LOW LOSS ACOUSTIC CAVITIES

FROM FREQUENCY CONTROL TO FUNDAMENTAL PHYSICS

ARC CENTRE OF EXCELLENCE FOR DARK MATTER

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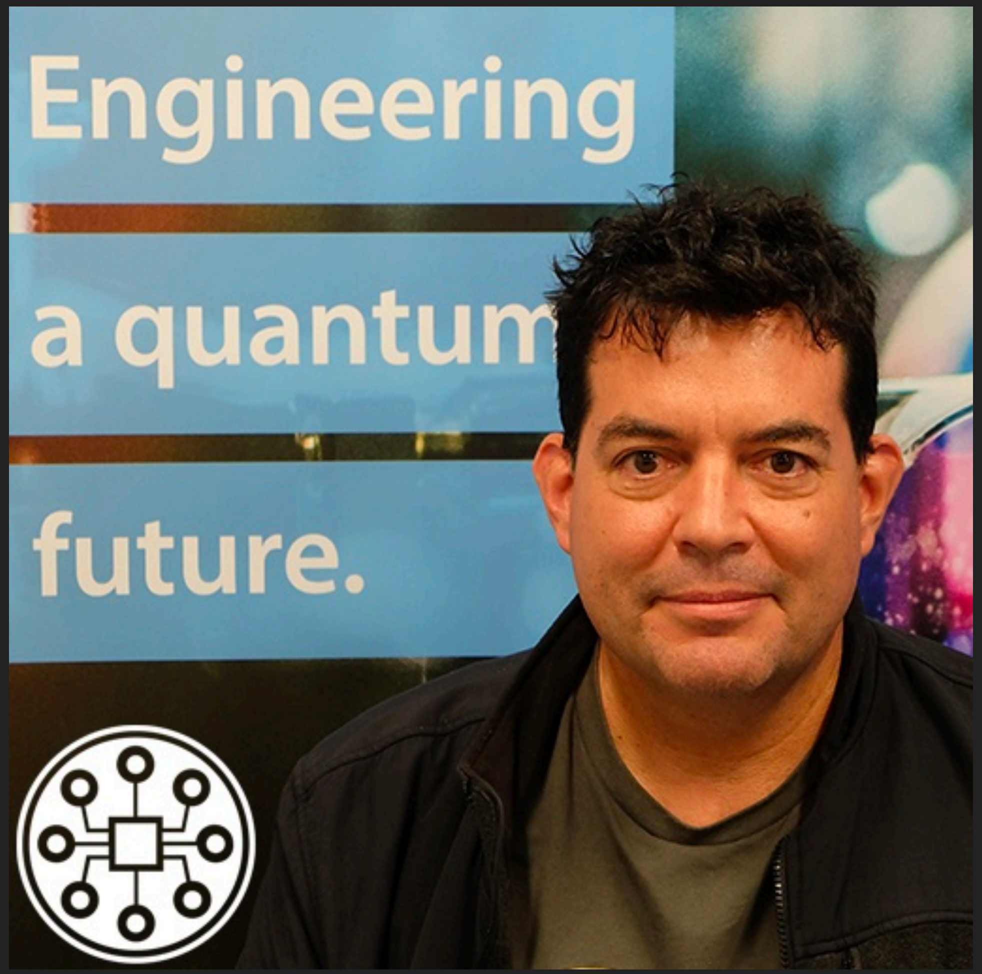
Contributors



