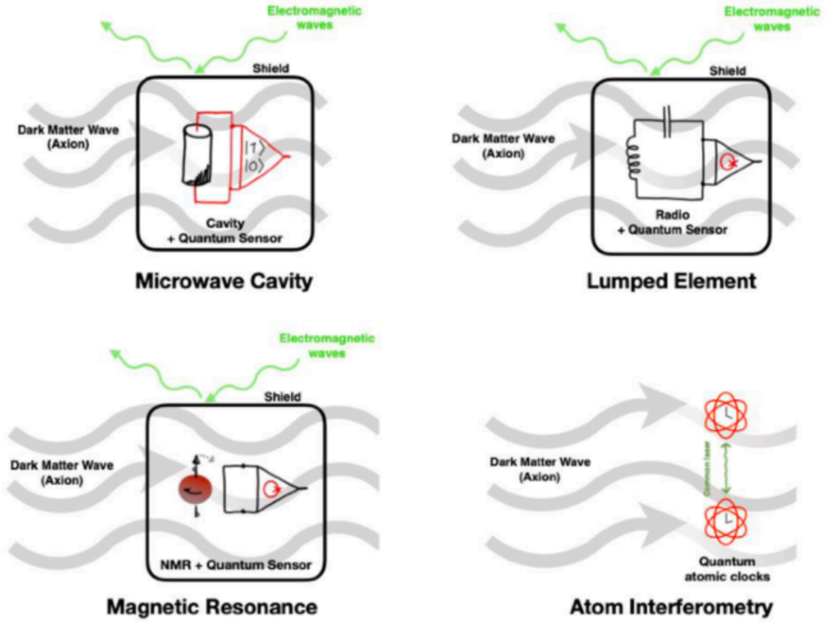

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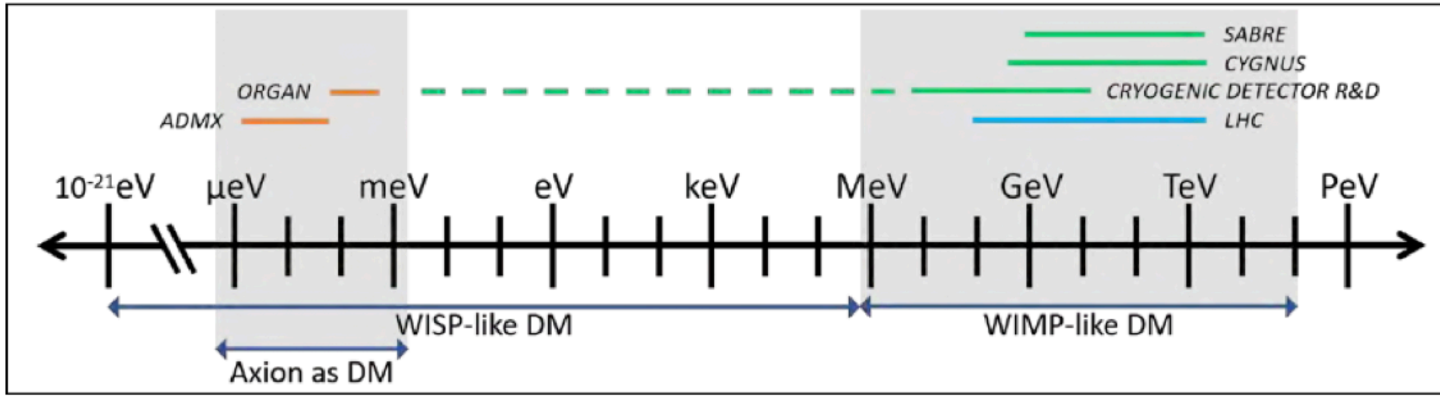

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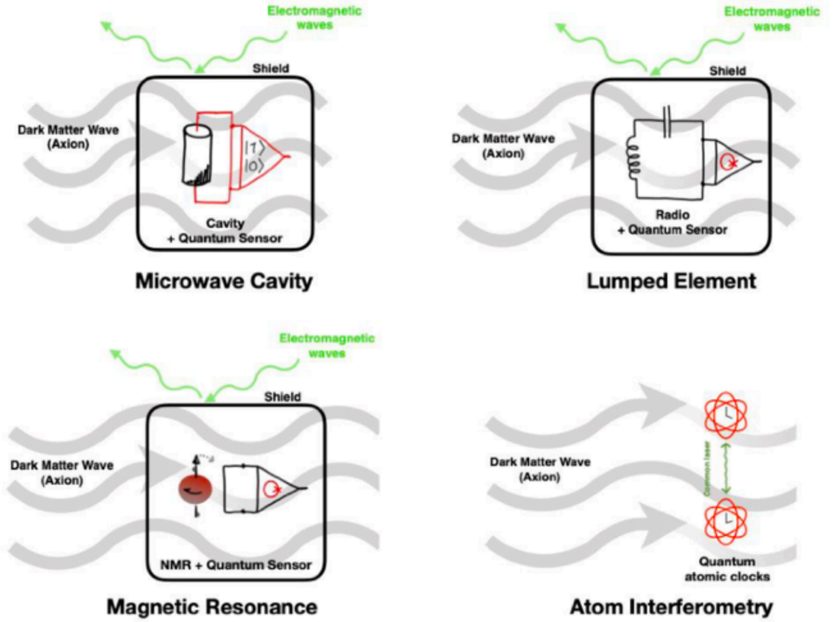

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-> Reduce Noise, Fundamental Limit is Quantum Noise

-> Surpass Quantum Limit: Quantum Metrology

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(6) **Light Scalar Dark Matter** (Dilaton) Clock Comparisons, Acoustic/EM Detectors UWA

PHYSICAL REVIEW APPLIED **14,** 044051 (2020)

(2) ORGAN

Dielectric-Boosted Sensitivity to Cylindrical Azimuthally Varying Transverse-Magnetic Resonant Modes in an Axion Haloscope

Aaron P. Quiskamp,[1,*] Ben T. McAllister,[1] Gray Rybka,[2] and Michael E. Tobar[1,†]
[1] *ARC Centre of Excellence for Engineered Quantum Systems and ARC Centre of Excellence for Dark Matter Particle Physics, Department of Physics, University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia*
[2] *Centre for Experimental Nuclear Physics and Astrophysics, University of Washington, 1410 NE Campus Parkway, Seattle, Washington 98195, USA*

(Received 15 June 2020; revised 6 August 2020; accepted 28 September 2020; published 27 October 2020)

Axions are a popular dark-matter candidate that are often searched for in experiments known as "haloscopes," which exploit a putative axion-photon coupling. These experiments typically rely on transverse-magnetic (TM) modes in resonant cavities to capture and detect photons generated via axion conversion. We present a study of a resonant-cavity design for application in haloscope searches, of particular use in the push to higher-mass axion searches (above approximately 60 μeV). In particular, we take advantage of azimuthally varying TM_{m10} modes that, while typically insensitive to axions due to field nonuniformity, can be made axion sensitive (and frequency tunable) through the strategic placement of dielectric wedges, becoming a type of resonator known as a dielectric-boosted axion-sensitivity (DBAS) resonator. Results from finite-element modeling are presented and compared with a simple proof-of-concept experiment. The results show a significant increase in axion sensitivity for these DBAS resonators over their empty-cavity counterparts and high potential for application in high-mass axion searches when benchmarked against simpler more traditional designs that rely on fundamental TM modes.

DOI: 10.1103/PhysRevApplied.14.044051

(3) UPLOAD

PHYSICAL REVIEW LETTERS **126,** 081803 (2021)

Upconversion Loop Oscillator Axion Detection Experiment: A Precision Frequency Interferometric Axion Dark Matter Search with a Cylindrical Microwave Cavity

Catriona A. Thomson,* Ben T. McAllister, Maxim Goryachev, Eugene N. Ivanov, and Michael E. Tobar†
ARC Centre of Excellence for Engineered Quantum Systems and ARC Centre of Excellence for Dark Matter Particle Physics, Department of Physics, University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia

(Received 5 January 2020; revised 11 November 2020; accepted 15 January 2021; published 23 February 2021)

First experimental results from a room-temperature tabletop phase-sensitive axion haloscope experiment are presented. The technique exploits the axion-photon coupling between two photonic resonator oscillators excited in a single cavity, allowing low-mass axions to be upconverted to microwave frequencies, acting as a source of frequency modulation on the microwave carriers. This new pathway to axion detection has certain advantages over the traditional haloscope method, particularly in targeting axions below 1 μeV (240 MHz) in energy. At the heart of the dual-mode oscillator, a tunable cylindrical microwave cavity supports a pair of orthogonally polarized modes ($\mathrm{TM}_{0,2,0}$ and $\mathrm{TE}_{0,1,1}$), which, in general, enables simultaneous sensitivity to axions with masses corresponding to the sum and difference of the microwave frequencies. However, in the reported experiment, the configuration was such that the sum frequency sensitivity was suppressed, while the difference frequency sensitivity was enhanced. The results place axion exclusion limits between 7.44–19.38 neV, excluding a minimal coupling strength above 5×10^{-7} 1/GeV, after a measurement period of two and a half hours. We show that a state-of-the-art frequency-stabilized cryogenic implementation of this technique, ambitious but realizable, may achieve the best limits in a vast range of axion space.

DOI: 10.1103/PhysRevLett.126.081803

(4) LCR Circuits

Physics of the Dark Universe 30 (2020) 100624

Contents lists available at ScienceDirect

Physics of the Dark Universe

journal homepage: www.elsevier.com/locate/dark

ELSEVIER

Broadband electrical action sensing techniques with conducting wires for low-mass dark matter axion detection

Michael E. Tobar *, Ben T. McAllister, Maxim Goryachev
ARC Centre of Excellence For Engineered Quantum Systems, Department of Physics, University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia

(6) SCALAR DARK MATTER

PHYSICAL REVIEW LETTERS **126,** 071301 (2021)

Searching for Scalar Dark Matter via Coupling to Fundamental Constants with Photonic, Atomic, and Mechanical Oscillators

William M. Campbell, Ben T. McAllister, Maxim Goryachev, Eugene N. Ivanov, and Michael E. Tobar*
ARC Centre of Excellence for Engineered Quantum Systems and ARC Centre of Excellence for Dark Matter Particle Physics, Department of Physics, University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia

(Received 16 October 2020; revised 25 November 2020; accepted 15 January 2021; published 18 February 2021)

We present a way to search for light scalar dark matter (DM), seeking to exploit putative coupling between dark matter scalar fields and fundamental constants, by searching for frequency modulations in direct comparisons between frequency stable oscillators. Specifically we compare a cryogenic sapphire oscillator (CSO), hydrogen maser (HM) atomic oscillator, and a bulk acoustic wave quartz oscillator (OCXO). This work includes the first calculation of the dependence of acoustic oscillators on variations of the fundamental constants, and demonstration that they can be a sensitive tool for scalar DM experiments. Results are presented based on 16 days of data in comparisons between the HM and OCXO, and 2 days of comparison between the OCXO and CSO. No evidence of oscillating fundamental constants consistent with a coupling to scalar dark matter is found, and instead limits on the strength of these couplings as a function of the dark matter mass are determined. We constrain the dimensionless coupling constant d_e and combination $|d_{m_e} - d_g|$ across the mass band $4.4 \times 10^{-19} \lesssim m_\varphi \lesssim 6.8 \times 10^{-14}$ eV c^{-2}, with most sensitive limits $d_e \gtrsim 1.59 \times 10^{-1}$, $|d_{m_e} - dg| \gtrsim 6.97 \times 10^{-1}$. Notably, these limits do not rely on maximum reach analysis (MRA), instead employing the more general coefficient separation technique. This experiment paves the way for future, highly sensitive experiments based on state-of-the-art acoustic oscillators, and we show that these limits can be competitive with the best current MRA-based exclusion limits.

DOI: 10.1103/PhysRevLett.126.071301

What is an Axion and Why Should it Exist?

Is Dark matter the Axion [ak-see-on]

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1. a hypothetical particle having no charge, zero spin, and small mass: postulated in some forms of quantum chromodynamics.

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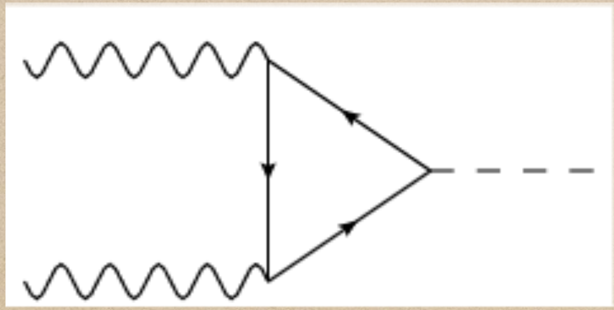

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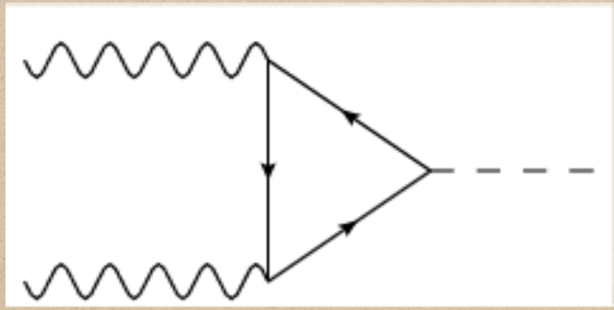

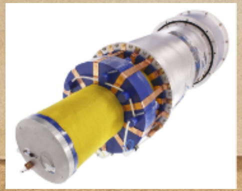

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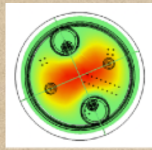
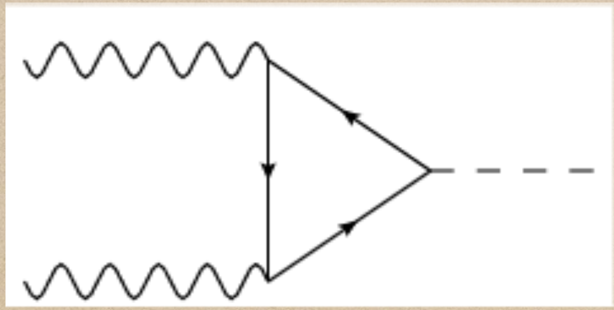
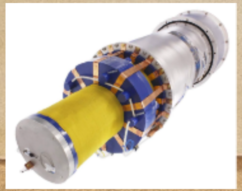


Measure





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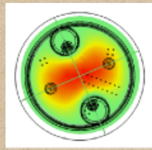
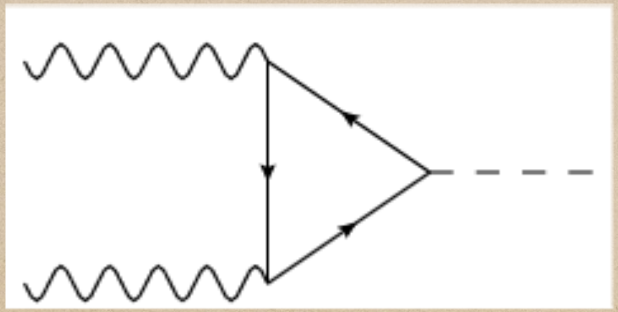
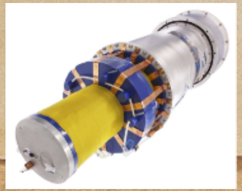


Measure





$$c^2 Mass_{axion} = hf_{photon}$$

Axion is predicted to be produced in the early Universe

PHYSICAL REVIEW LETTERS **124**, 251802 (2020)

Axion Kinetic Misalignment Mechanism

Raymond T. Co,[1] Lawrence J. Hall,[2,3] and Keisuke Harigaya[4]

[1]*Leinweber Center for Theoretical Physics, University of Michigan, Ann Arbor, Michigan 48109, USA*
[2]*Department of Physics, University of California, Berkeley, California 94720, USA*
[3]*Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
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(Received 22 November 2019; revised manuscript received 6 April 2020; accepted 8 June 2020; published 26 June 2020)

In the conventional misalignment mechanism, the axion field has a constant initial field value in the early Universe and later begins to oscillate. We present an alternative scenario where the axion field has nonzero initial velocity, allowing an axion decay constant much below the conventional prediction from axion dark matter. This axion velocity can be generated from explicit breaking of the axion shift symmetry in the early Universe, which may occur as this symmetry is approximate.

High Energy Physics – Phenomenology

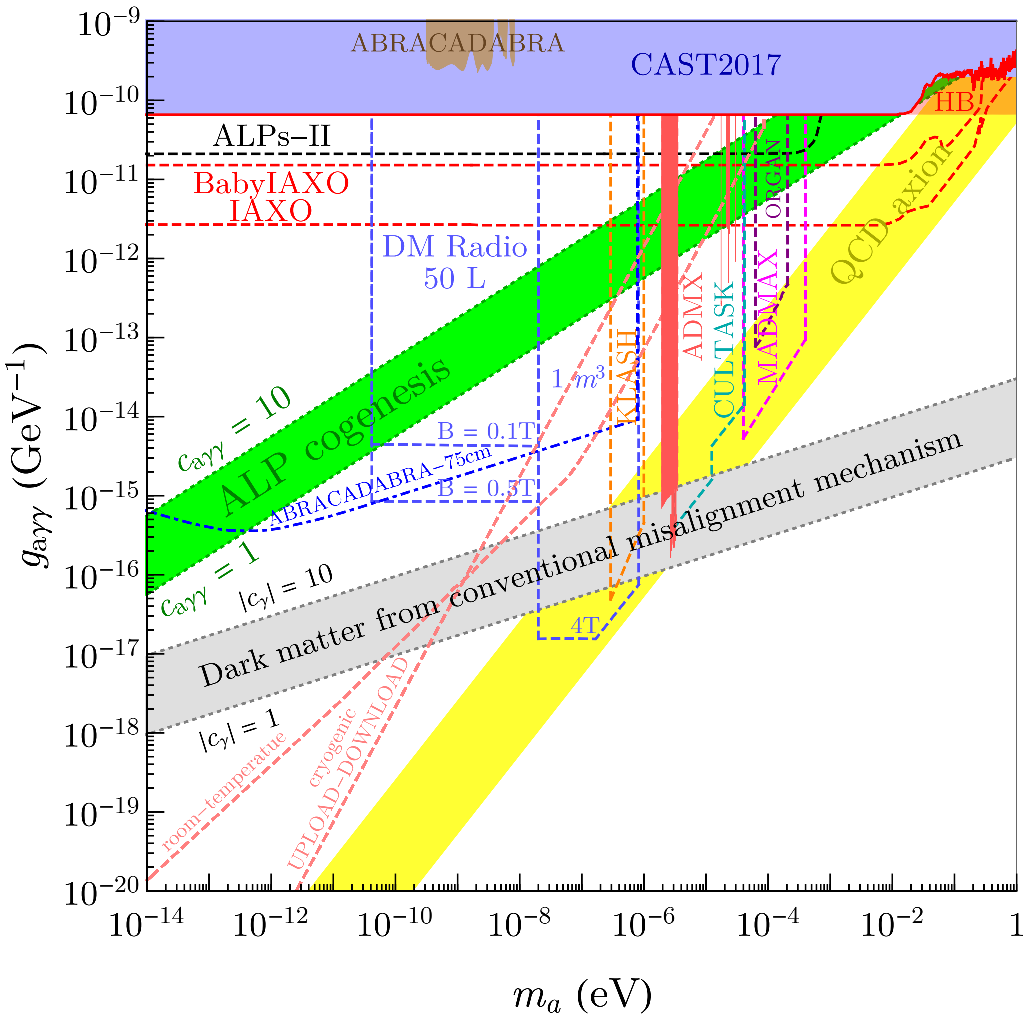
[Submitted on 8 Jun 2020]

Predictions for Axion Couplings from ALP Cogenesis

Raymond T. Co, Lawrence J. Hall, Keisuke Harigaya

Adding an axion-like particle (ALP) to the Standard Model, with a field velocity in the early universe, simultaneously explains the observed baryon and dark matter densities. This requires one or more couplings between the ALP and photons, nucleons, and/or electrons that are predicted as functions of the ALP mass. These predictions arise because the ratio of dark matter to baryon densities is independent of the ALP field velocity, allowing a correlation between the ALP mass, m_a, and decay constant, f_a. The predicted couplings are orders of magnitude larger than those for the QCD axion and for dark matter from the conventional ALP misalignment mechanism. As a result, this scheme, ALP cogenesis, is within reach of future experimental ALP searches from the lab and stellar objects, and for dark matter.