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https://www.qdmlab.com

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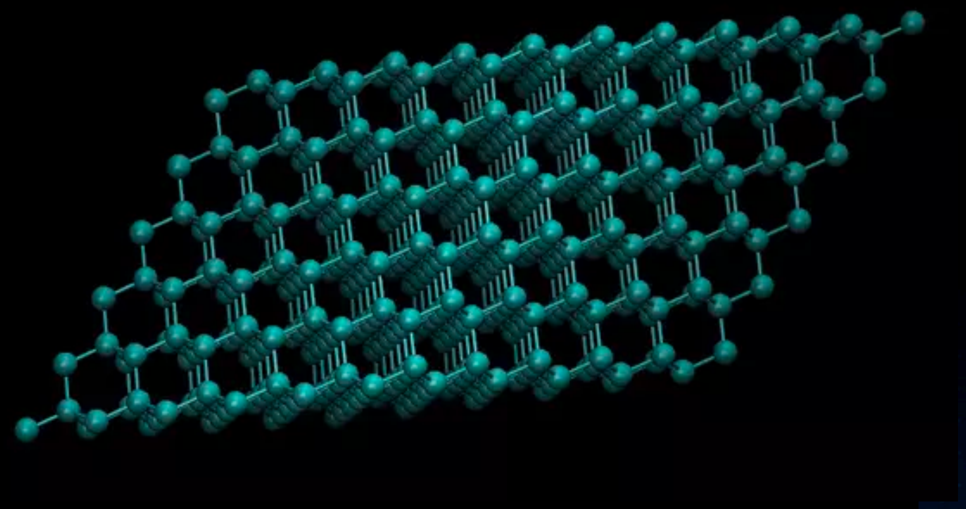
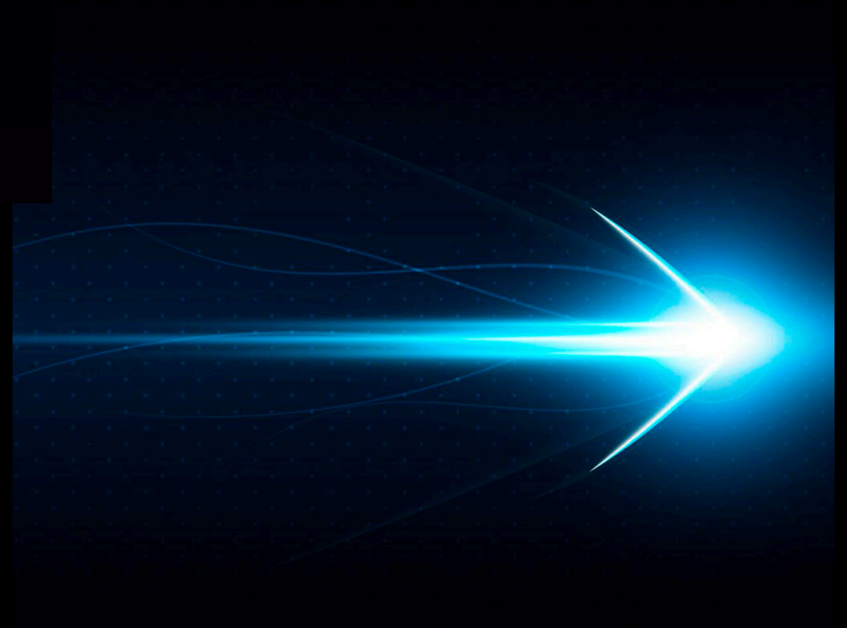
Outline