Comments: 24 pages, 3 figures
Subjects: **High Energy Physics – Phenomenology (hep-ph)**; Cosmology and Nongalactic Astrophysics (astro-ph.CO); High Energy Physics – Experiment (hep-ex)
Report number: LCTP-20-11
Cite as: arXiv:2006.04809 **[hep-ph]**
(or arXiv:2006.04809v1 **[hep-ph]** for this version)



Electromagnetic Couplings of Axions

Anton V. Sokolov, Andreas Ringwald

Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany

E-mail: anton.sokolov@desy.de, andreas.ringwald@desy.de

For axion DM detection, leaving only the dominant terms on the right-hand side, we obtain:

$$\nabla\times\mathbf{B}_a - \dot{\mathbf{E}}_a = 0\,,$$
$$\nabla\times\mathbf{E}_a + \dot{\mathbf{B}}_a = -g_{a\mathrm{BB}}\left(\mathbf{B}_0\times\nabla a + \dot{a}\mathbf{E}_0\right) + g_{a\mathrm{AB}}\dot{a}\mathbf{B}_0\,, \qquad \xrightarrow{m_a L \ll 1} \qquad E_a \gg B_a$$
$$\nabla\cdot\mathbf{B}_a = 0\,,$$
$$\nabla\cdot\mathbf{E}_a = 0\,,$$

m_a - axion mass
L - detector size

This is to be contrasted with the conventional axion Maxwell equations used for axion DM detection:

$$\nabla\times\mathbf{B}_a - \dot{\mathbf{E}}_a = -g_{a\mathrm{AA}}\dot{a}\mathbf{B}_0,$$
$$\nabla\times\mathbf{E}_a + \dot{\mathbf{B}}_a = 0\,, \qquad \xrightarrow{m_a L \ll 1} \qquad B_a \gg E_a$$
$$\nabla\cdot\mathbf{B}_a = 0\,,$$
$$\nabla\cdot\mathbf{E}_a = 0\,,$$

QUANTUM ELECTROMAGNETODYNAMICS

1971 ZWANZIGER

A_μ and $B_\mu \longleftrightarrow$ photon

$$\mathcal{L} = \mathcal{L}_{\mathrm{kin}}\left(A_\mu, B_\mu, n_\mu\right) - j_e^\nu A_\nu - \boxed{j_m^\nu B_\nu}$$

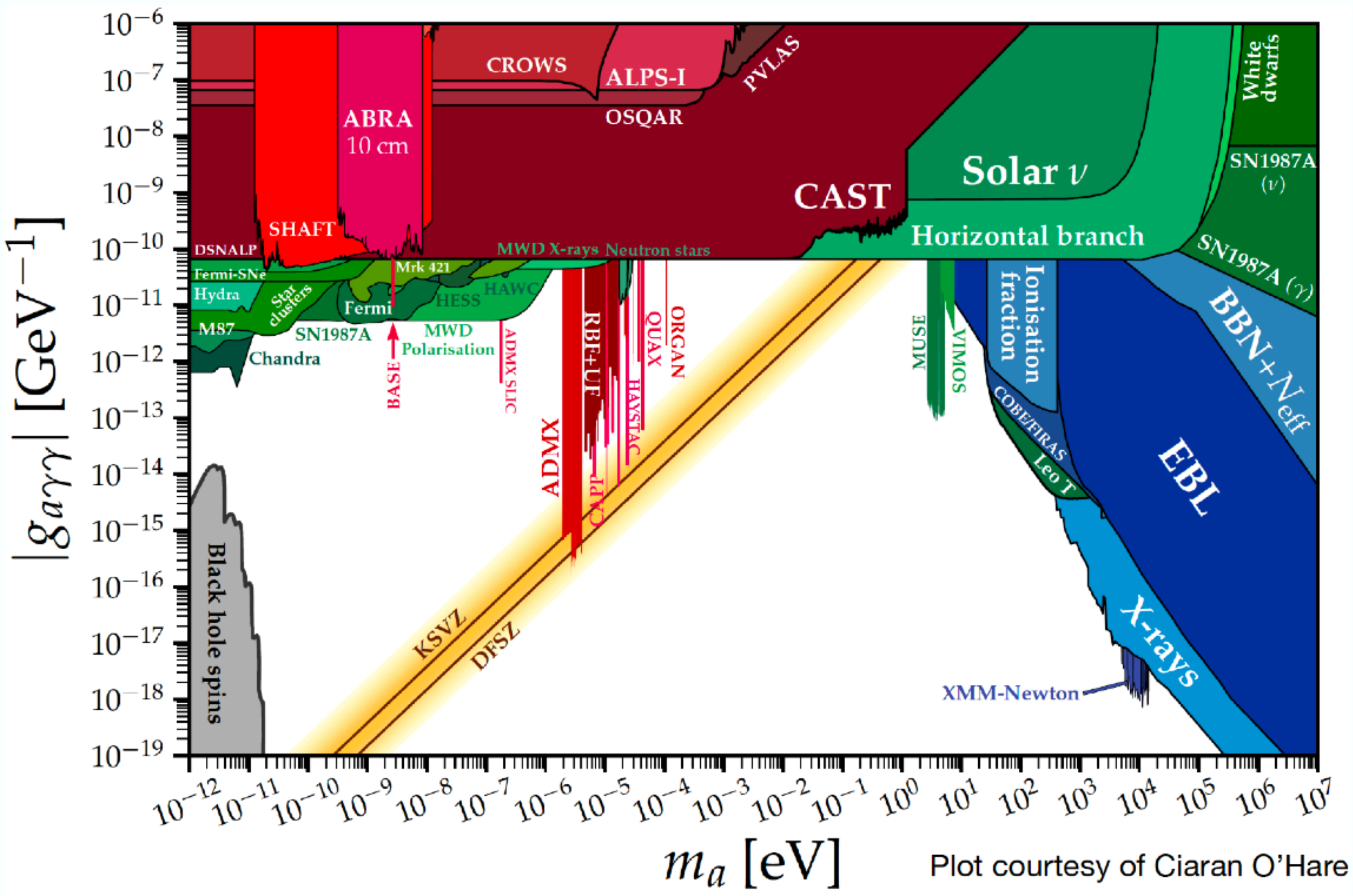
1977 ZBN

$$Z\left(a, b, \cancel{n_\mu}\right) = \int \exp\left\{i\left(\mathcal{S}[\mathbf{A}_\mu, \mathbf{B}_\mu, \mathbf{n}_\mu, \chi, \bar{\chi}] + j_e a + j_m b\right)\right\} \times \mathcal{D}\mathbf{A}_\mu\,\mathcal{D}\mathbf{B}_\mu\,\mathcal{D}\chi\,\mathcal{D}\bar{\chi}$$

- TWO vector-potentials describe ONE particle - photon
- partition function is Lorentz-invariant
- theory is generally not CP-invariant

The QCD Axion

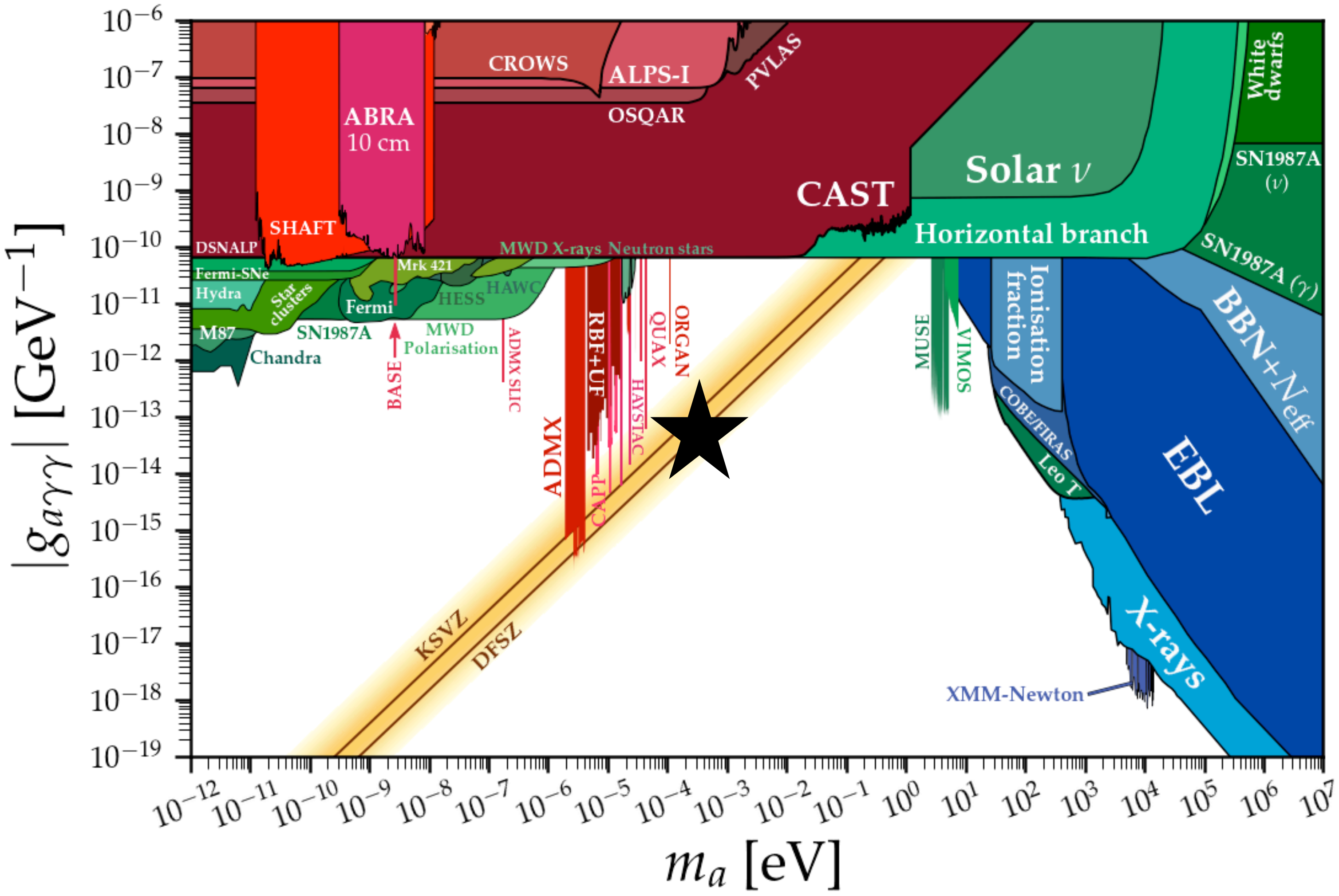
- $U(1)_{PQ}$ introduced to preserve CP symmetry in the Strong Interaction.
- The QCD axion is a psuedo-Nambu-Goldstone boson produced by the breaking of $U(1)_{PQ}$.
- Couples to **photons**, nucleons, electrons.
- Broad Categories of models:
    - **KSVZ** introduces heavy quarks.
    - **DFSZ** introduces additional Higgs fields.*



Plot courtesy of Ciaran O'Hare

Consequence of Discovery:

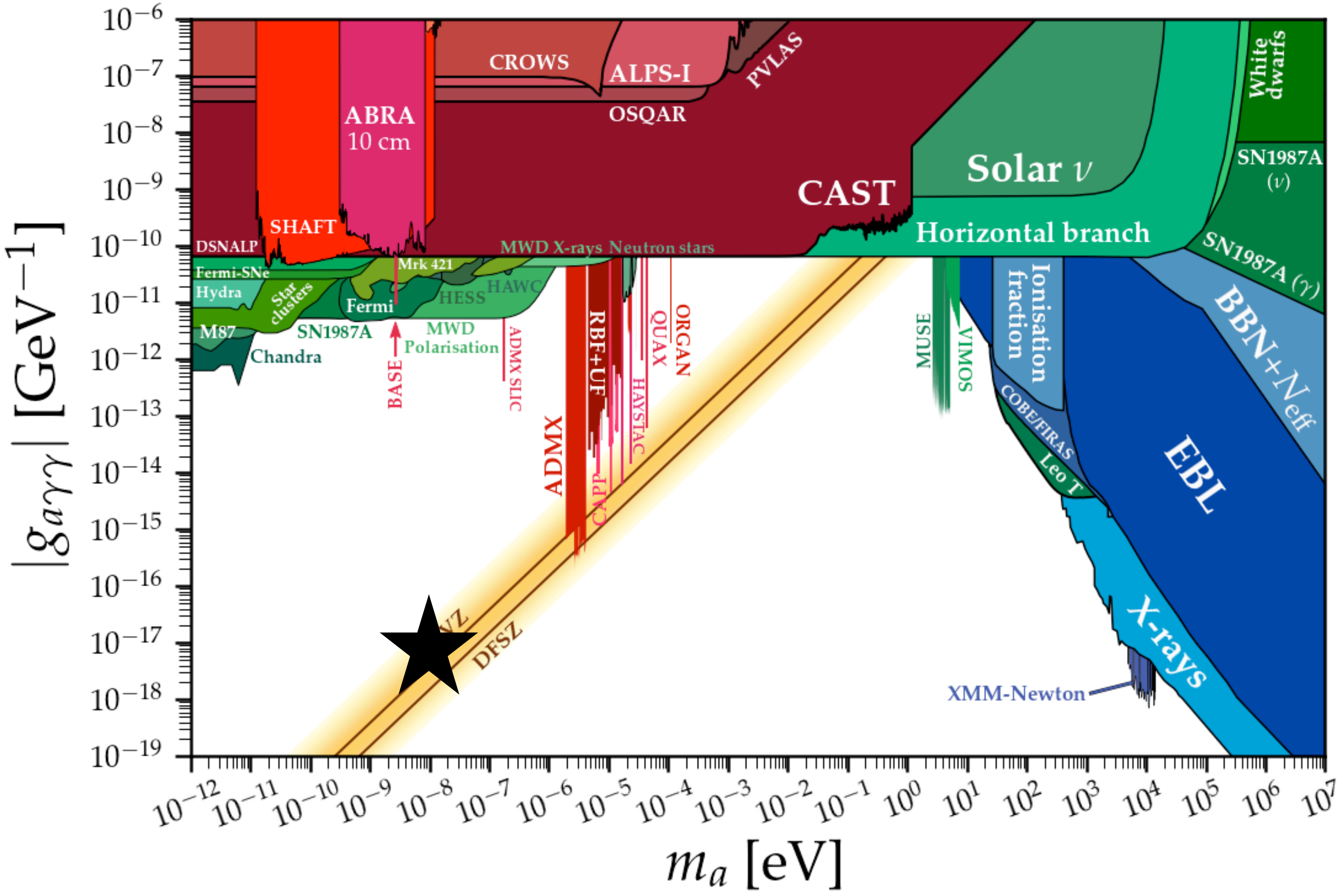
- This is a QCD axion that was created <u>after inflation</u>.
- Expanded Higgs sector or additional quarks.



https://cajohare.github.io/AxionLimits/docs/ap.html

Consequence of Discovery:

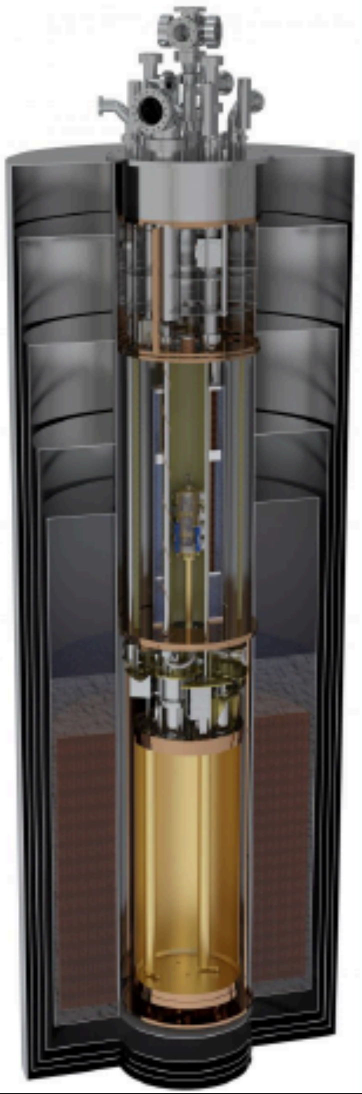
- This is a QCD axion that was created before inflation.
- GUT-scale axion clear proof of new physics at this scale.
- Expanded Higgs sector or additional quarks.
- Connected to CMB signatures.

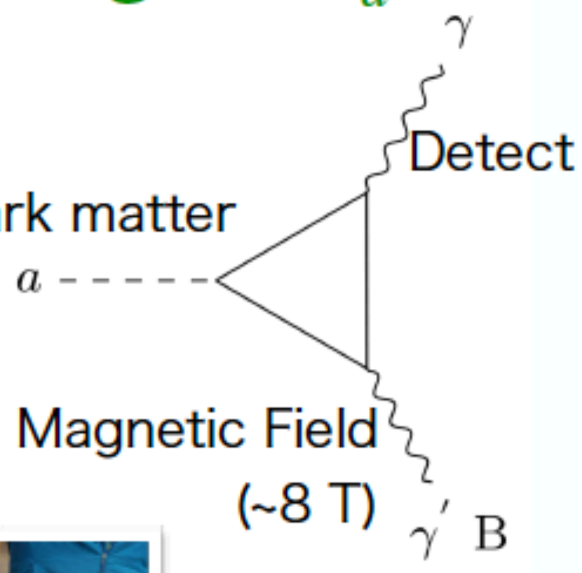


https://cajohare.github.io/AxionLimits/docs/ap.html

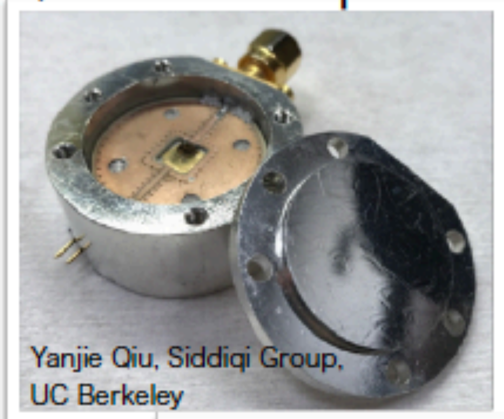
ADMX Collaboration

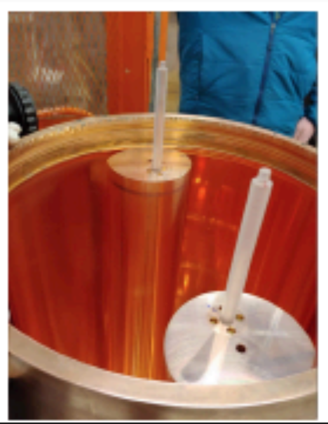
Higher P_a $\oplus$ Low Noise = High SNR





Quantum Amplifier

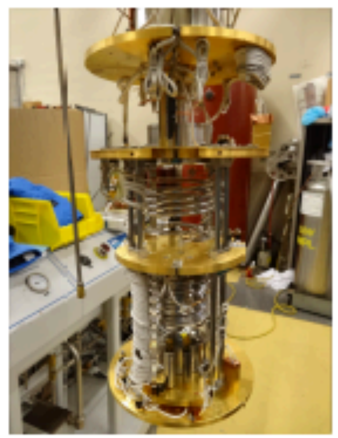




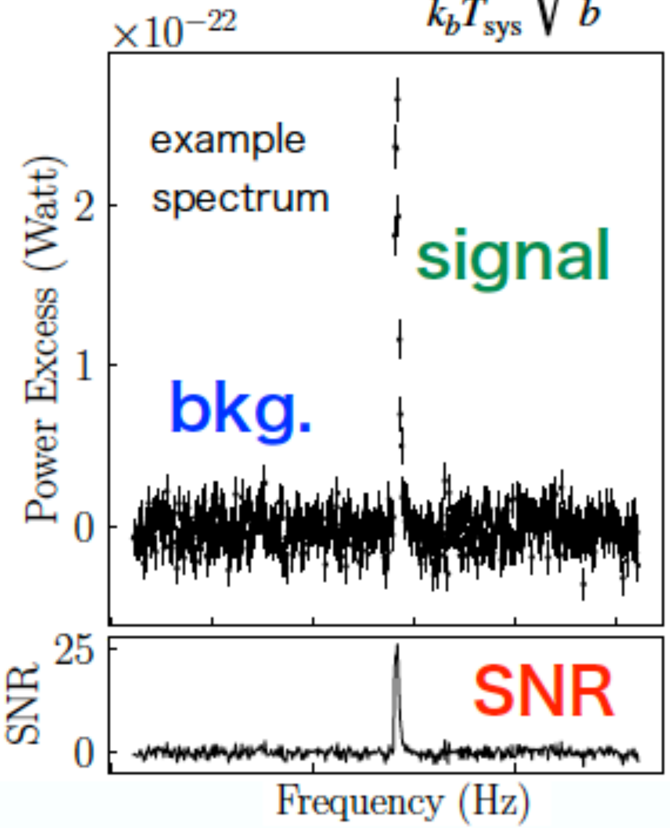
High Q_o (160k)

Large V (136 L)

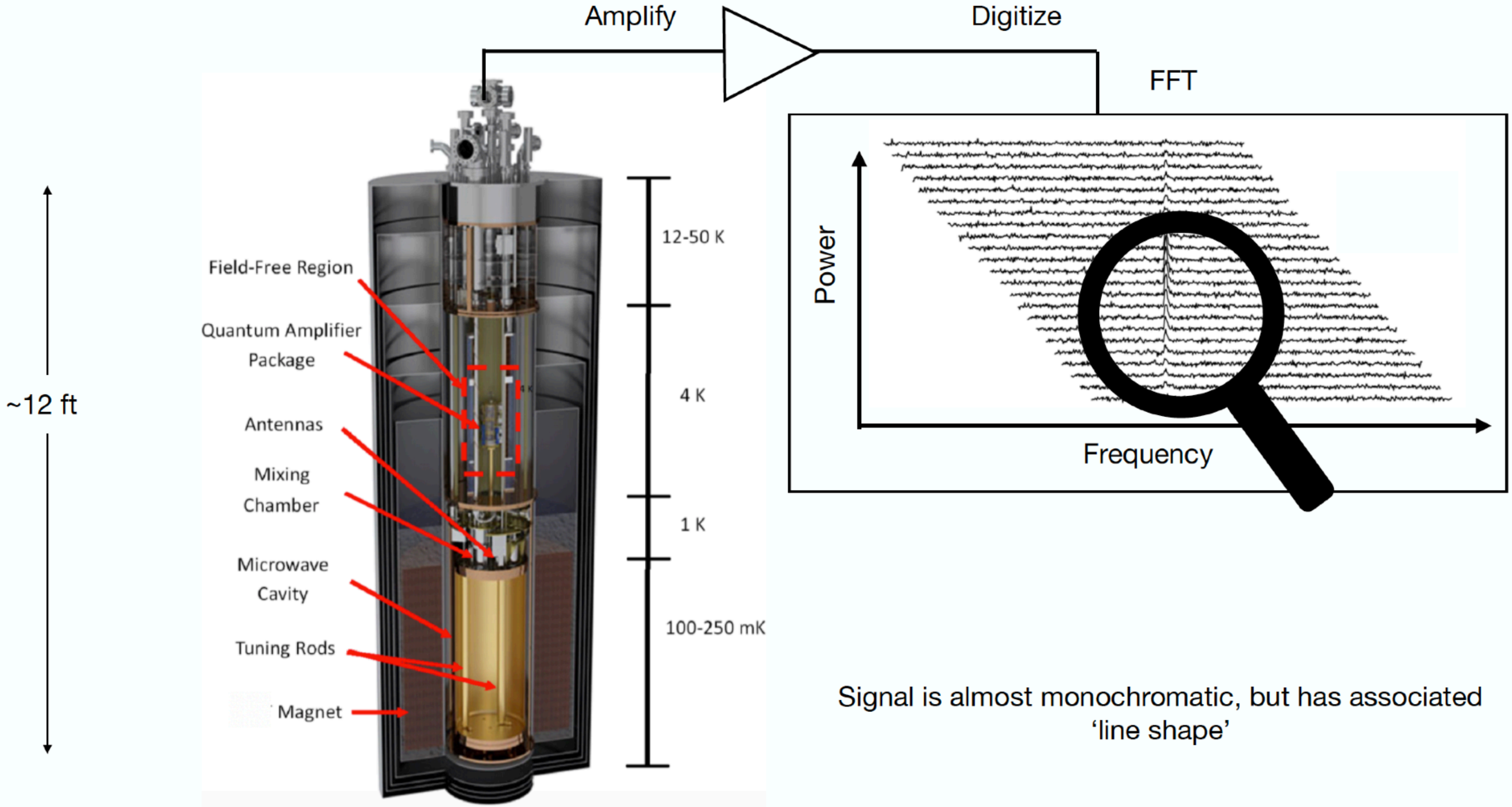
Dill fridge
~100 mK



$$\mathrm{SNR} = \frac{P_{\mathrm{sig}}}{k_b T_{\mathrm{sys}}}\sqrt{\frac{t}{b}}$$