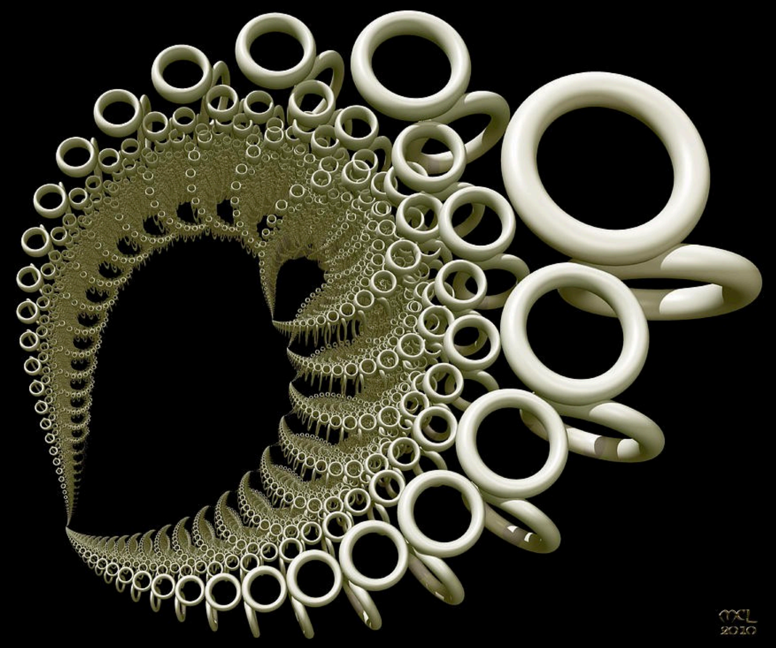
Fundamental Losses



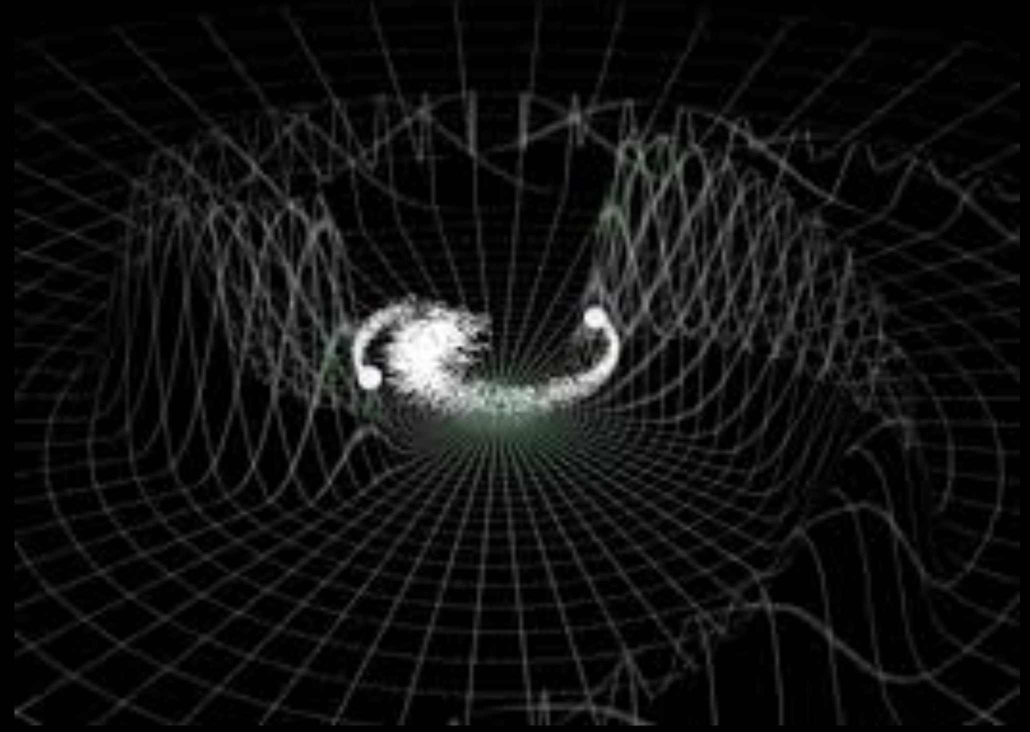
Lorentz Invariance



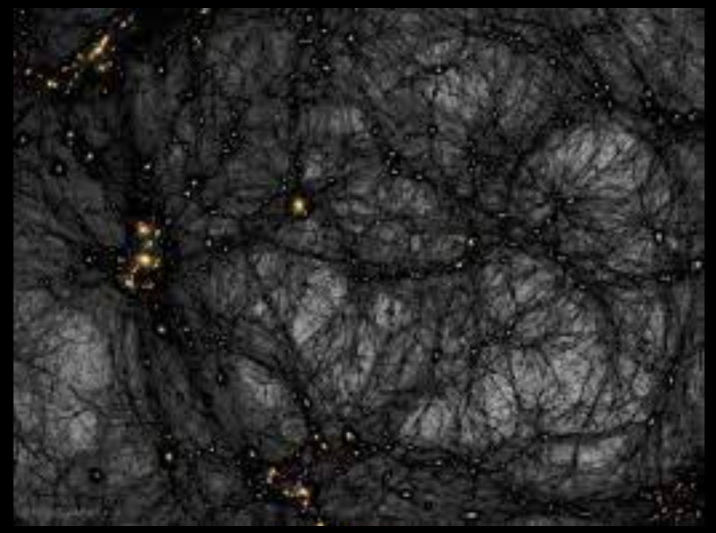
Quantum Gravity



High Frequency GW



Scalar DM



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Quartz BAW

Quartz BAWs Past and Present

SLCET-TR-88-1 (Rev.8.4.3)

AD-A328861 (revised)