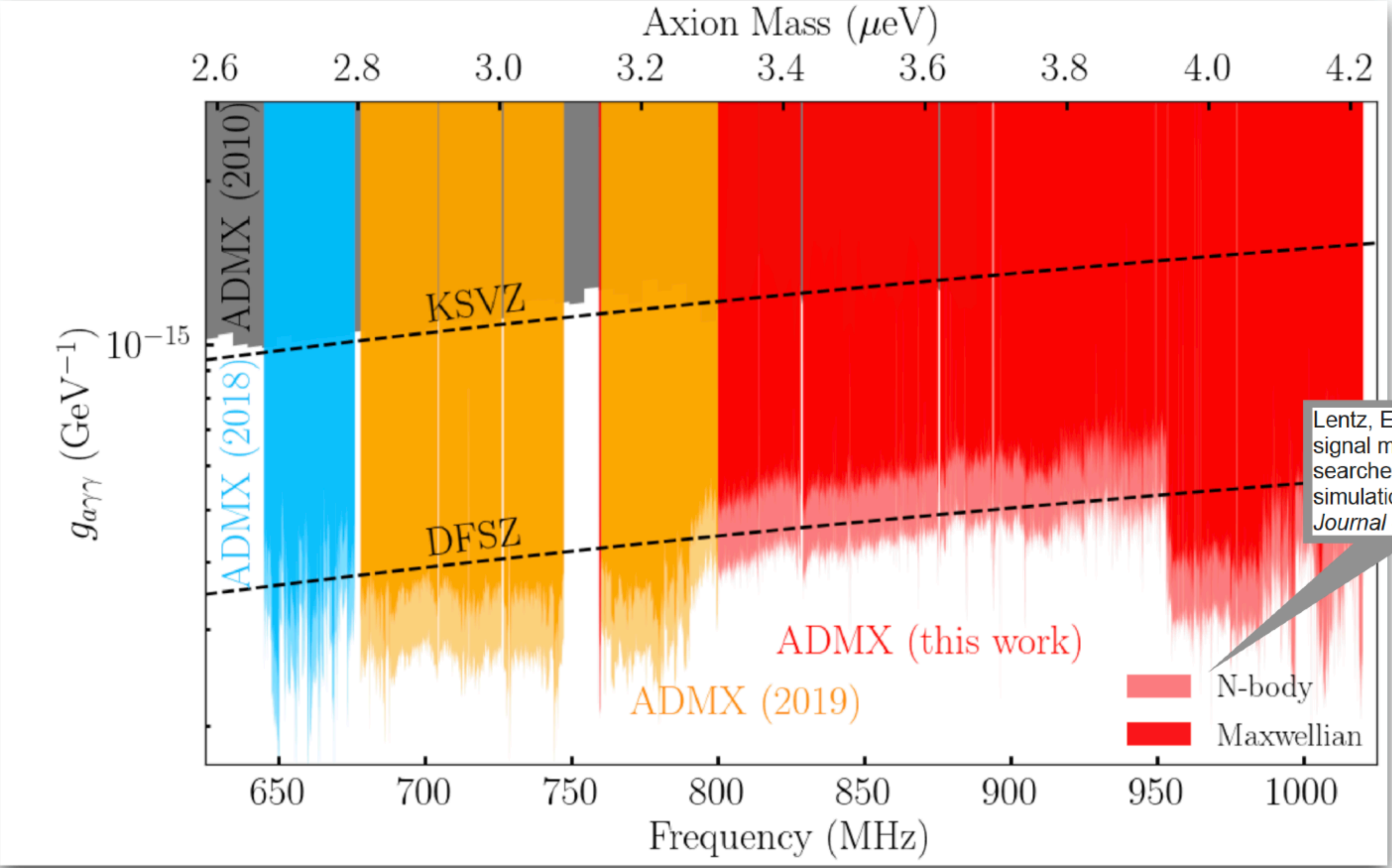
Resonant Haloscope



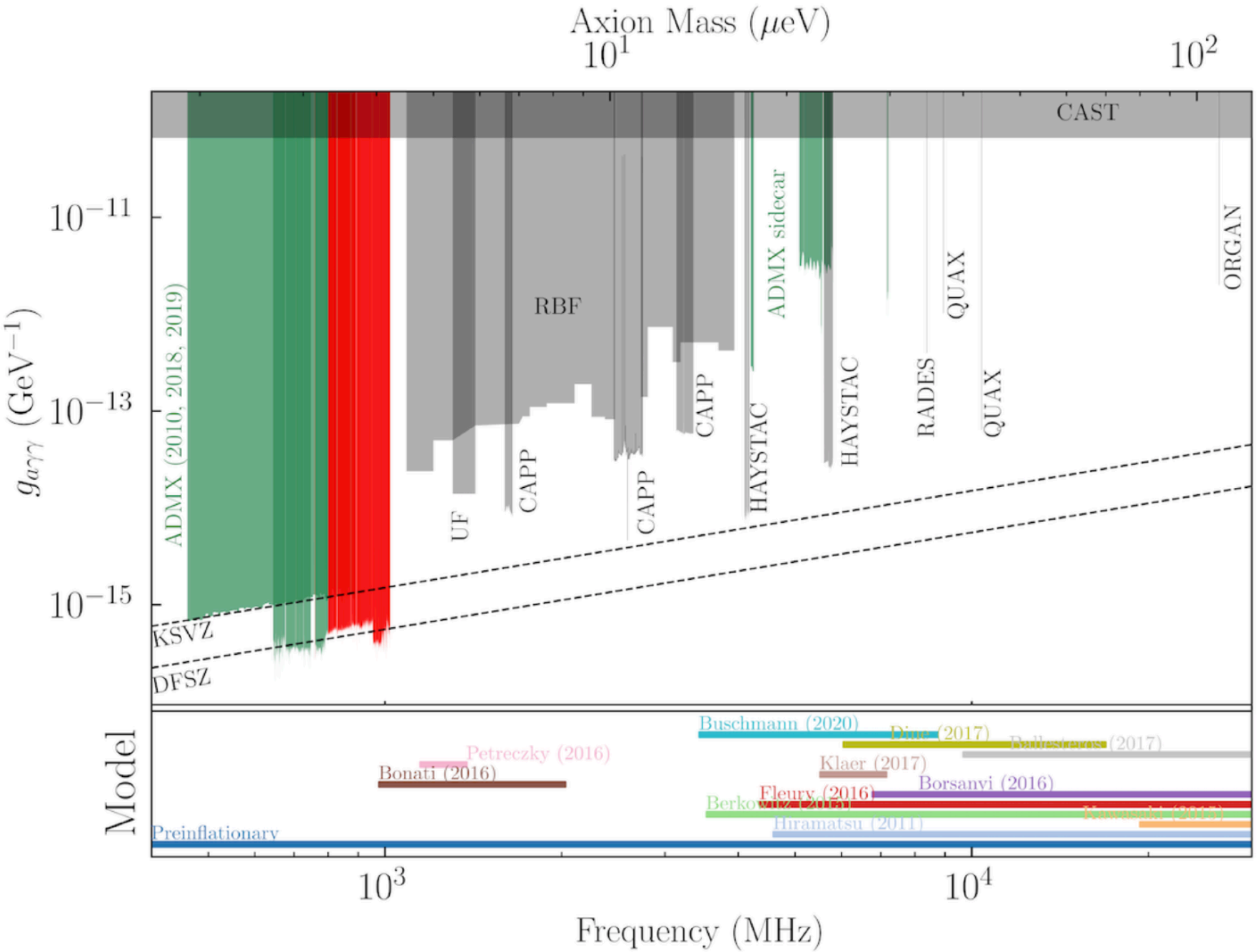
Signal is almost monochromatic, but has associated 'line shape'

ADMX Exclusion 2019-2021

Bartram, C., et al. "Search for Invisible Axion Dark Matter in the 3.3–4.2 μ eV Mass Range." *Physical review letters* 127.26 (2021): 261803.



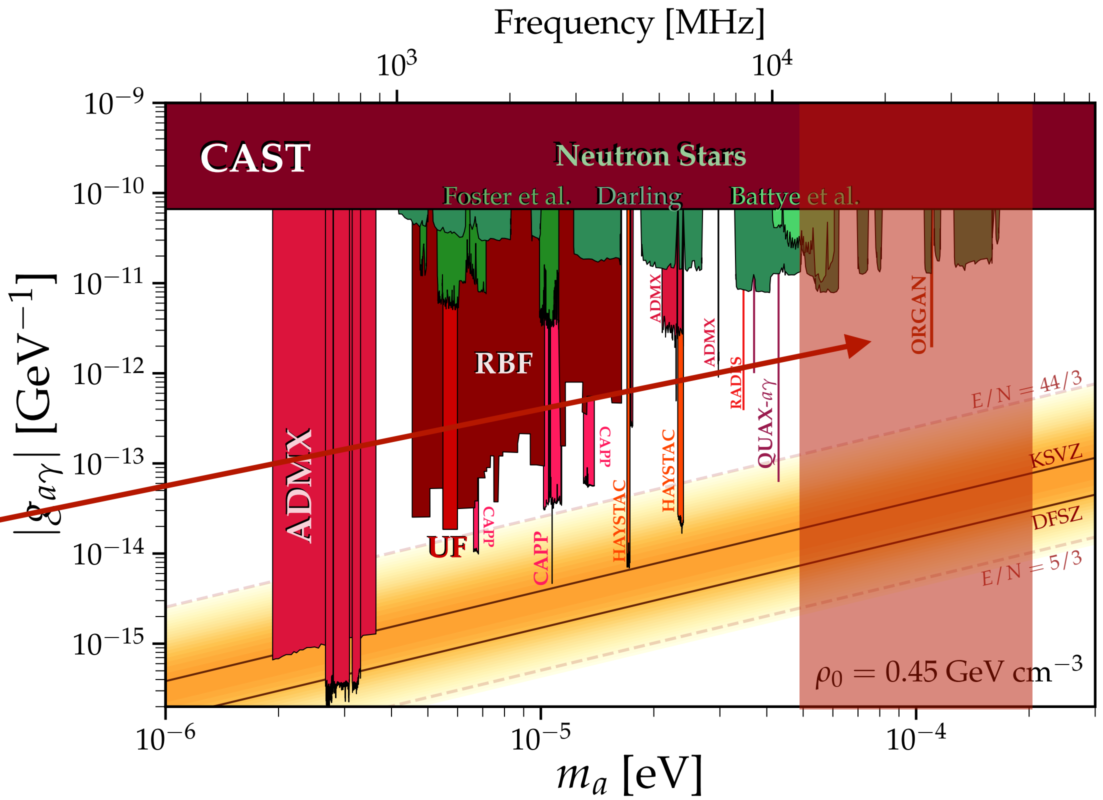
Lentz, Erik W., et al. "A new signal model for axion cavity searches from N-body simulations." *The Astrophysical Journal* 845.2 (2017): 121.

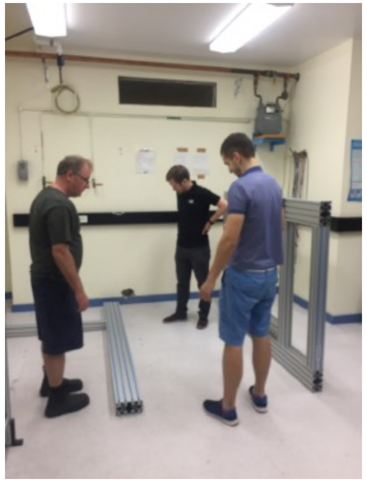


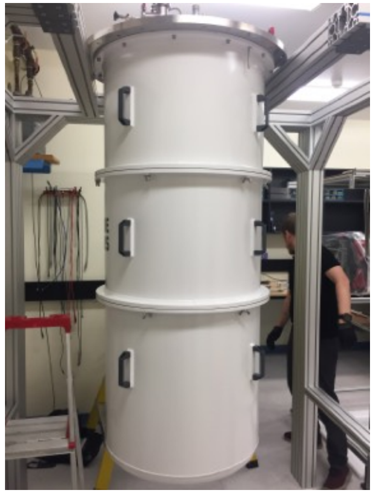
Axion Mass (μeV)
10^1
10^2
CAST
10^{-11}
10^{-13}
10^{-15}
$g_{a\gamma\gamma}$ (GeV^{-1})
ADMX (2010, 2018, 2019)
RBF
UF
CAPP
CAPP
CAPP
HAYSTAC
ADMX sidecar
HAYSTAC
RADES
QUAX
QUAX
ORGAN
KSVZ
DFSZ
Model
Buschmann (2020)
Petreczky (2016)
Klaer (2017)
Bonati (2016)
Borsanyi (2016)
Fleury (2016)
Preinflationary
10^3
10^4
Frequency (MHz)

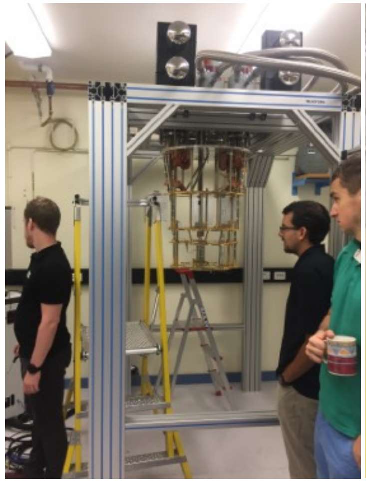
2) **ORGAN**: **O**scillating **R**esonant **G**roup **A**xio**N** Experiment @ UWA

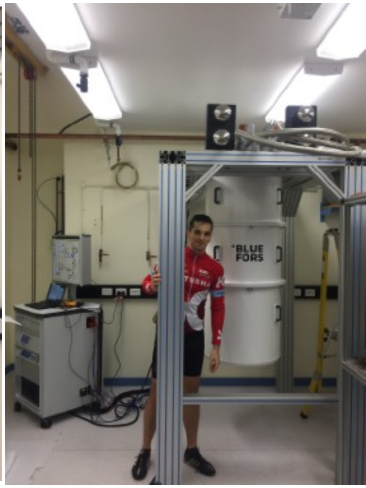
- High frequency wrt Others. (>15 GHz) axion haloscope
- High frequency parameter space is largely un-probed and ripe for exploration
- SMASH model predicts axion mass (m_a) between 50 and 200 μeV









Quiskamp *et al.*, *Sci. Adv.* **8**, eabq3765 (2022) 6 July 2022

SCIENCE ADVANCES | RESEARCH ARTICLE

PHYSICS

Direct search for dark matter axions excluding ALP cogenesis in the 63- to 67-μeV range with the ORGAN experiment

Aaron Quiskamp[1]*, Ben T. McAllister[1,2]*, Paul Altin[3], Eugene N. Ivanov[1], Maxim Goryachev[1], Michael E. Tobar[1]*

The standard model axion seesaw Higgs portal inflation (SMASH) model is a well-motivated, self-contained description of particle physics that predicts axion dark matter particles to exist within the mass range of 50 to 200 micro–electron volts. Scanning these masses requires an axion haloscope to operate under a constant magnetic field between 12 and 48 gigahertz. The ORGAN (Oscillating Resonant Group AxioN) experiment (in Perth, Australia) is a microwave cavity axion haloscope that aims to search the majority of the mass range predicted by the SMASH model. Our initial phase 1a scan sets an upper limit on the coupling of axions to two photons of $|g_{a\gamma\gamma}| \leq 3 \times 10^{-12}$ per giga–electron volts over the mass range of 63.2 to 67.1 micro–electron volts with 95% confidence interval. This highly sensitive result is sufficient to exclude the well-motivated axion-like particle cogenesis model for dark matter in the searched region.

Limits

- The most sensitive limits in this region: Predicted signals from Lattice QCD and SMASH

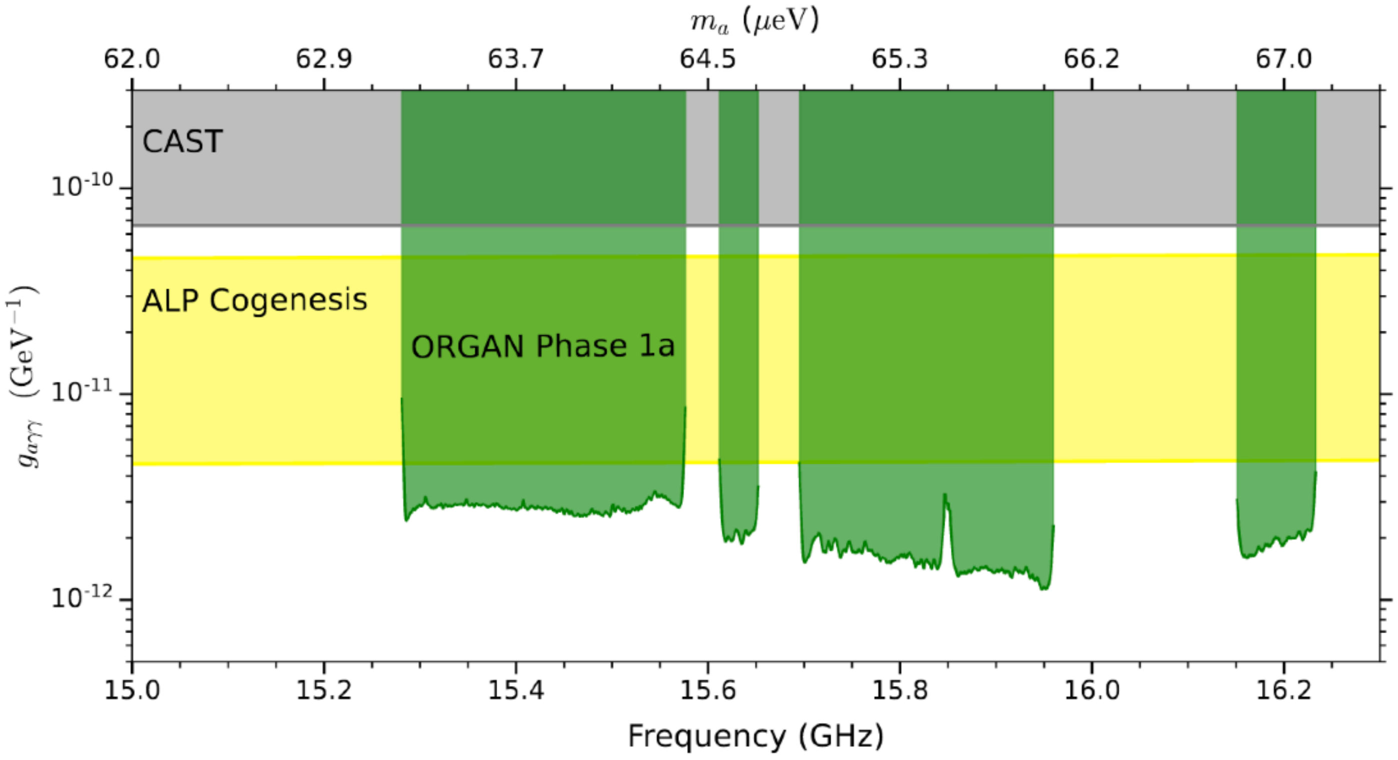


FIG. 4. Our 95% confidence exclusion limits on the axion mass-coupling parameter space are shown in green, surpassing the limits set by CAST (grey) [20] and beyond the ALP-cogenesis model band (yellow) [17–19]. The gaps in the exclusion plot correspond to mode-mixing regions where no axion-sensitive data could be taken. See the supplementary material for a detailed analysis of the fractional uncertainty on these limits, as well as future projections.

ORGAN: Axion Detection

- Critical research areas to improve scan rate and axion model sensitivity:
  - Tuneable sensitive resonators
  - Low noise amplification
  - Data acquisition and analysis

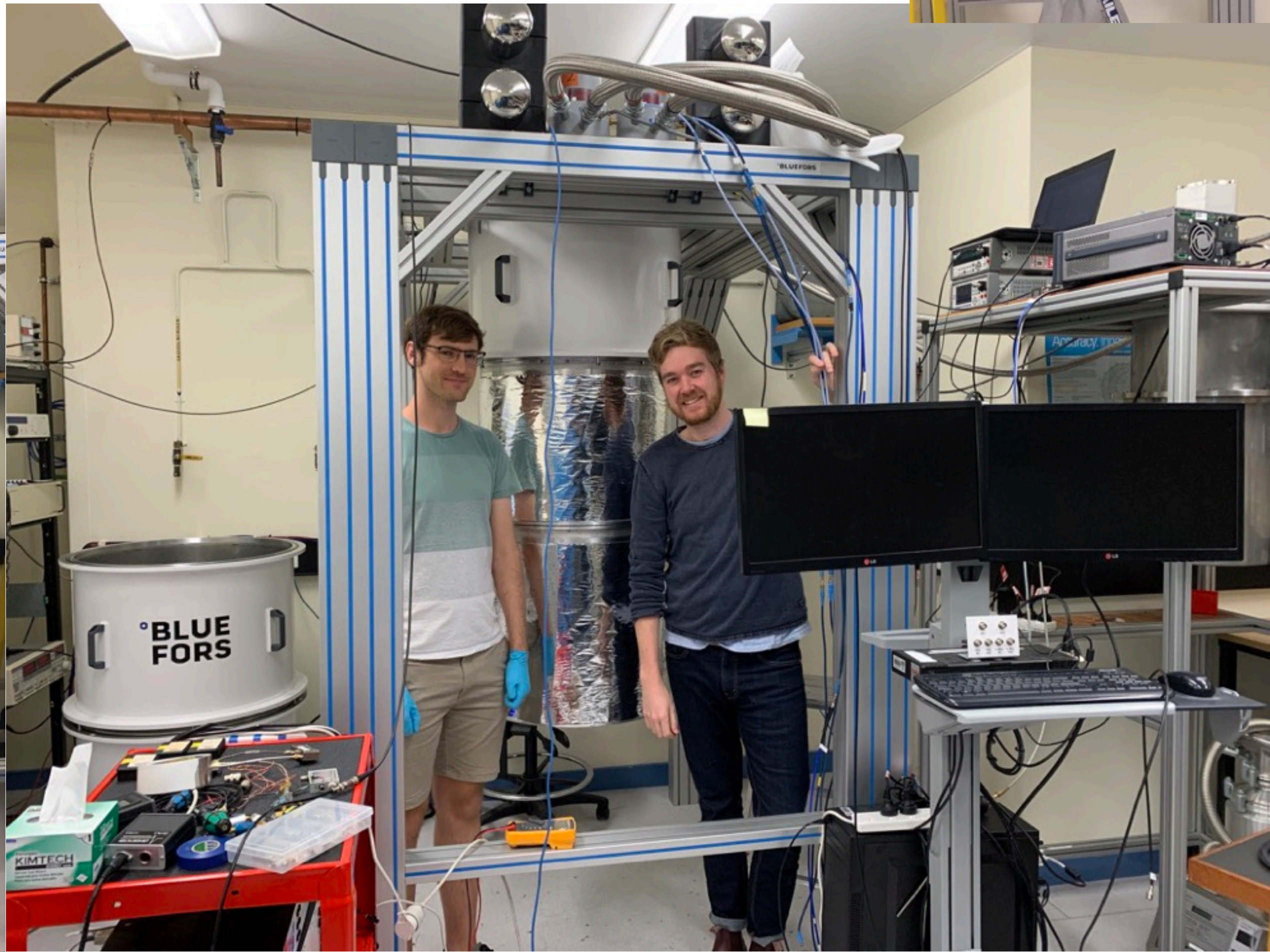
- Haloscope scan rate:

$$\frac{df}{dt} \propto \frac{1}{SNR_{goal}^2} \frac{g_{a\gamma\gamma}^4 \boxed{B^4} \boxed{C^2} \boxed{V^2} \rho_a^2 \boxed{Q_L} Q_a}{m_a^2 (k_B \boxed{T_n})^2}$$

- Three aspects to this:
  - Magnet/dilution fridge: Look to purchasing larger magnet with larger bore
  - Resonator design: Dielectric, with novel tuning
  - Amplifier noise temperature: Single photon counter

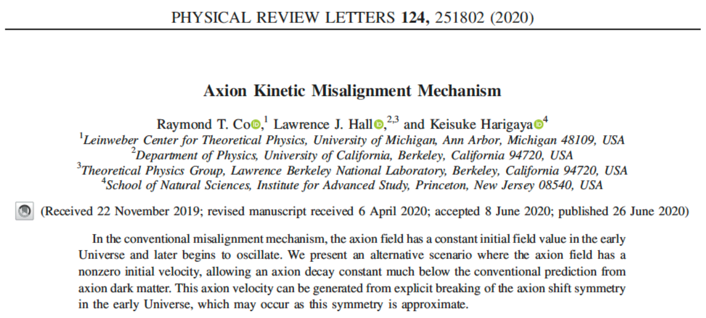
ORGAN Dilution Refrigerator and Magnet

- Dedicated dilution refrigerator (Nov 2019), BF-XLD1000
- Equipped with 12.5 T magnet



ORGAN Run Plan

- Phase 1: Narrow searches around 15-16 GHz and 26-27 GHz
- Runs 1a/1b (dark green): HEMT-based amplifiers and TM_{010} tuning rod resonators, form factor of 0.4.
- Phase 2: Wider searches (15-50GHz) building on expertise gained in Phase 1
- Phase 2, dark red: Quantum limited linear amplifiers (2-4 cavities)
- Light red/green: Single photon counter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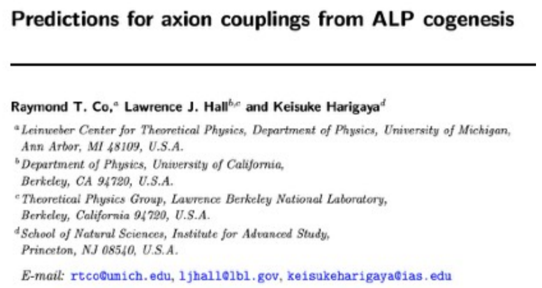
Predictions for axion couplings from ALP cogenesis

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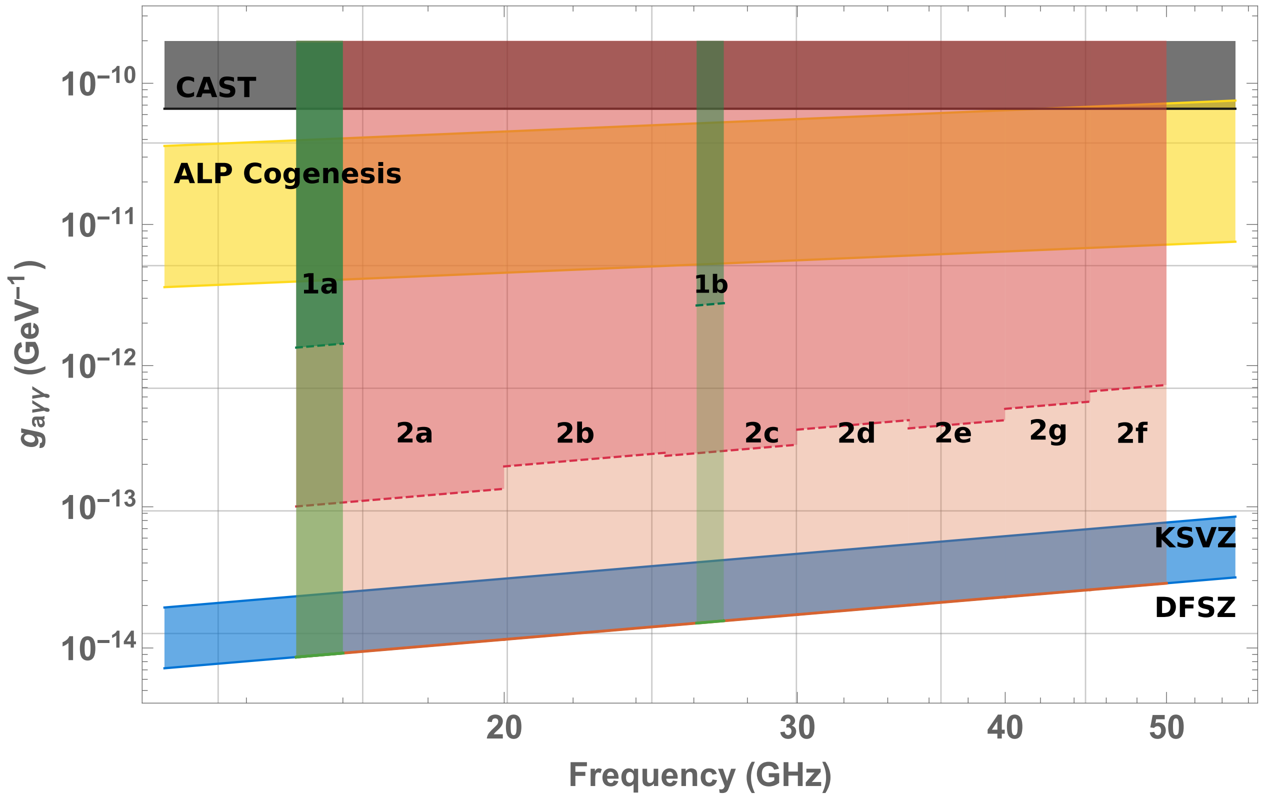
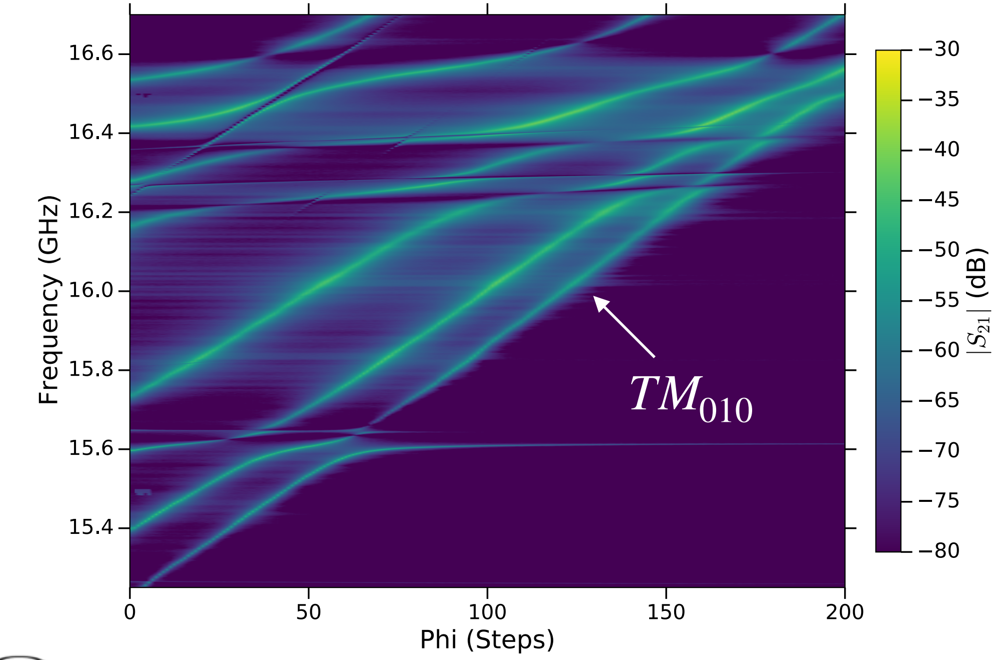
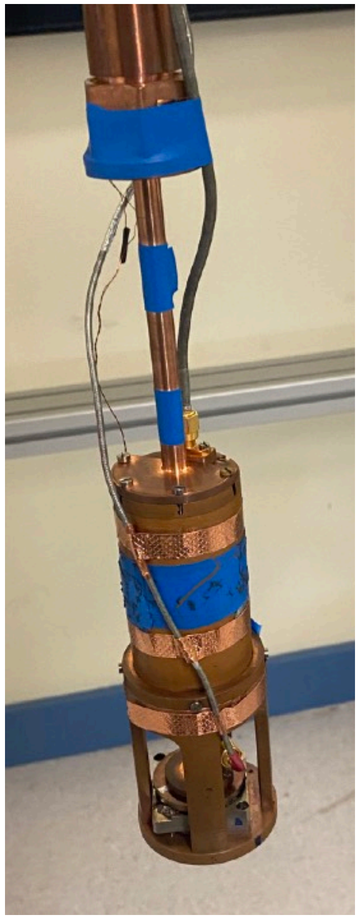
[d]*School of Natural Sciences, Institute for Advanced Study, Princeton, NJ 08540, U.S.A.*
E-mail: rtco@umich.edu, ljhall@lbl.gov, keisukeharigaya@ias.edu

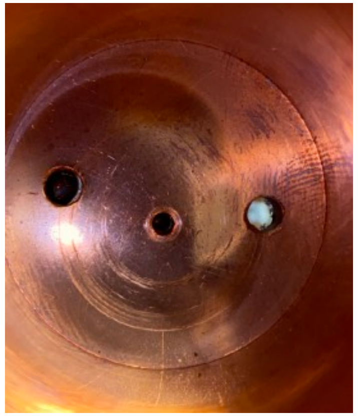


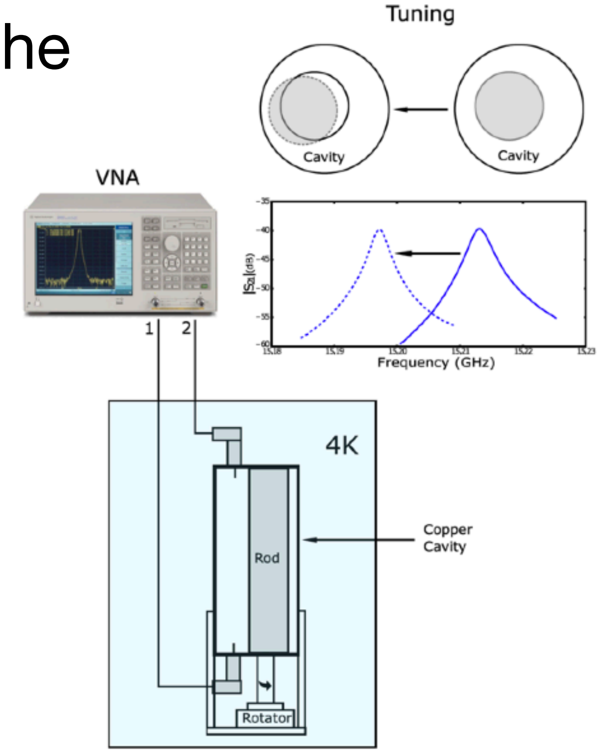
Cavity Characterisation

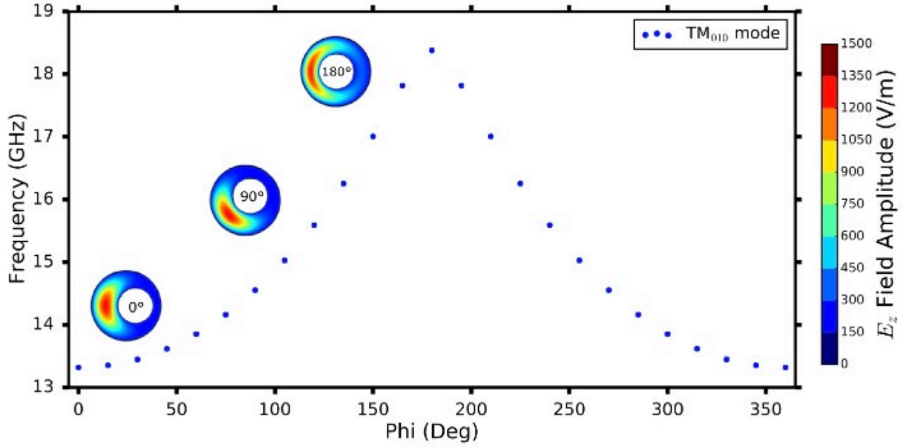
- By **moving the rod radially** the mode is perturbed, shifting the frequency
- Some difficulty tuning when cold
- Solution: ramp the magnet to 11T





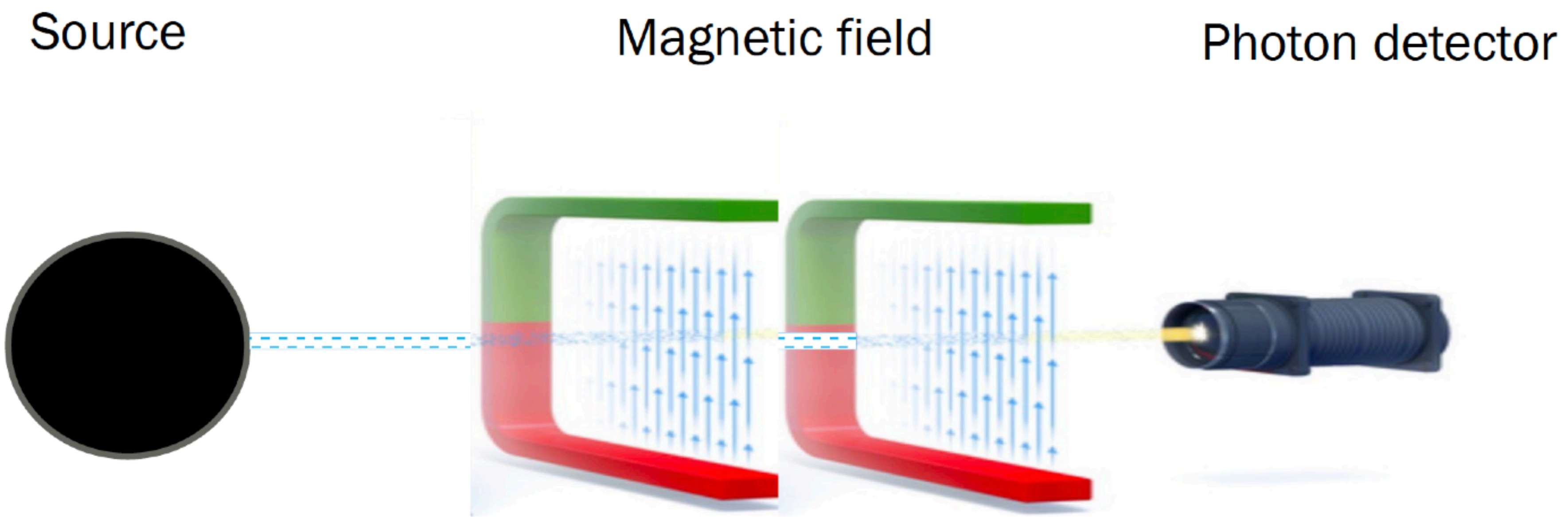






Magnetic conversion (Inverse Gertsenshtein effect)

- Gravitational-wave propagating in magnetic fields convert into photons.
  Gertsenshtein, Sov. Phys., JETP 14, 84 (1962), G. A. Lupanov JETP 25, 76 (1967)



High Energy Physics - Phenomenology

[Submitted on 21 Dec 2021]

Detecting High-Frequency Gravitational Waves with Microwave Cavities

Asher Berlin, Diego Blas, Raffaele Tito D'Agnolo, Sebastian A. R. Ellis, Roni Harnik, Yonatan Kahn, Jan Schütte-Engel

We give a detailed treatment of electromagnetic signals generated by gravitational waves (GWs) in resonant cavity experiments. Our investigation corrects and builds upon previous studies by carefully accounting for the gauge dependence of relevant quantities. We work in a preferred frame for the laboratory, the proper detector frame, and show how to resum short-wavelength effects to provide analytic results that are exact for GWs of arbitrary wavelength. This formalism allows us to firmly establish that, contrary to previous claims, cavity experiments designed for the detection of axion dark matter only need to reanalyze existing data to search for high-frequency GWs with strains as small as $h \sim 10^{-22} - 10^{-21}$. We also argue that directional detection is possible in principle using readout of multiple cavity modes. Further improvements in sensitivity are expected with cutting-edge advances in superconducting cavity technology.

Comments: 20 pages + appendix, 7 figures
Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Astrophysical Phenomena (astro-ph.HE); Instrumentation and Methods for Astrophysics (astro-ph.IM); High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:2112.11465 **[hep-ph]**
(or arXiv:2112.11465v1 **[hep-ph]** for this version)

Submission history

From: Jan Schütte-Engel [view email]
[v1] Tue, 21 Dec 2021 19:00:01 UTC (3,548 KB)

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From: Jan Schütte-Engel [view email]
[v1] Tue, 21 Dec 2021 19:00:01 UTC (3,548 KB)

II. GW ELECTRODYNAMICS IN THE PROPER DETECTOR FRAME

A. Analogies with Axion Dark Matter Detection

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High Energy Physics – Phenomenology

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[Submitted on 21 Dec 2021]

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Comments: 20 pages + appendix, 7 figures
Subjects: High Energy Physics – Phenomenology (hep-ph); High Energy Astrophysical Phenomena (astro-ph.HE); Instrumentation and Methods for Astrophysics (astro-ph.IM); High Energy Physics – Experiment (hep-ex)
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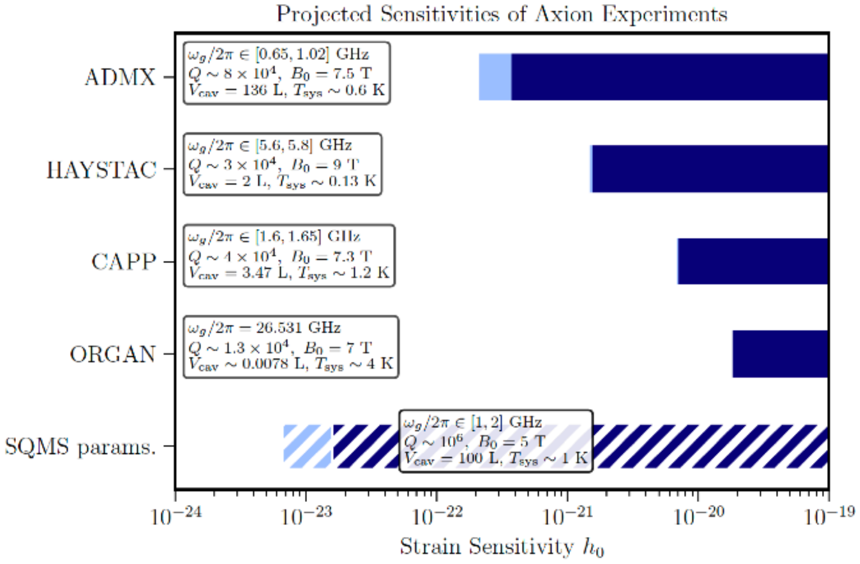

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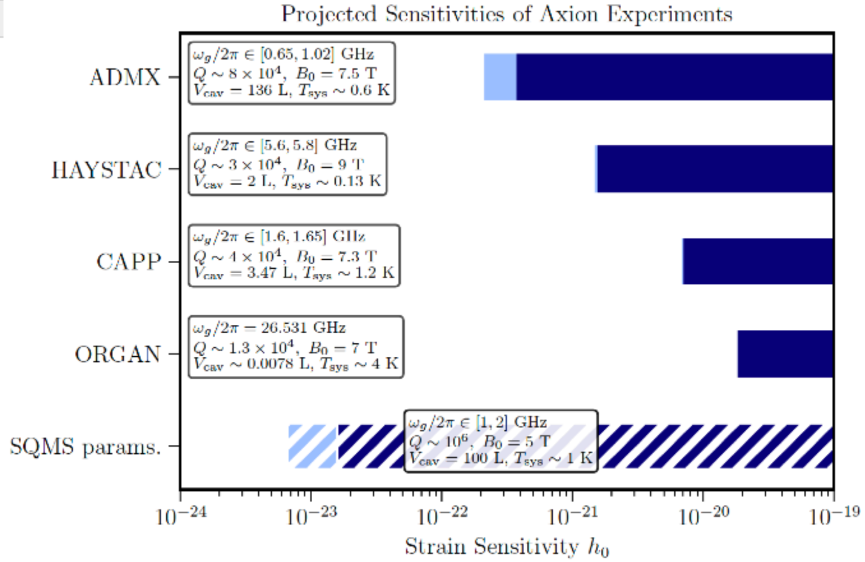

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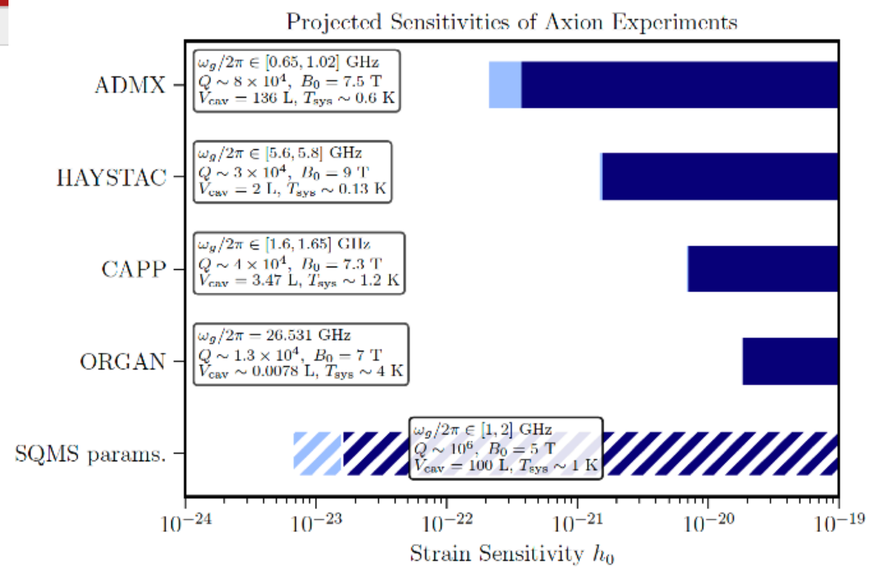

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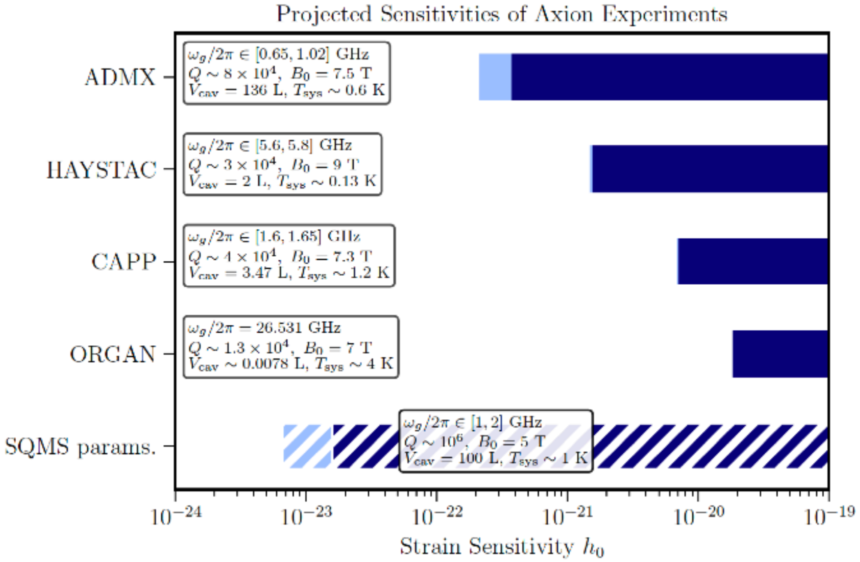

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identifying $\theta_a \sim h$

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A strong motivation to explore higher frequencies from the theoretical perspective is that there are *no known astrophysical objects* which are small and dense enough to emit at

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What do you think the chance of having ultra-high frequency GWs in the universe?

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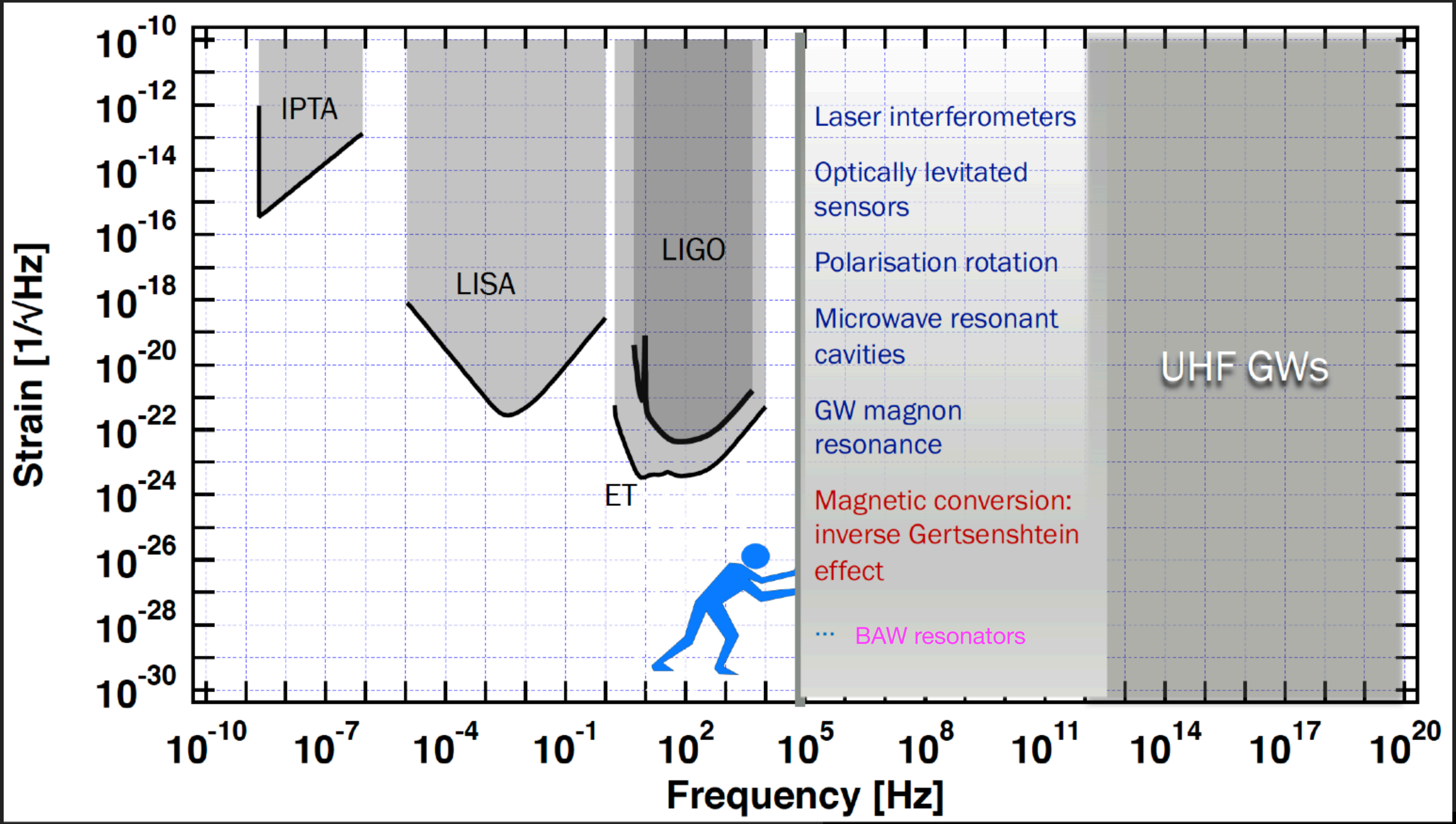
Gravitation Wave Instrument Sensitivity



Aldo Ejlli

Ultra-High-Frequency GWs: A Theory and Technology Roadmap

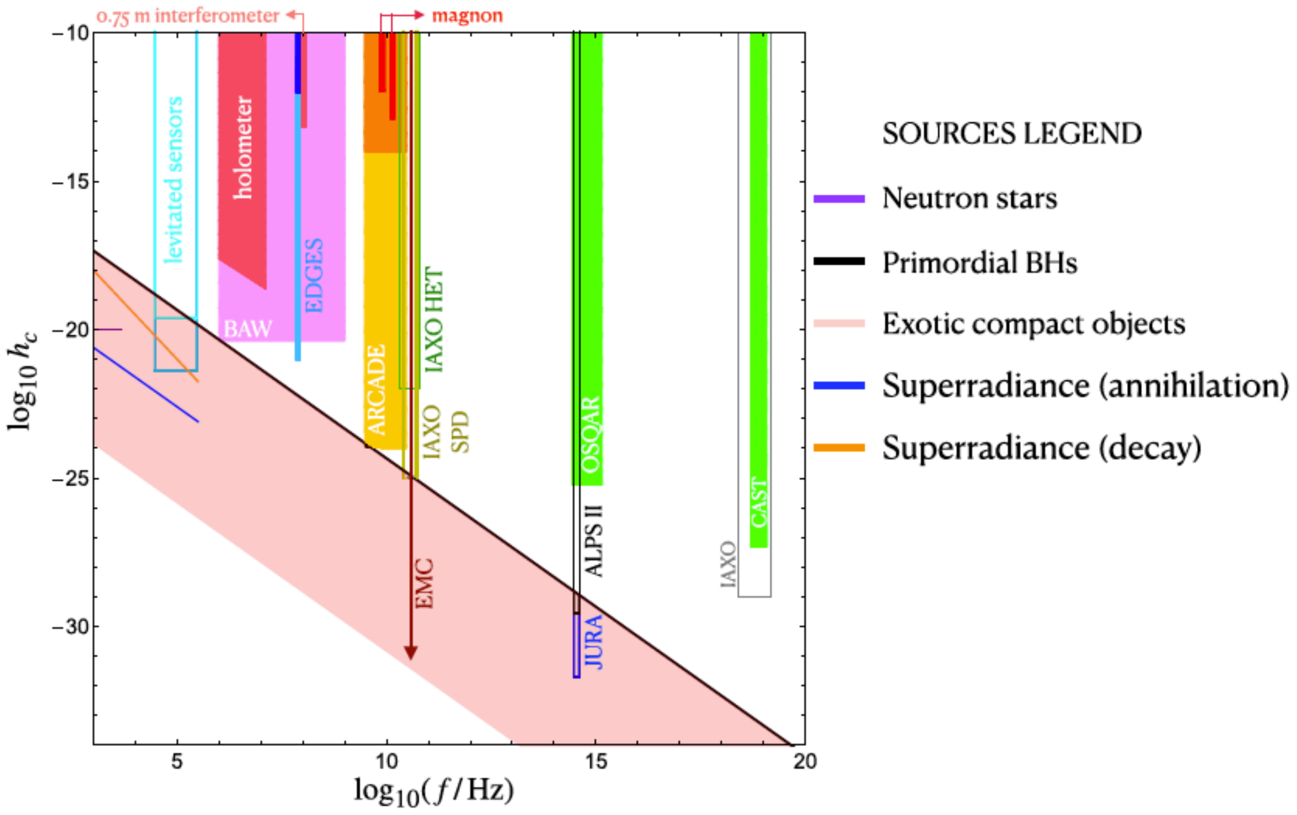
13/10/2021

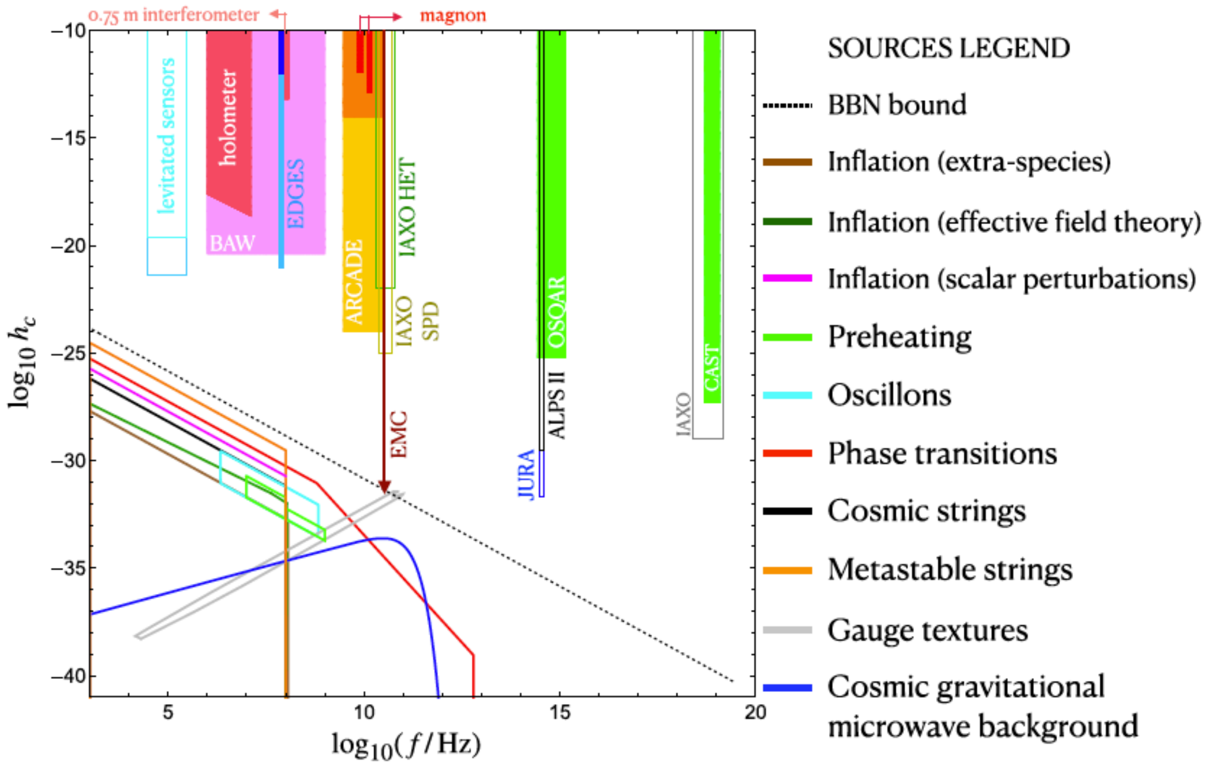
HFGW GW Sources

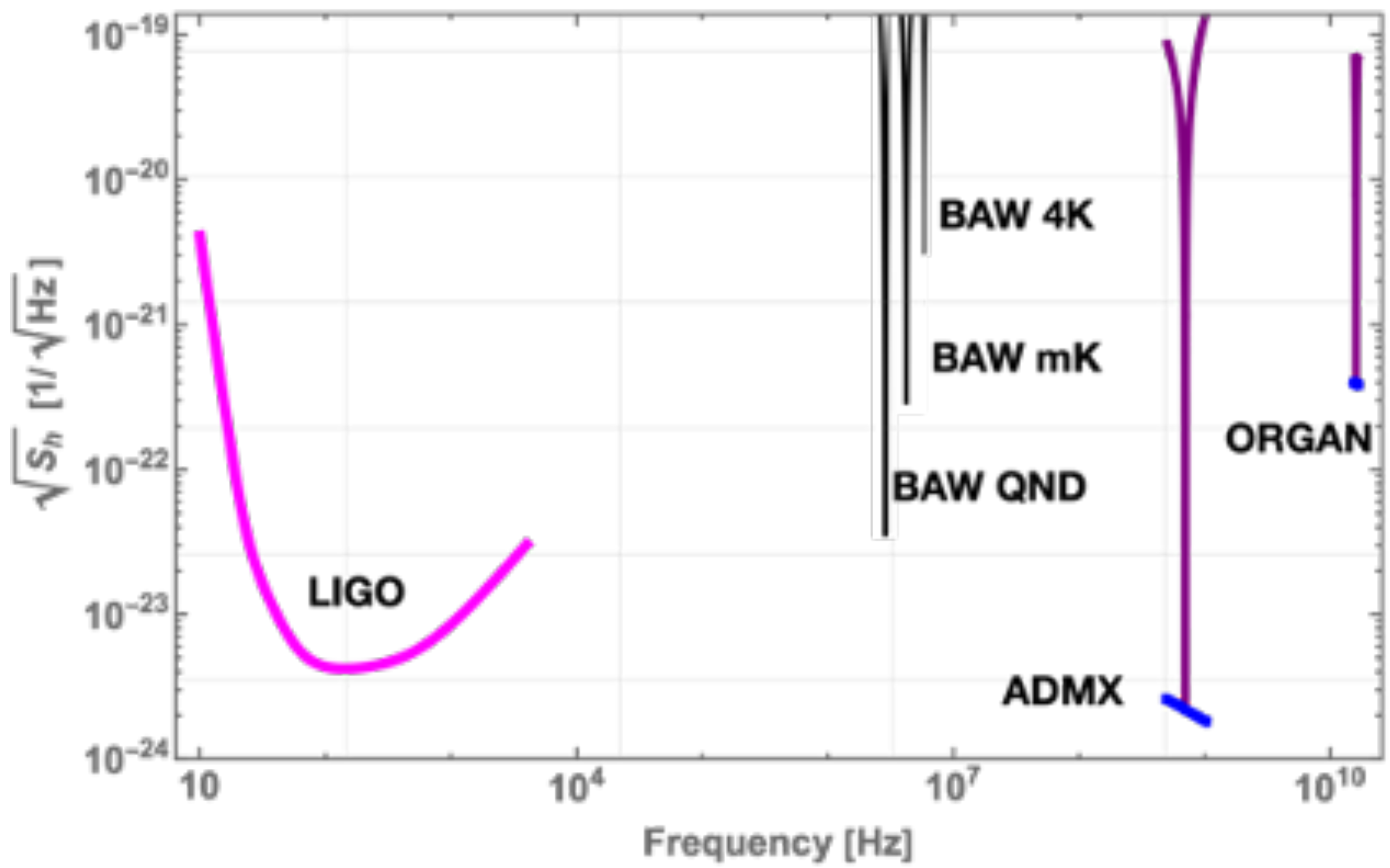
Living Reviews in Relativity (2021)24:4
https://doi.org/10.1007/s41114-021-00032-5

REVIEW ARTICLE

Challenges and opportunities of gravitational-wave searches at MHz to GHz frequencies

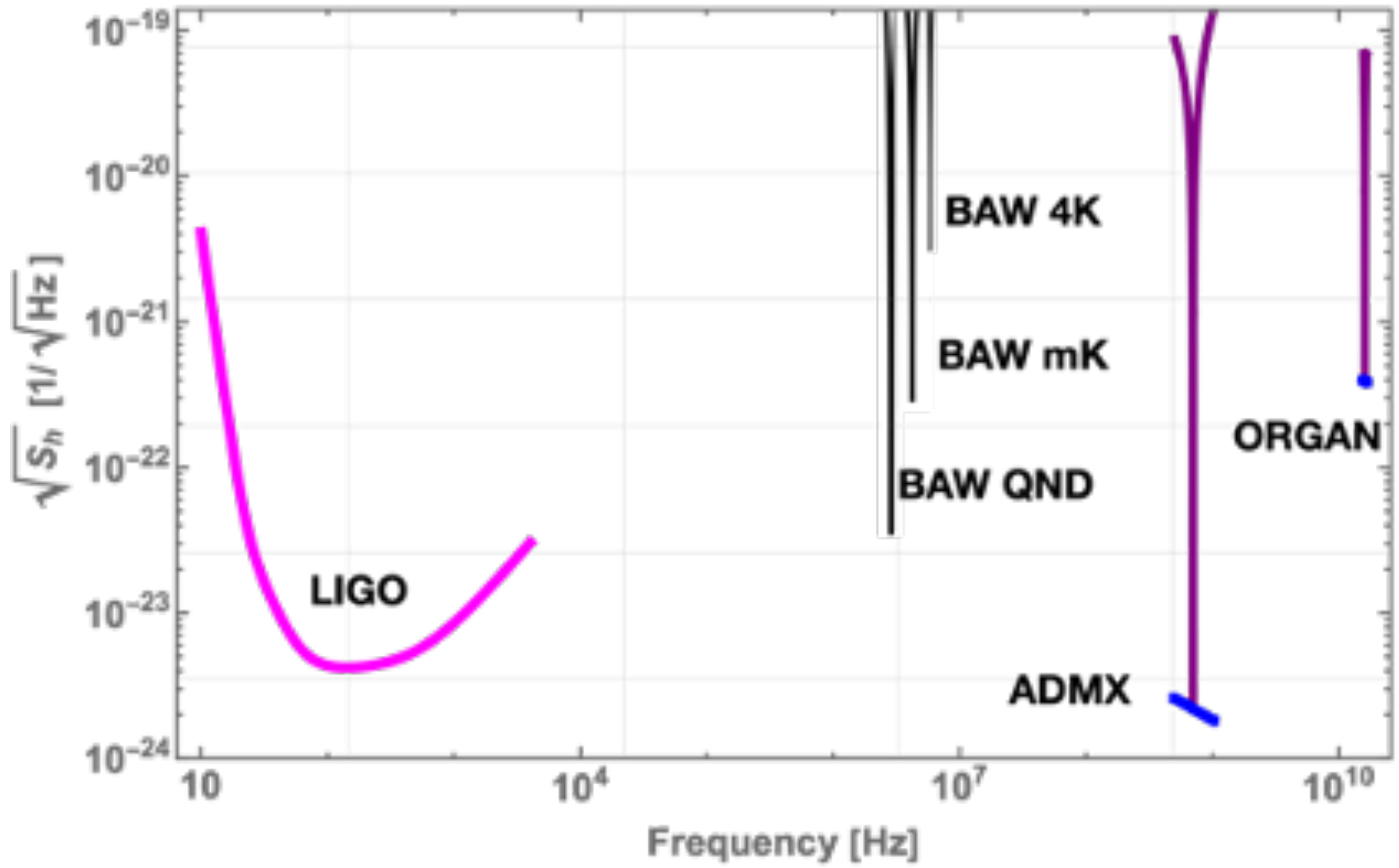






ADMX and ORGAN (purple) with current tuning locus (blue);
0.6-1.2 GHz for ADMX and 15.2 to 16.2 GHz for ORGAN

identifying $\theta_a \sim h$



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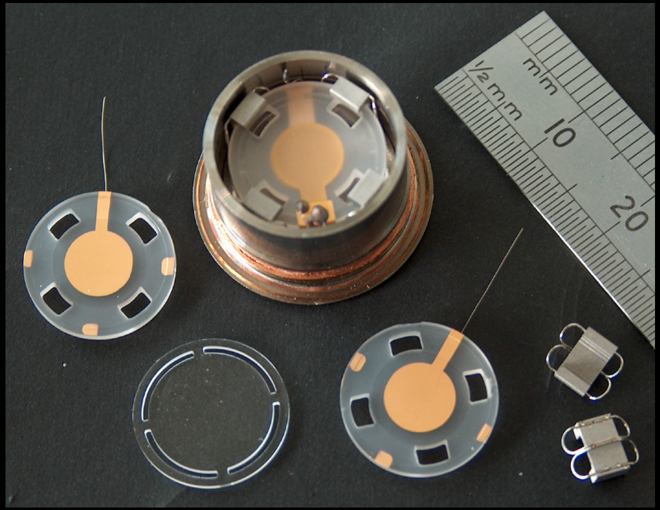
Prof. Michael Tobar



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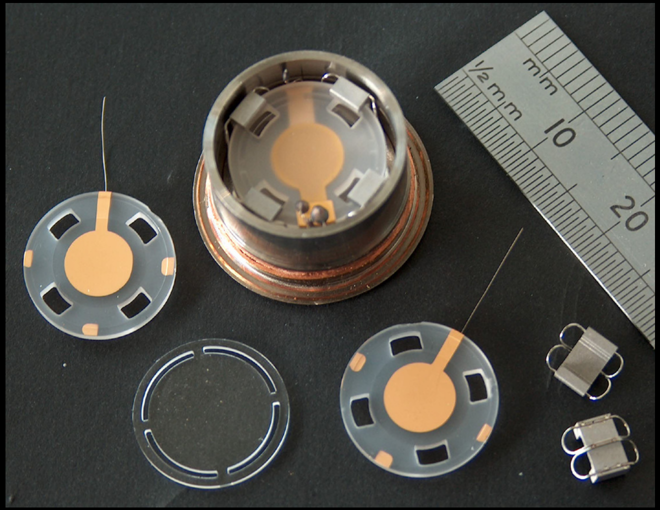

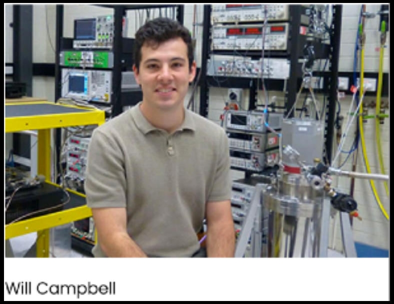

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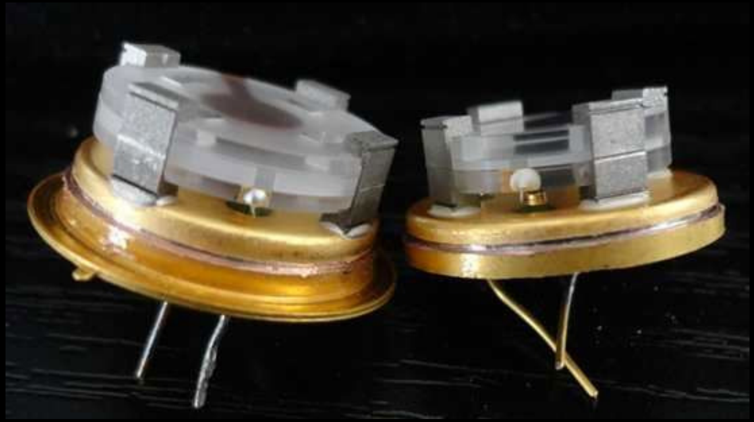

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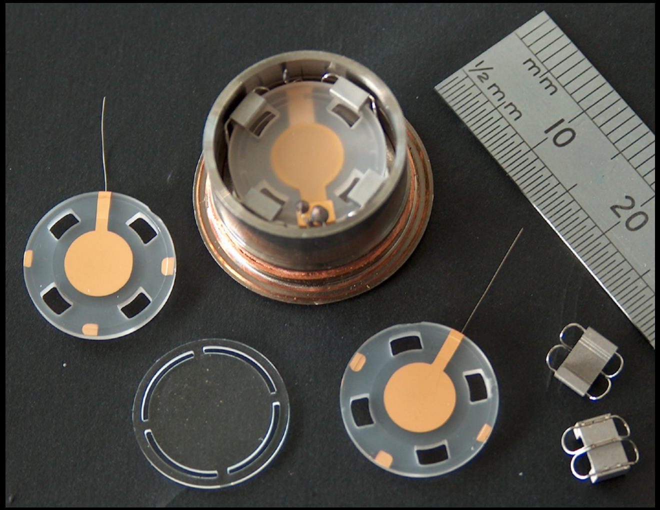

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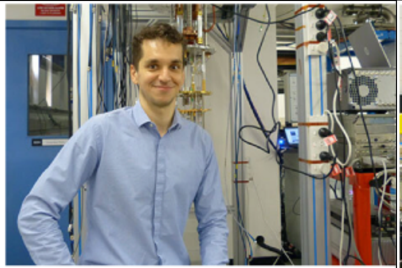

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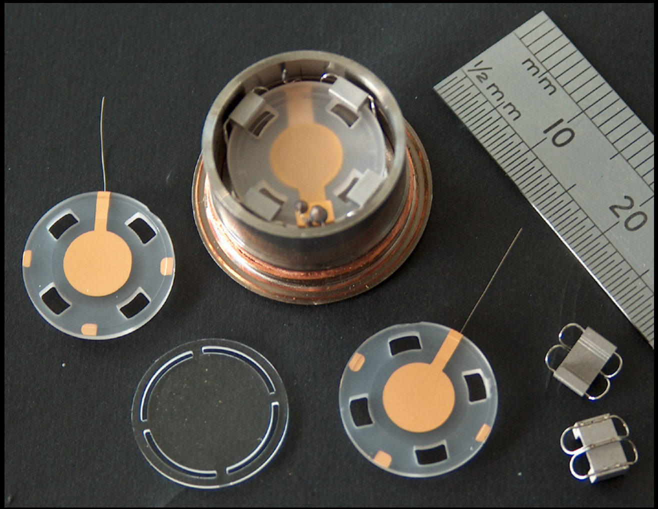

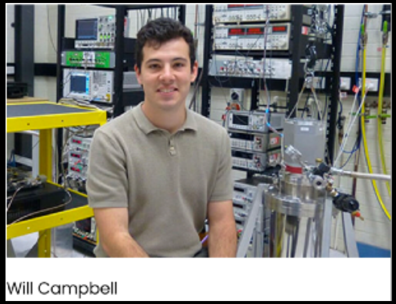

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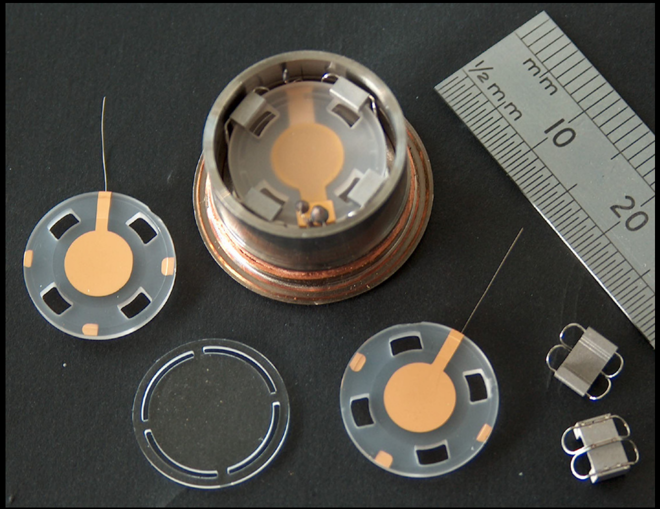


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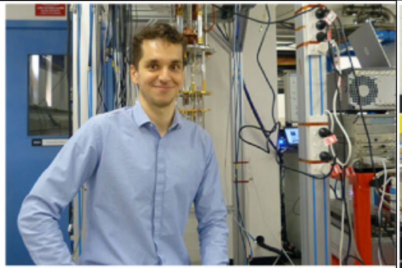
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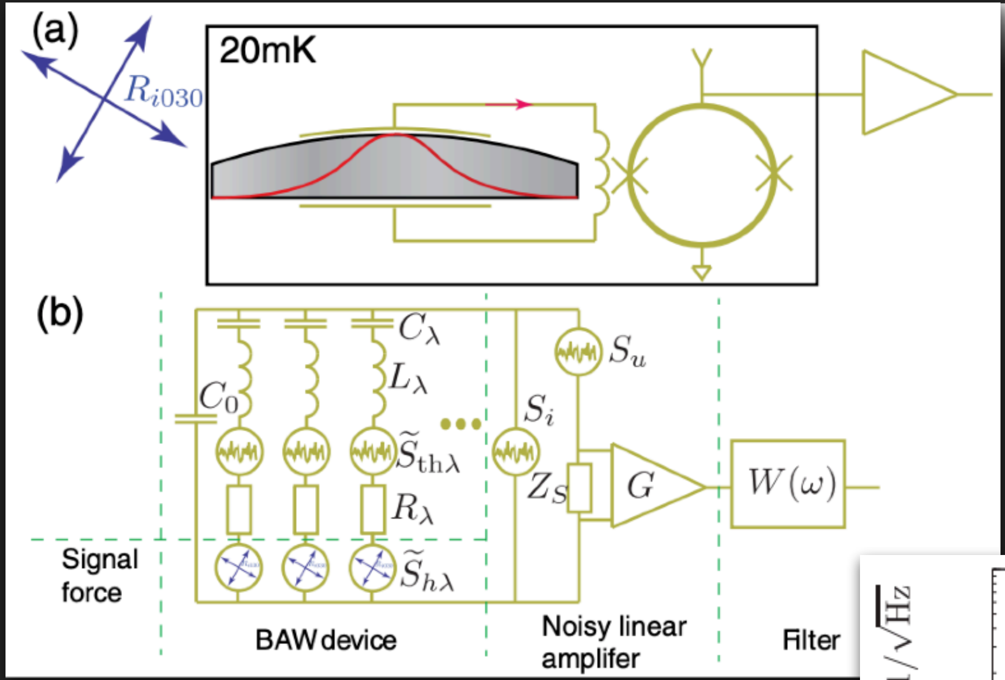
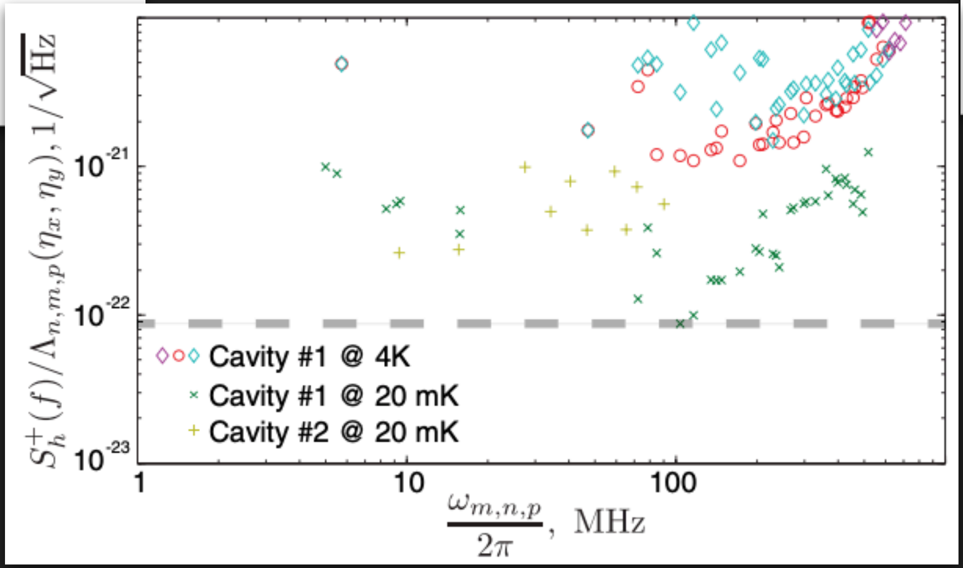
High Frequency Gravitational Waves?

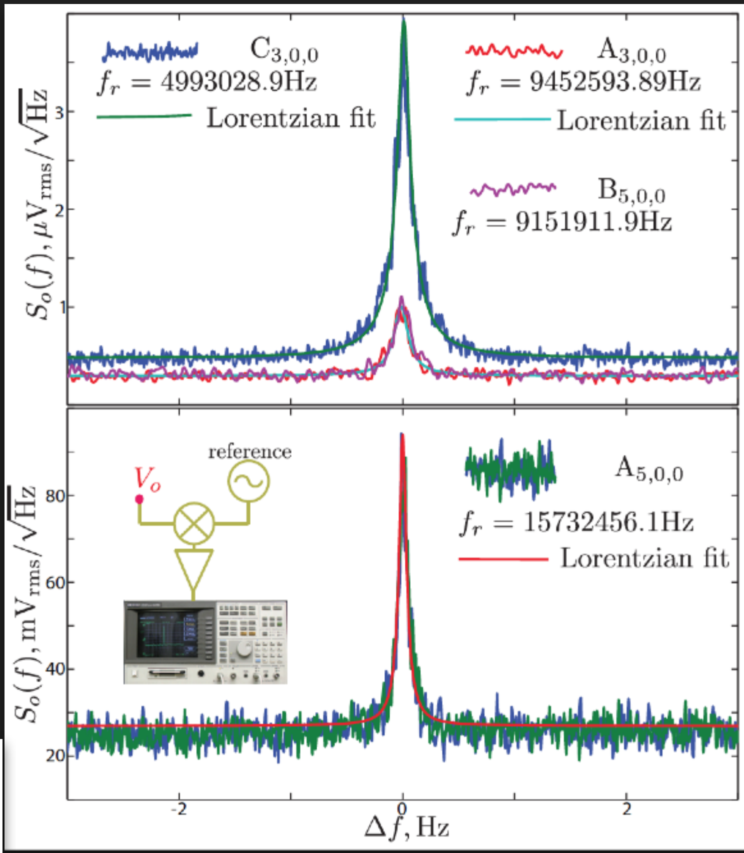
Gravitational wave detection with high frequency phonon trapping acoustic cavities

Maxim Goryachev and Michael E. Tobar

Phys. Rev. D **90**, 102005 – Published 24 November 2014







Appl. Phys. Lett. 105, 153505 (2014)

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Recent Experiment: First Detection, unlikely! Or not?

PHYSICAL REVIEW LETTERS **127**, 071102 (2021)

Rare Events Detected with a Bulk Acoustic Wave High Frequency Gravitational Wave Antenna

Maxim Goryachev,[1] William M. Campbell,[1] Ik Siong Heng,[2] Serge Galliou,[3]
Eugene N. Ivanov,[1] and Michael E. Tobar[1,*]

[1] *ARC Centre of Excellence for Engineered Quantum Systems, ARC Centre of Excellence for Dark Matter Particle Physics, Department of Physics, University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia*
[2] *SUPA, School of Physics and Astronomy, University of Glasgow, Glasgow, Scotland G12 8QQ, United Kingdom*
[3] *Department of Time and Frequency, FEMTO-ST Institute, ENSMM, 26 Chemin de l'Épitaphe, 25000 Besançon, France*

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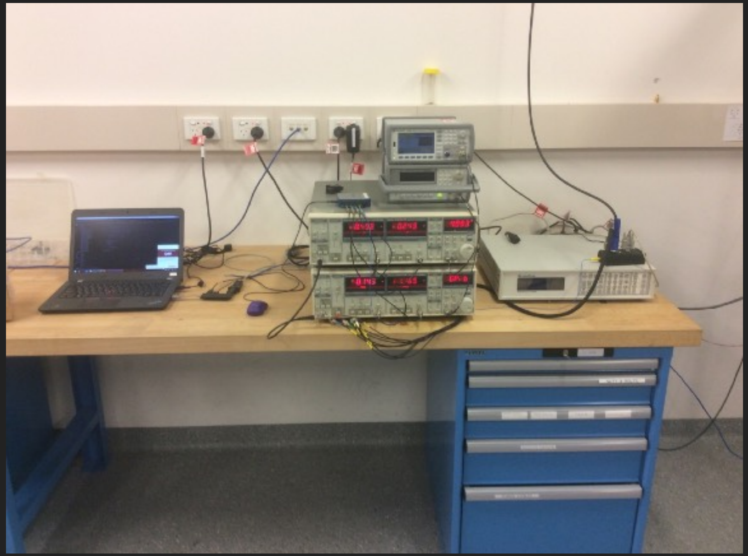
__Excluded sources:__
LIGO/VIRGO event catalogue, weather perturbations, earthquakes, meteor events / cosmic showers, FRBs

__Possible sources:__
Internal solid state processes, internal radioactive events, cosmic ray events, HFGW sources, domain walls, WIMPs, dark matter

Recent Experiment

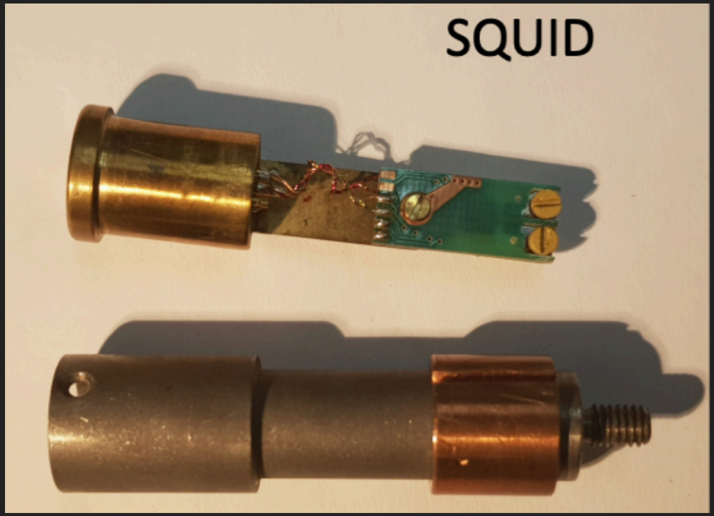
Control and Signal Processing

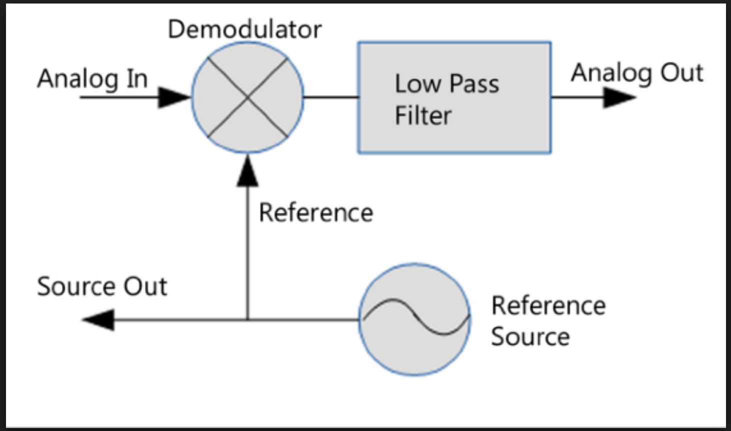


Two standalone lockin amplifiers
Two Signal generators
Locked to an H-maser
Temperature controller
SQUID control
Python data logging

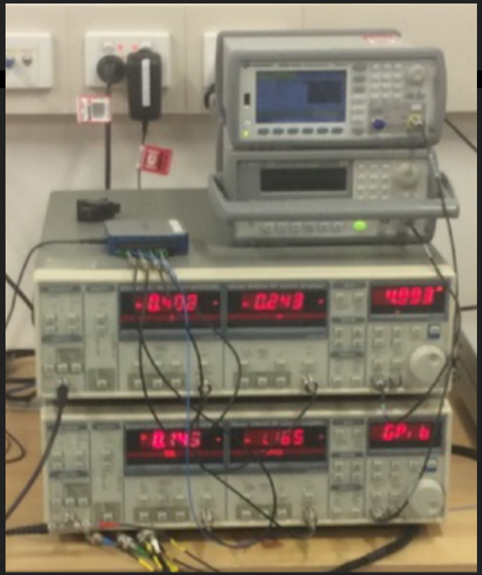
Cryogenic Part

3.4K cryocooler
SQUID electronics





digital downconversion



Recent Experiment ?153 days of observation

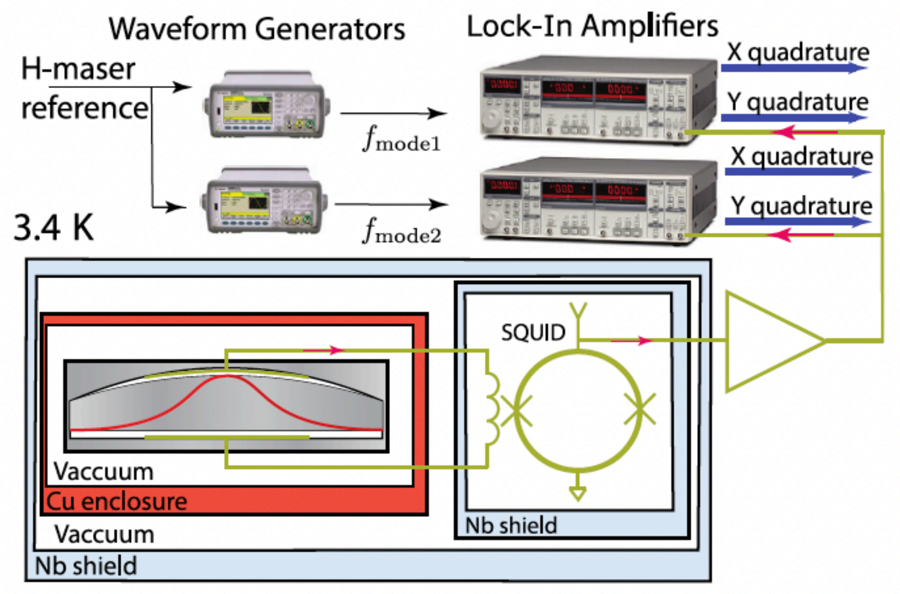


FIG. 1. Experimental setup showing BAW cavity connected to SQUID amplifier and shielding arrangement. Note that 4 and 50 K shields as well as stainless still vacuum chamber not shown.

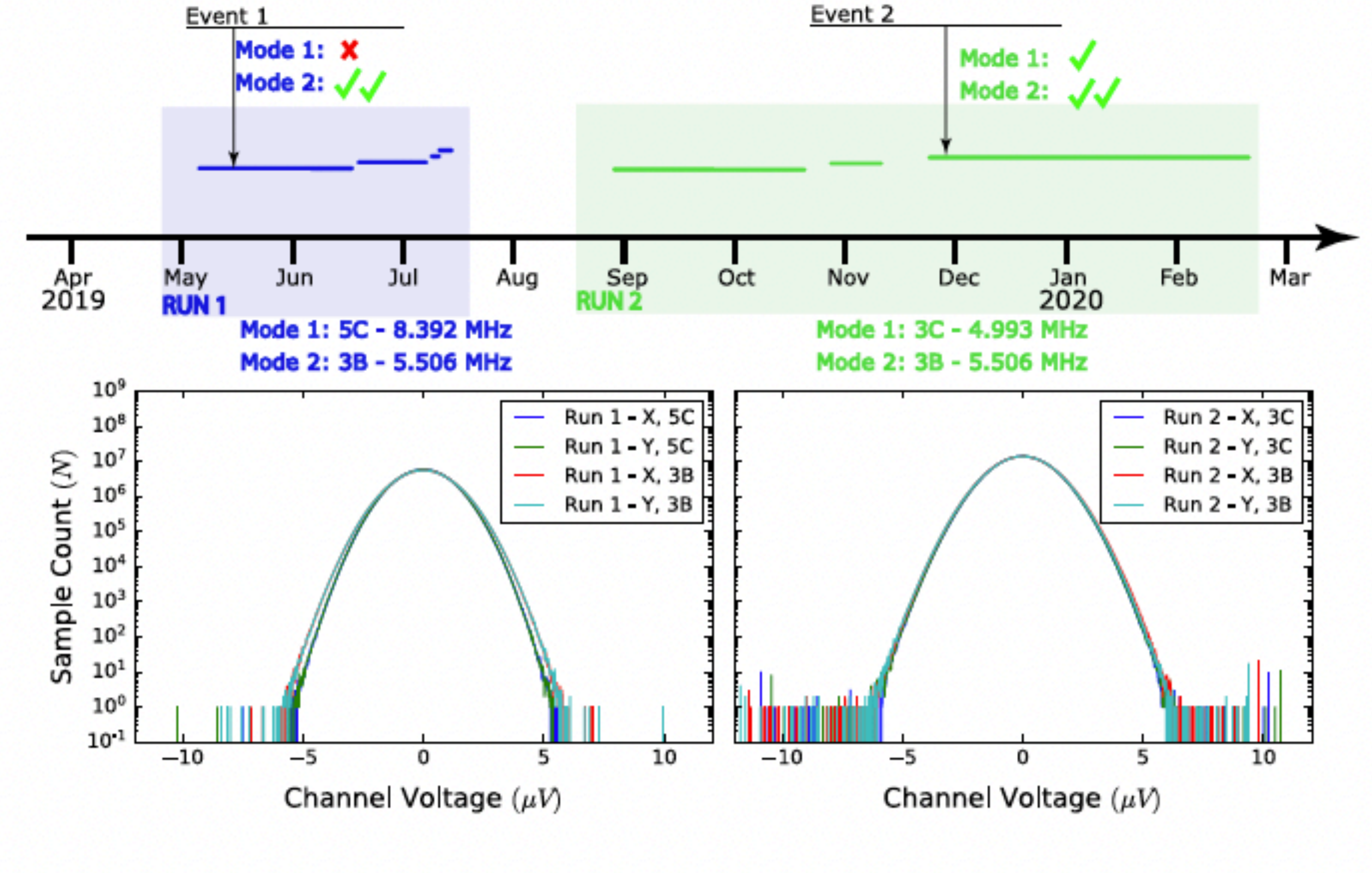


FIG. 2. Timeline of described experiment as well as histogram of total data collection at the detector output. Blue and green lines on timeline show separate data acquisition periods for two runs. Arrows point to the dates of two observed events.

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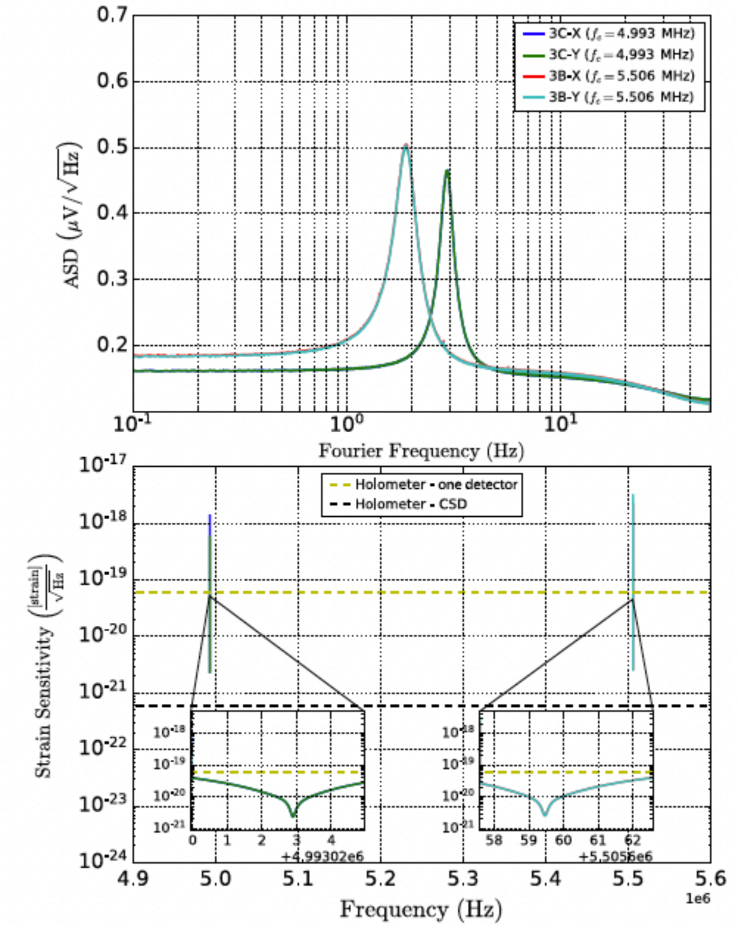

FIG. 3. Top figure displays averaged amplitude spectral density (ASD) of each output channel of lock-ins for longest continuous data taking run; here, each mode has been demodulated from the carrier. Bottom figure shows corresponding spectral strain sensitivity determined for each trace, as well as current best sensitivity in region given by Holometer experiment [6], which uses the cross spectral density (CSD) of two identical interferometers to search for HFGWs.

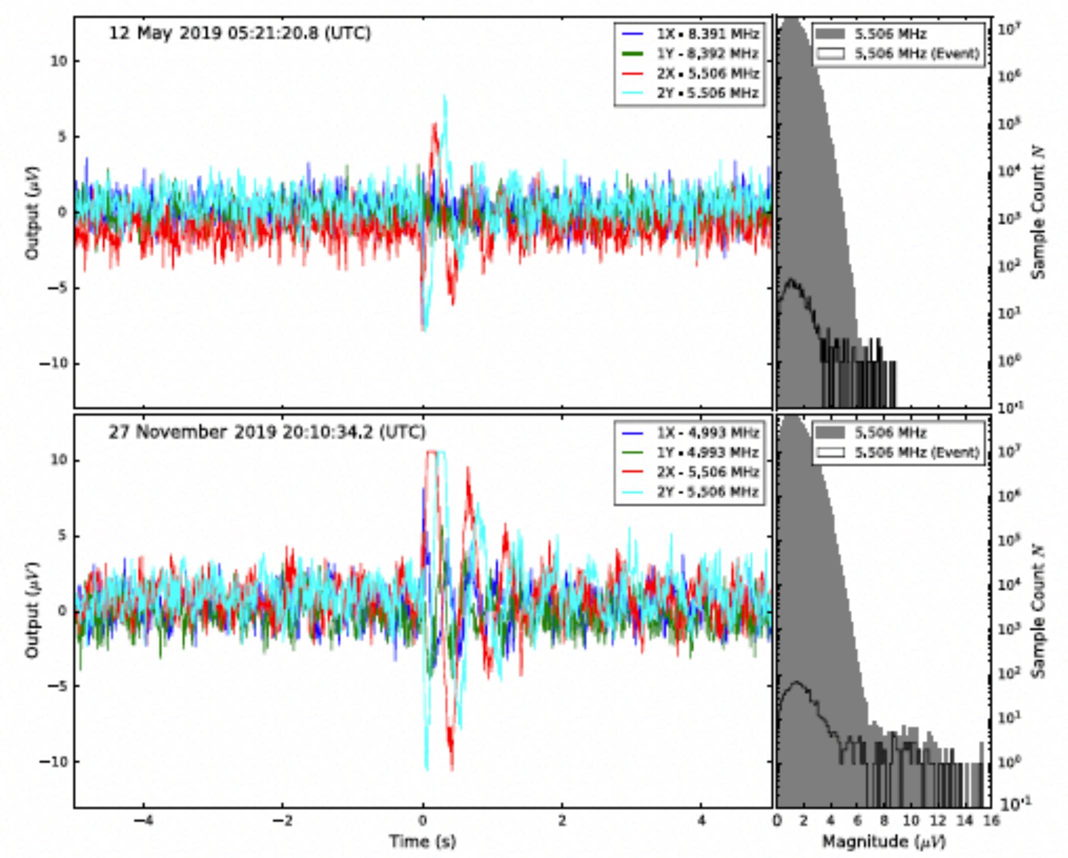

FIG. 4. Time series traces for two event signals detected by system. Each plot shows two quadratures for each mode. Also shown are histograms of output magnitude samples from only the 3B mode from both the entire corresponding run (gray) and just 10 s of data around the event (black). It is clear from this plot that the overwhelming majority of non-Gaussian outliers is due to these signals.

$$H(i\omega) = \frac{\kappa_\lambda^2 \omega_\lambda^2 Z_{\rm SQUID}^2 (-\omega^2/2) h_0 \xi}{(i\omega)^2 + \tau_\lambda^{-1} i\omega + \omega_\lambda^2}$$

EQUS
Australian Research Council
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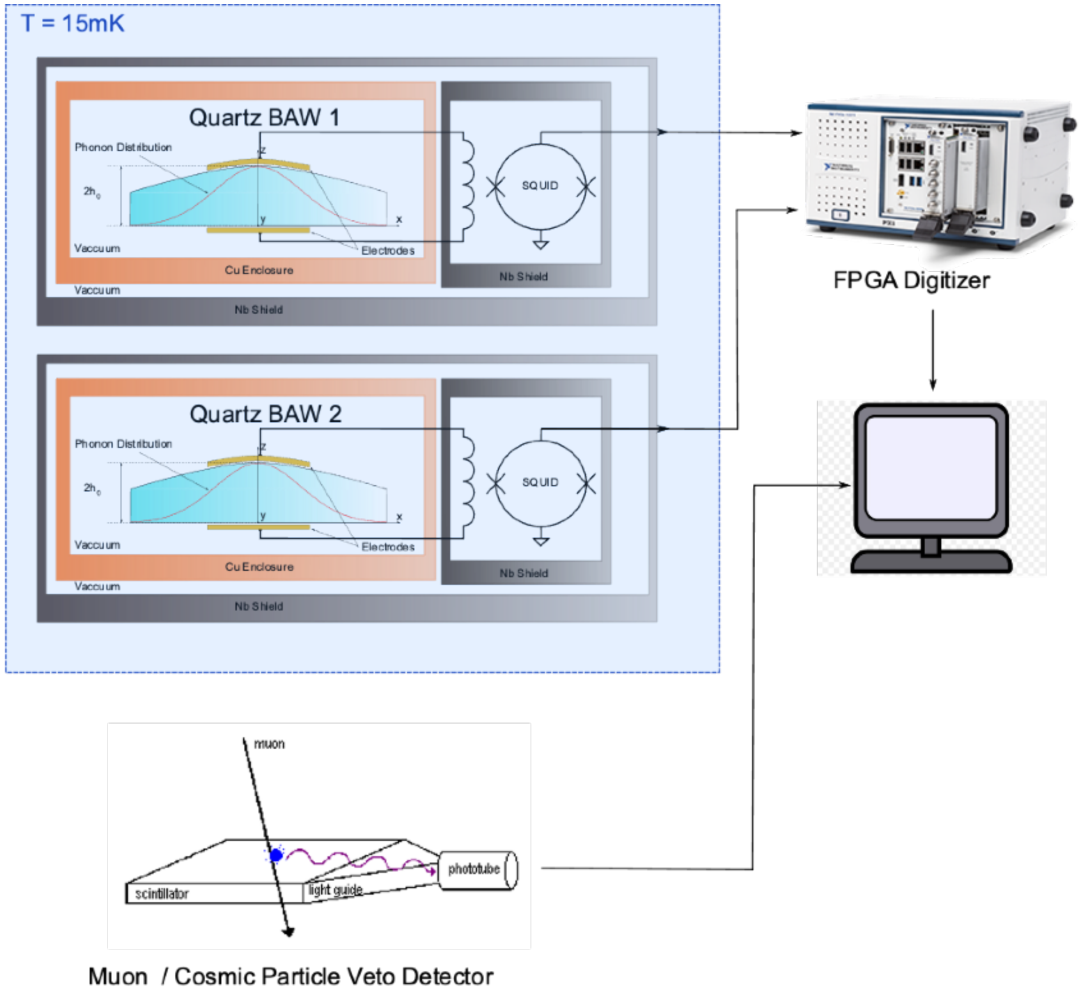
Engineered Quantum Systems

ARC CENTRE OF EXCELLENCE FOR
DARK MATTER

Introducing: the Multimode Acoustic Gravitational wave Experiment (MAGE)



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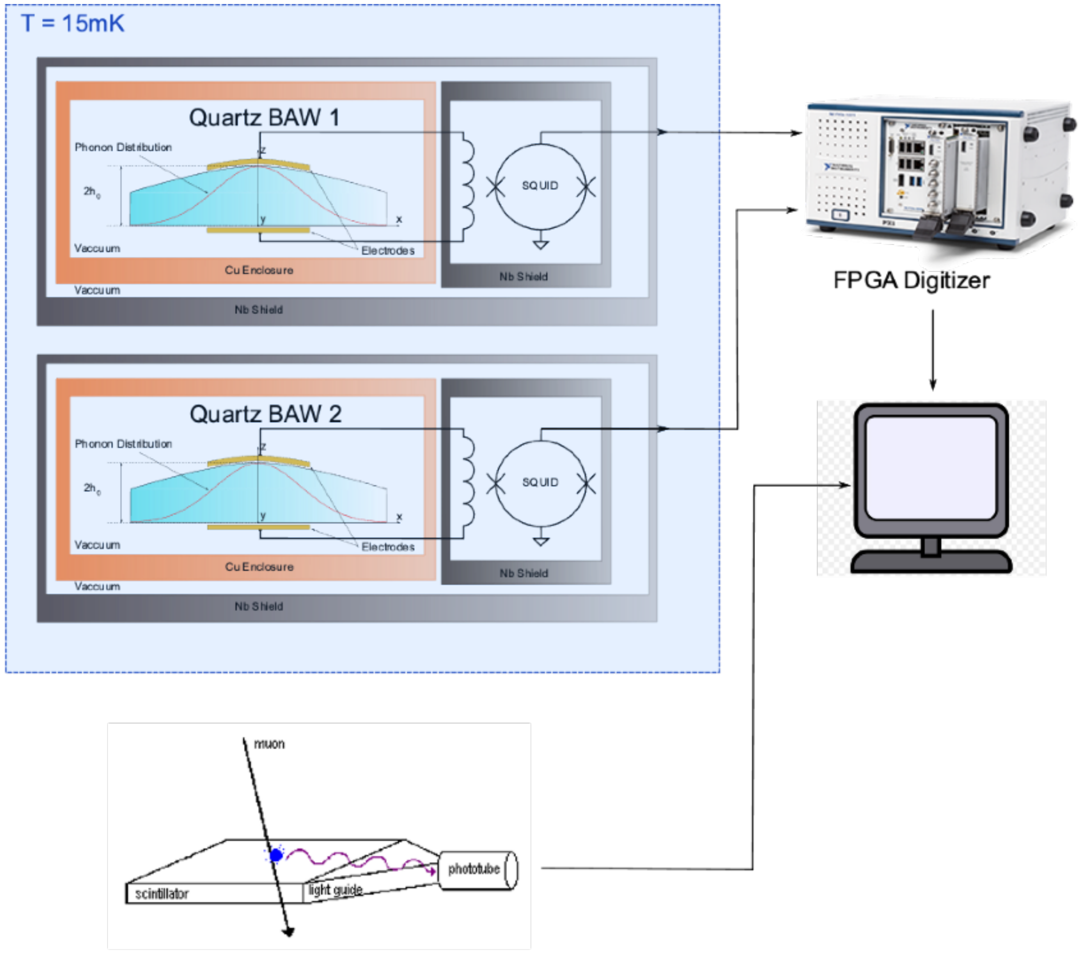
MAGE
Multimode Acoustic Gravitational Wave Experiment



Muon / Cosmic Particle Veto Detector

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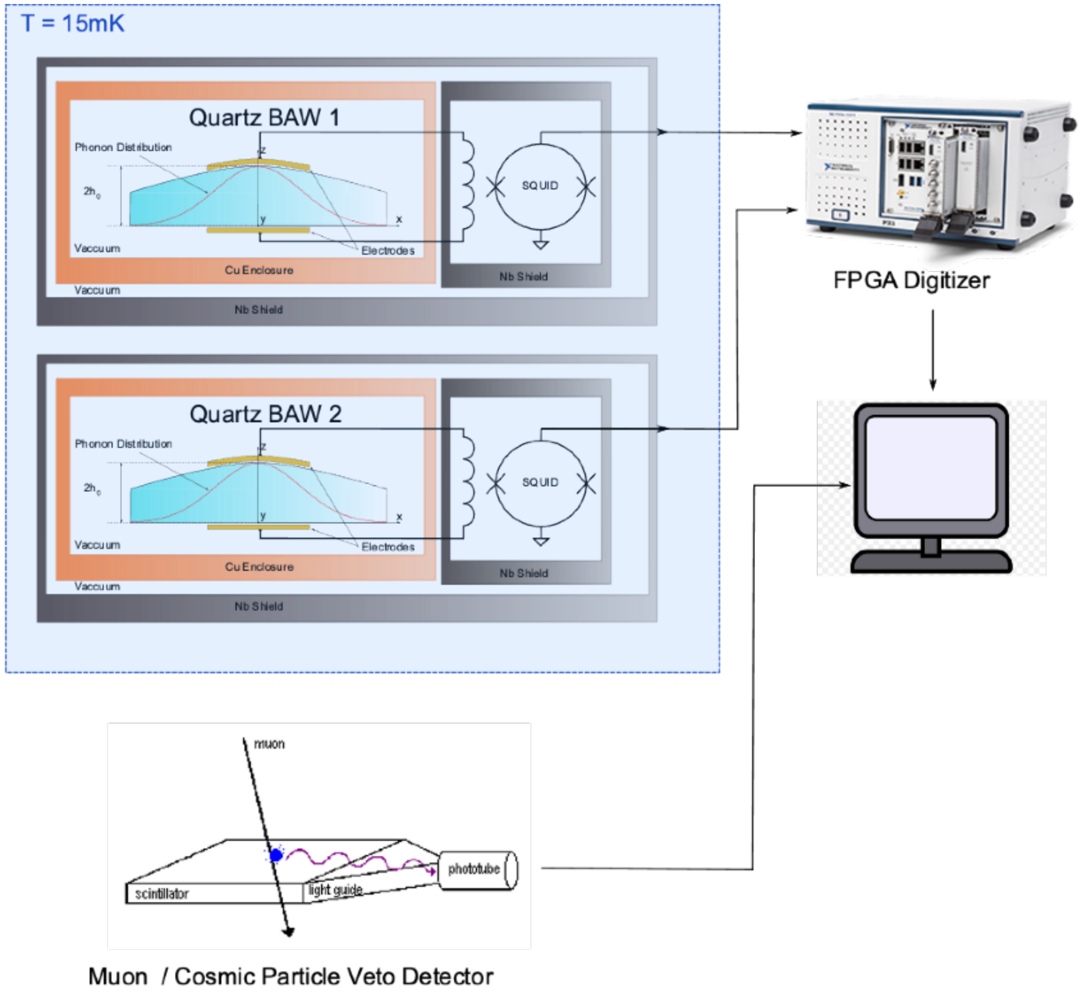

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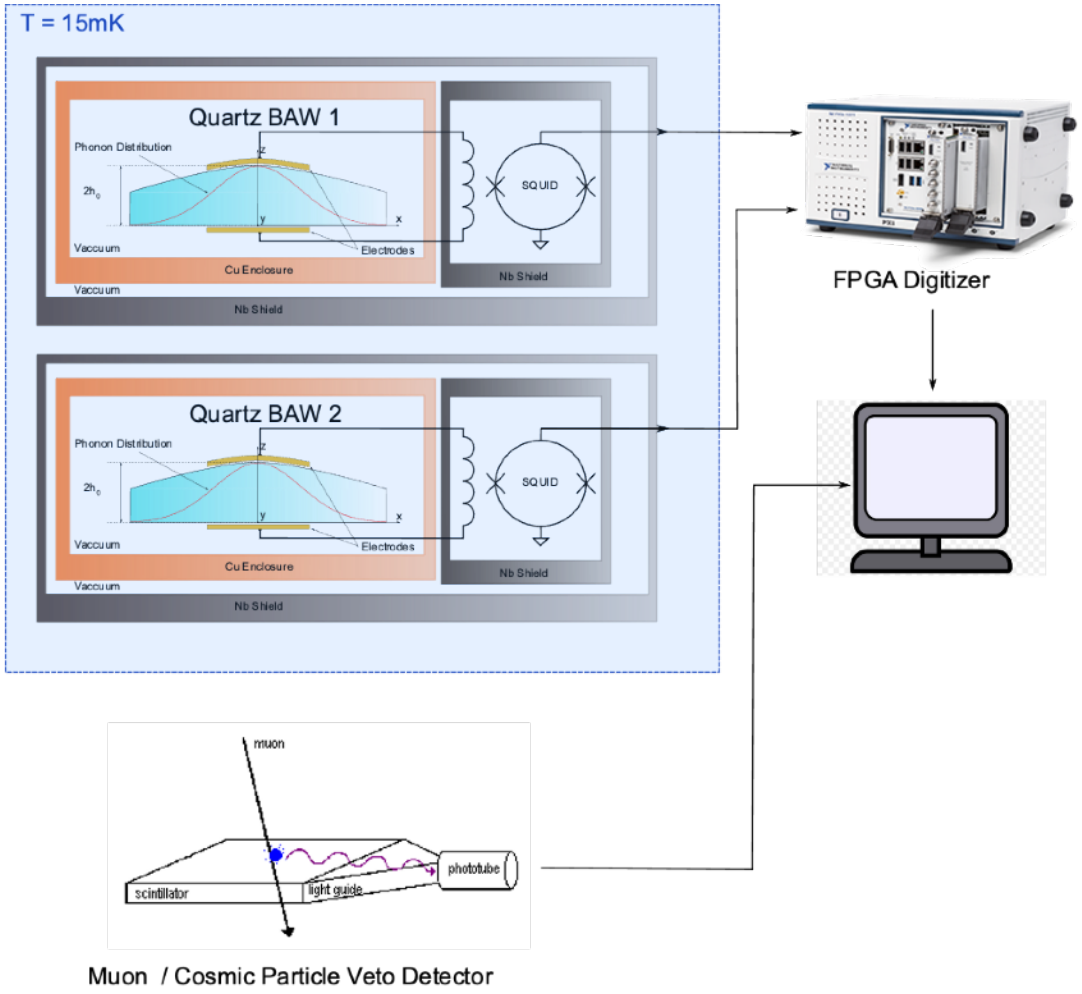

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- Two identical quartz BAW detectors, maybe more? (funding application)

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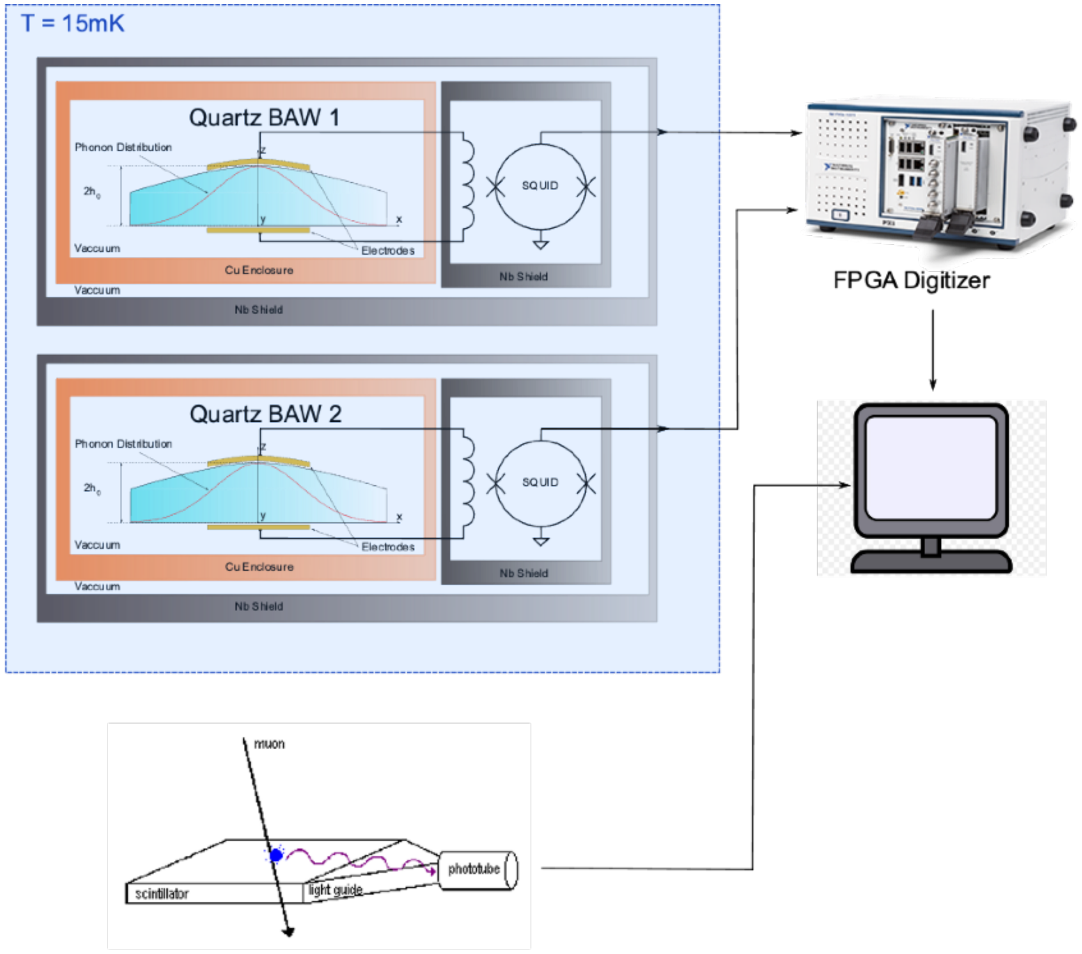

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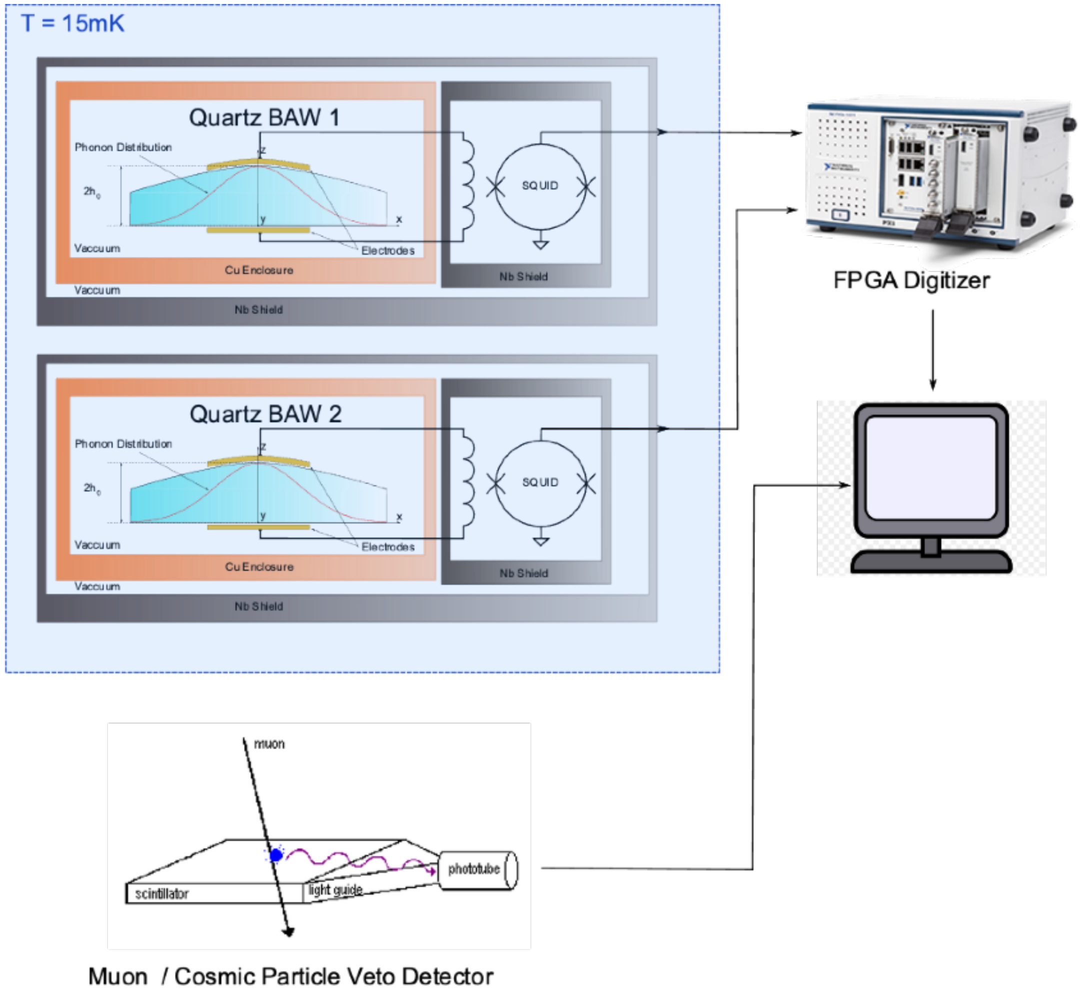

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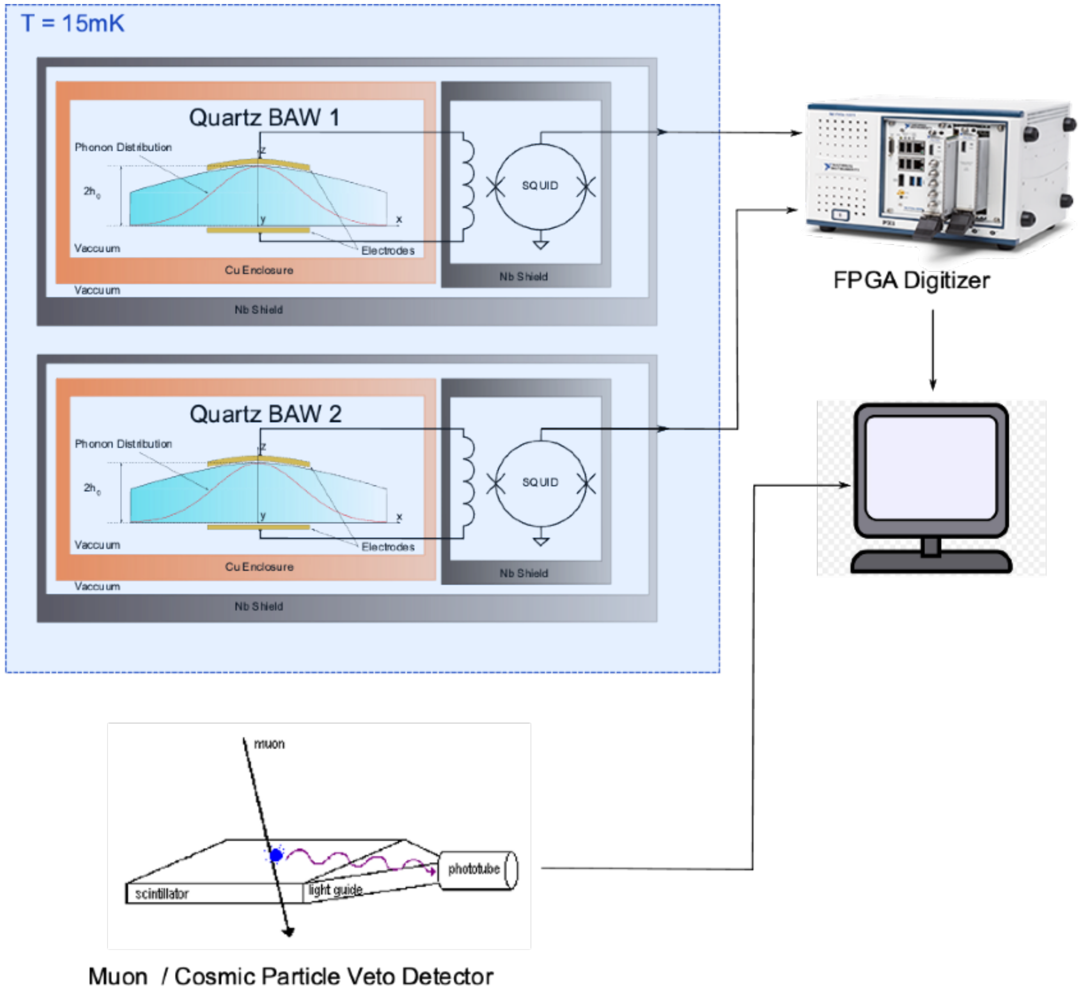

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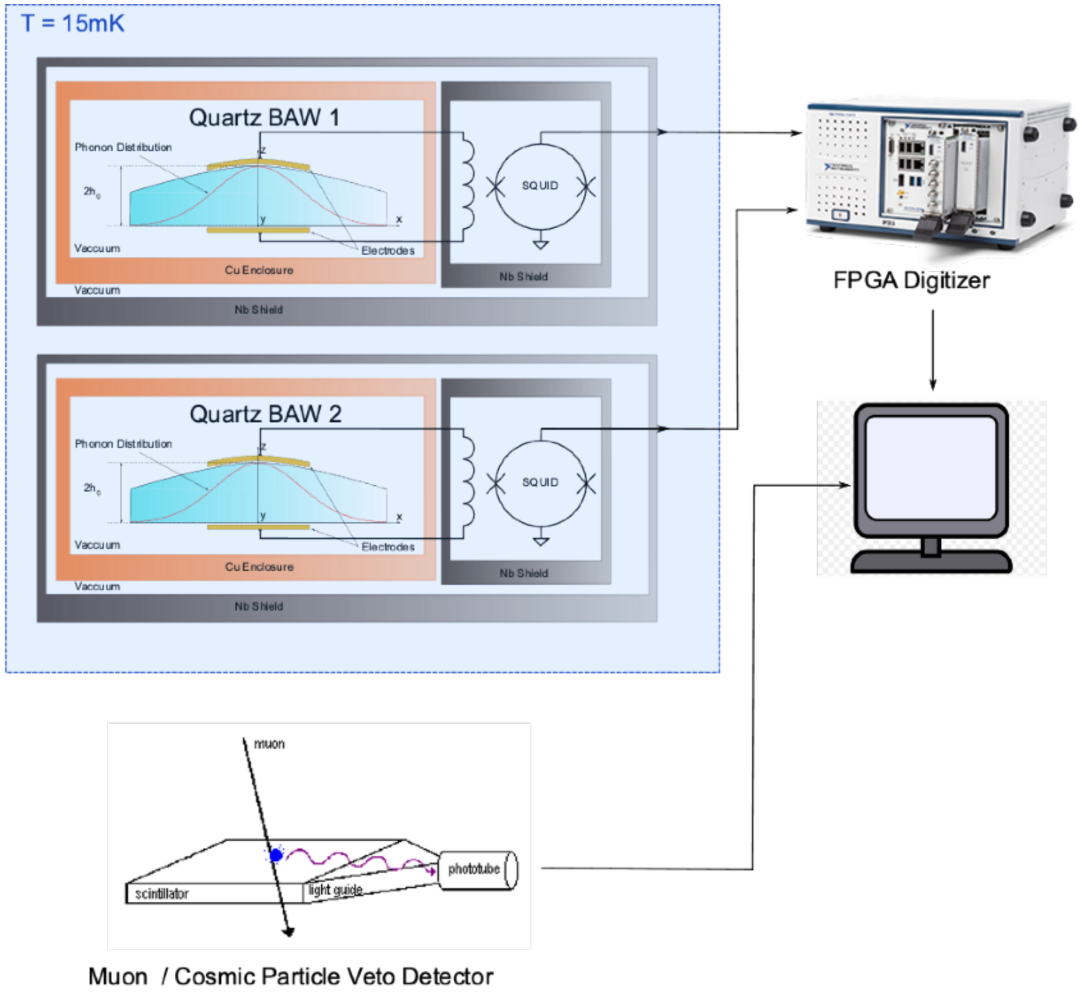

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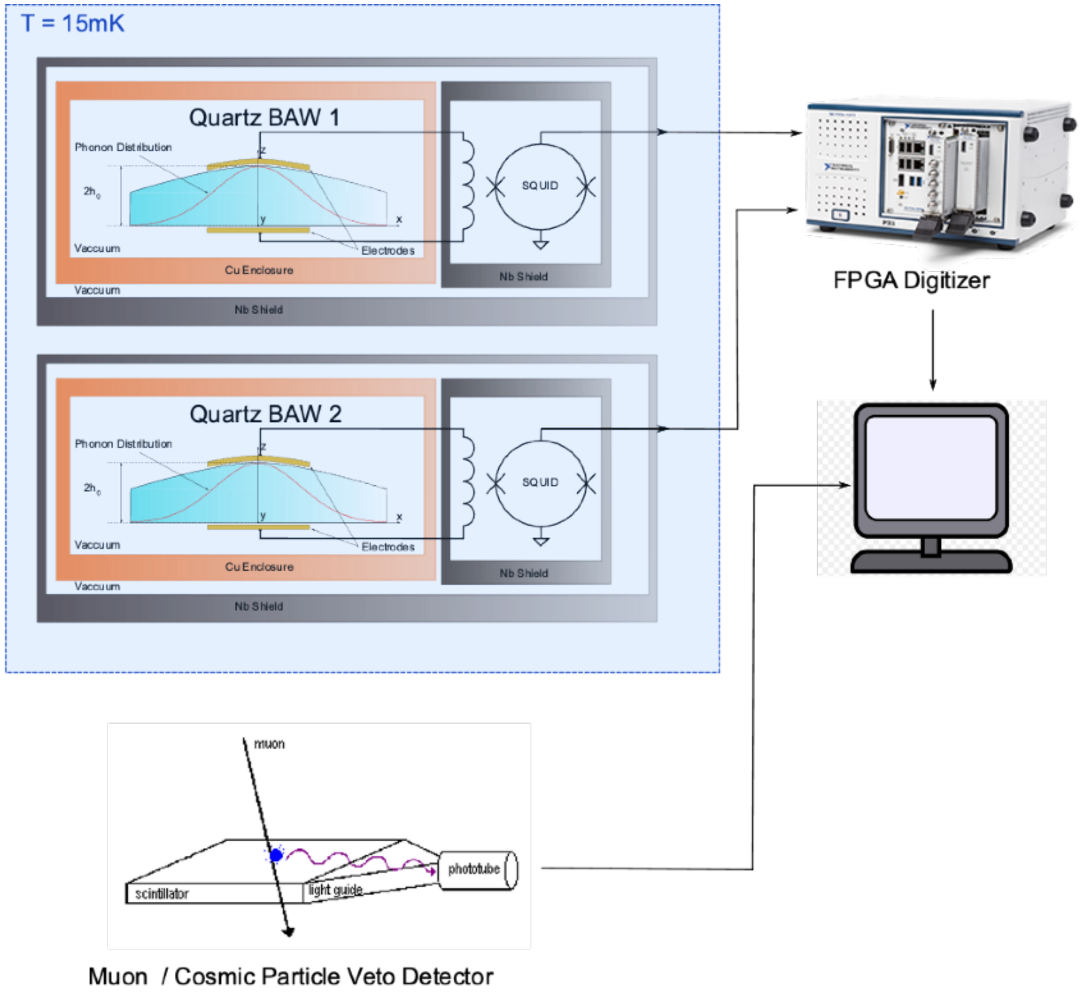

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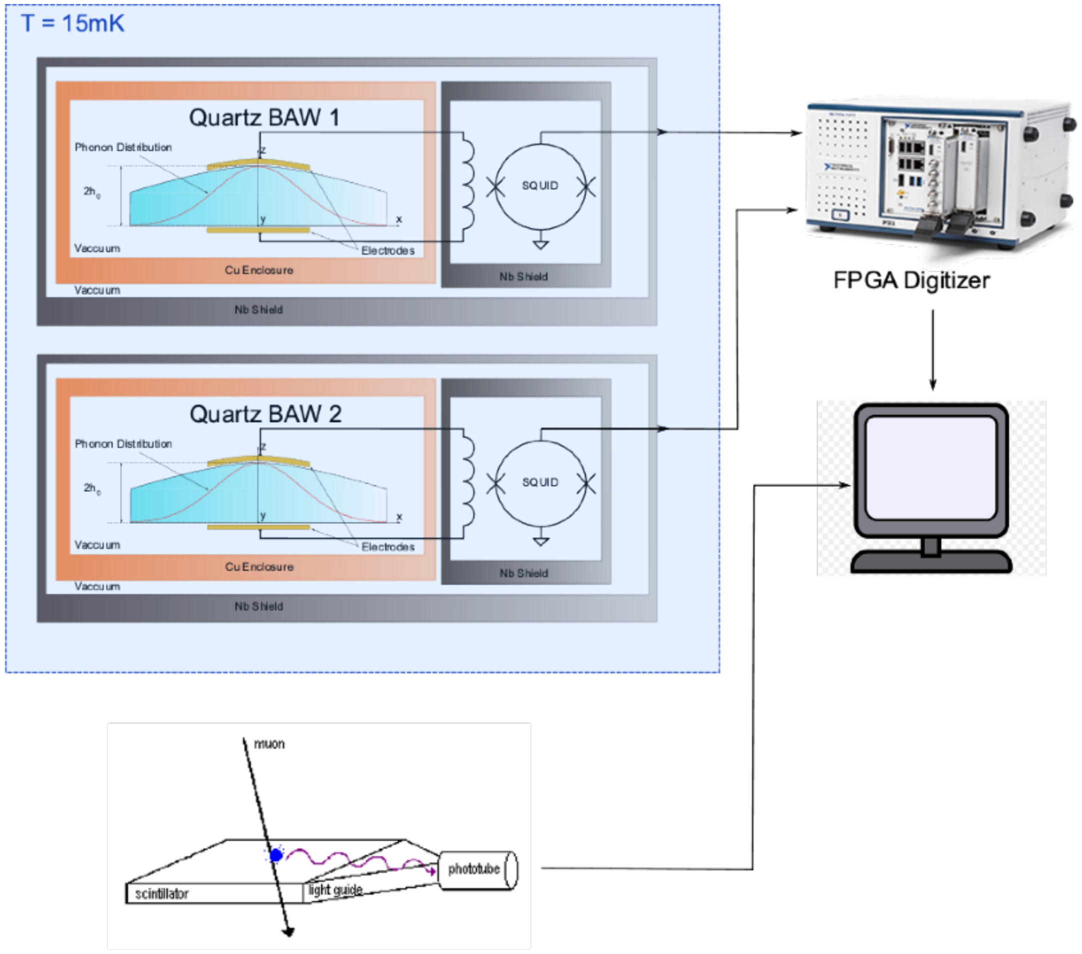
MAGE
Multimode Acoustic Gravitational Wave Experiment



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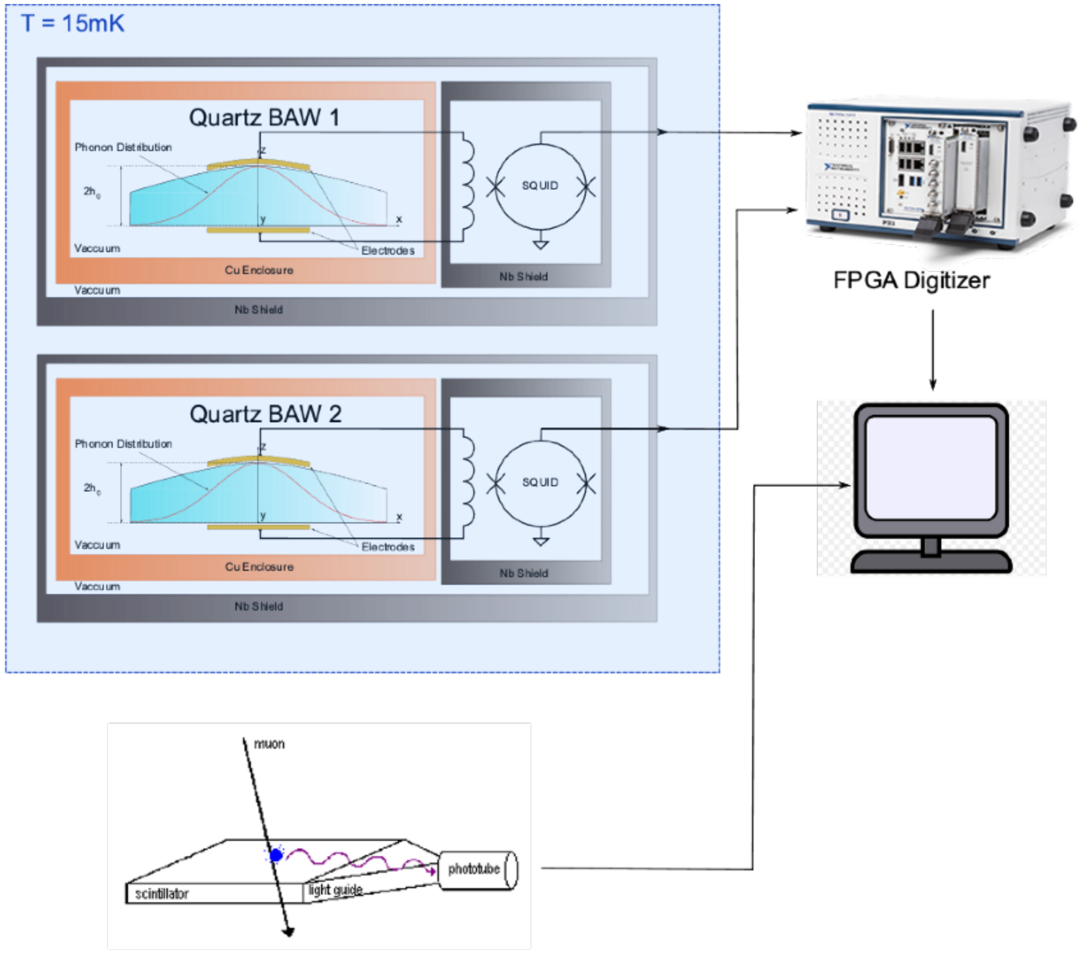

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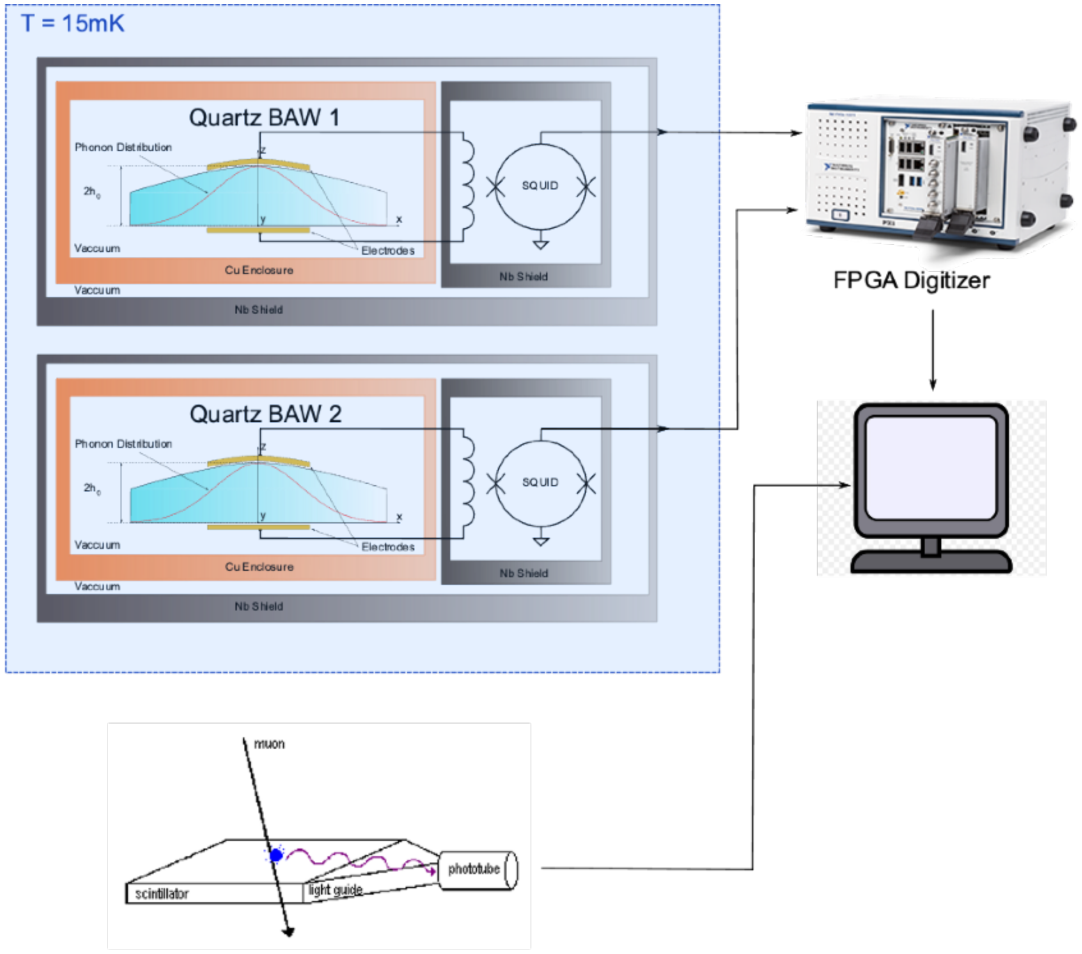

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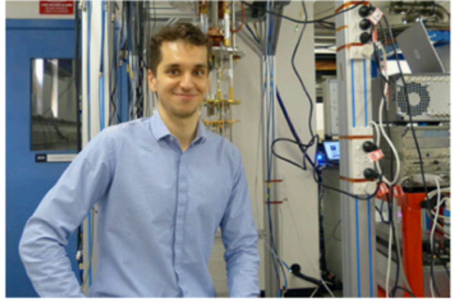
- Current status, waiting for second FPGA DAQ
- Collected one week of data monitoring 8 modes for BAW 1

Professor Mike Tobar
Director



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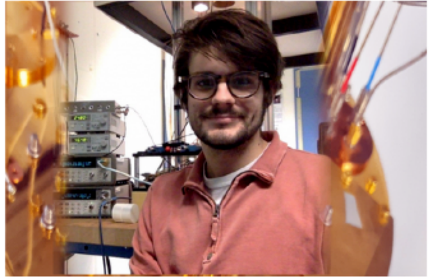
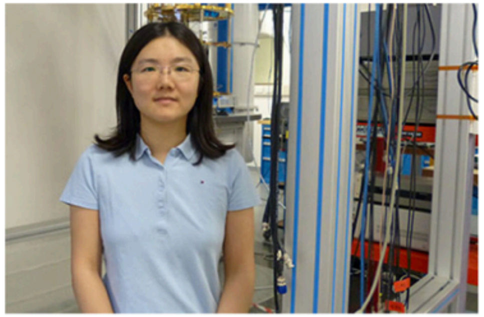
Research Associate

Dr Ben McAllister
Research Associate

Professor Eugene Ivanov
Winthrop Research Professor—Dept of Physics



Dr Jeremy Bourhill
Postdoctoral Research Associate



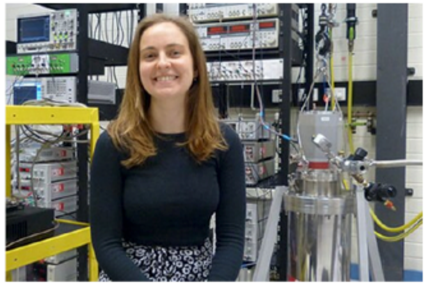
Dr Cindy Zhao
Deborah Jin Fellow—EQUS

Professor Alexey Veryaskin
Adjunct Professor

Graeme Flower
PhD

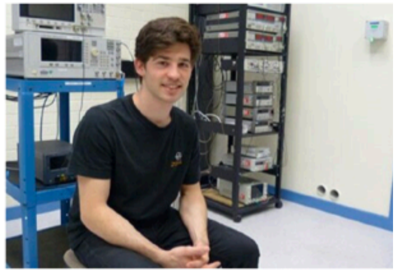
Aaron Quiskamp
PhD

Will Campbell
PhD



Catriona Thomson
PhD

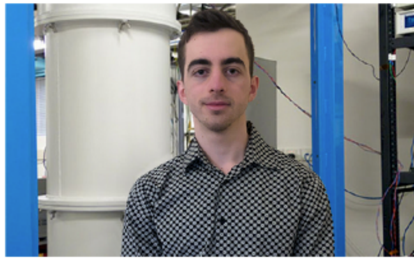
Elrina Hartman
PhD



Jay Mummery
Masters

Robert Crew
BPhil (Hons) Placement

Daniel Tobar
BPhil (Hons) Placement



Michael Hatzon
BPhil (Hons)Placement

Steve Osborne
Technician

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THE END
THE TEAM

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