QUARTZ CRYSTAL RESONATORS AND OSCILLATORS

For Frequency Control and Timing Applications

A Tutorial

John R. Vig

U.S. Army Communications-Electronics Command

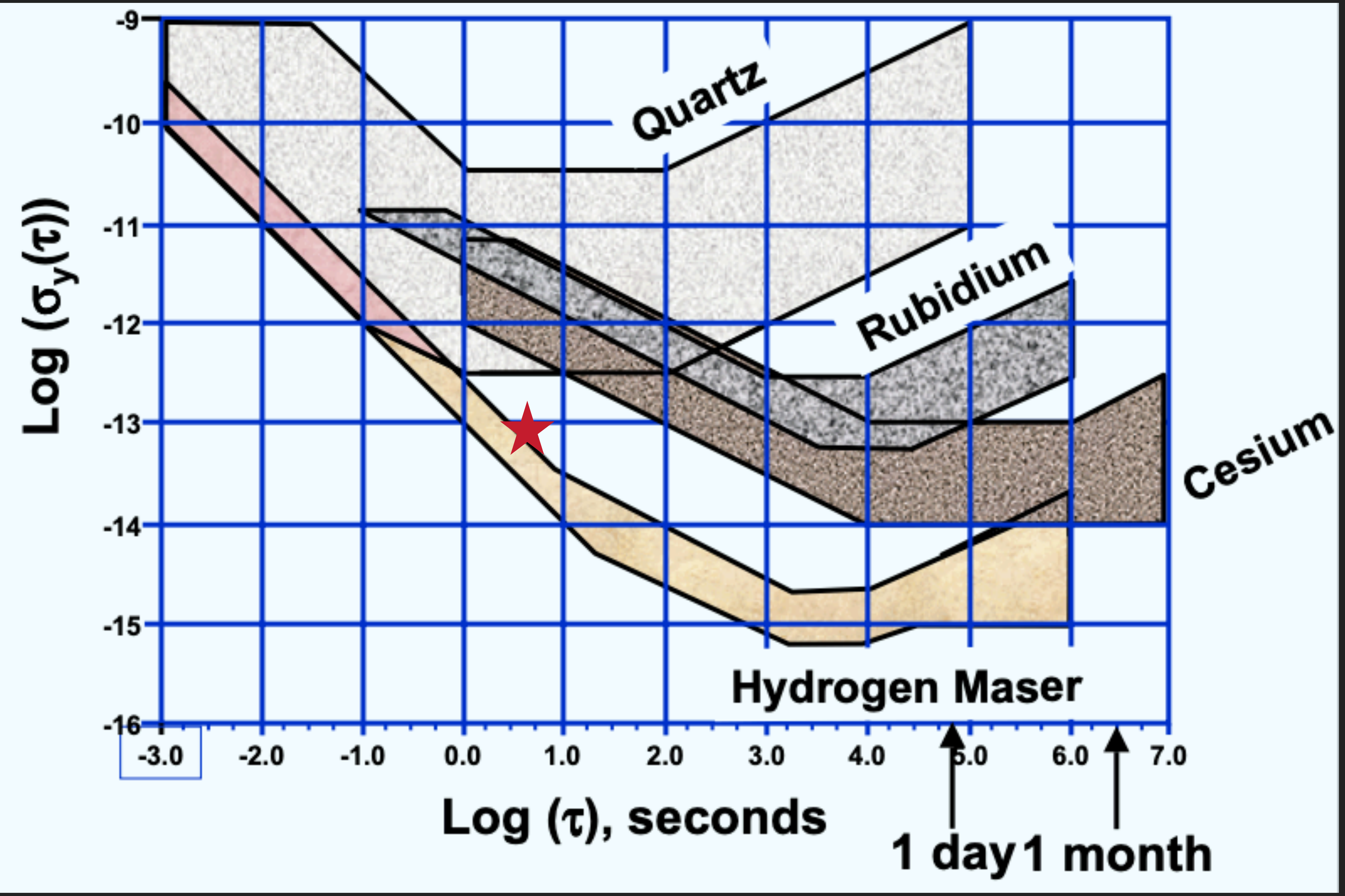
Attn: AMSEL-RD-C2-PT

Fort Monmouth, NJ 07703, USA

J.Vig@IEEE.org

January 2001

Approved for public release.
Distribution is unlimited.



★ BEST OCXO 2023 (>15K EURO)

Quality Factors ~ 3×10^6 @ 5MHz

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Performance Wall or Opportunity?

Quality Factors of the best Quartz Resonators are limited by fundamental material laws not their engineering

Phonon-Phonon Scattering is the fundamental mechanism

Wave-like (Akheiser) regime of acoustic scattering losses

$$f \times Q = \frac{\rho V_a^2\left(1 + (\omega\tau)^2\right)}{C_v T \gamma^2 \tau}, \text{ where } \omega\tau \ll 1$$

Particle-like (Landau-Rumer) regime acoustic scattering losses

$$f \times Q = \frac{15\rho V_a^5 h^3}{\pi^5 \gamma^2 \tau K^4 T^4}\omega, \text{ where } \omega\tau \gg 1$$

V_a: wave velocity, ω: angular resonance frequency, h: Planck constant, K: Boltzmann constant, γ: Grüneisen parameter, C_v: volumetric heat capacity, T: absolute temperature, ρ: density, τ: the phonon relaxation time.

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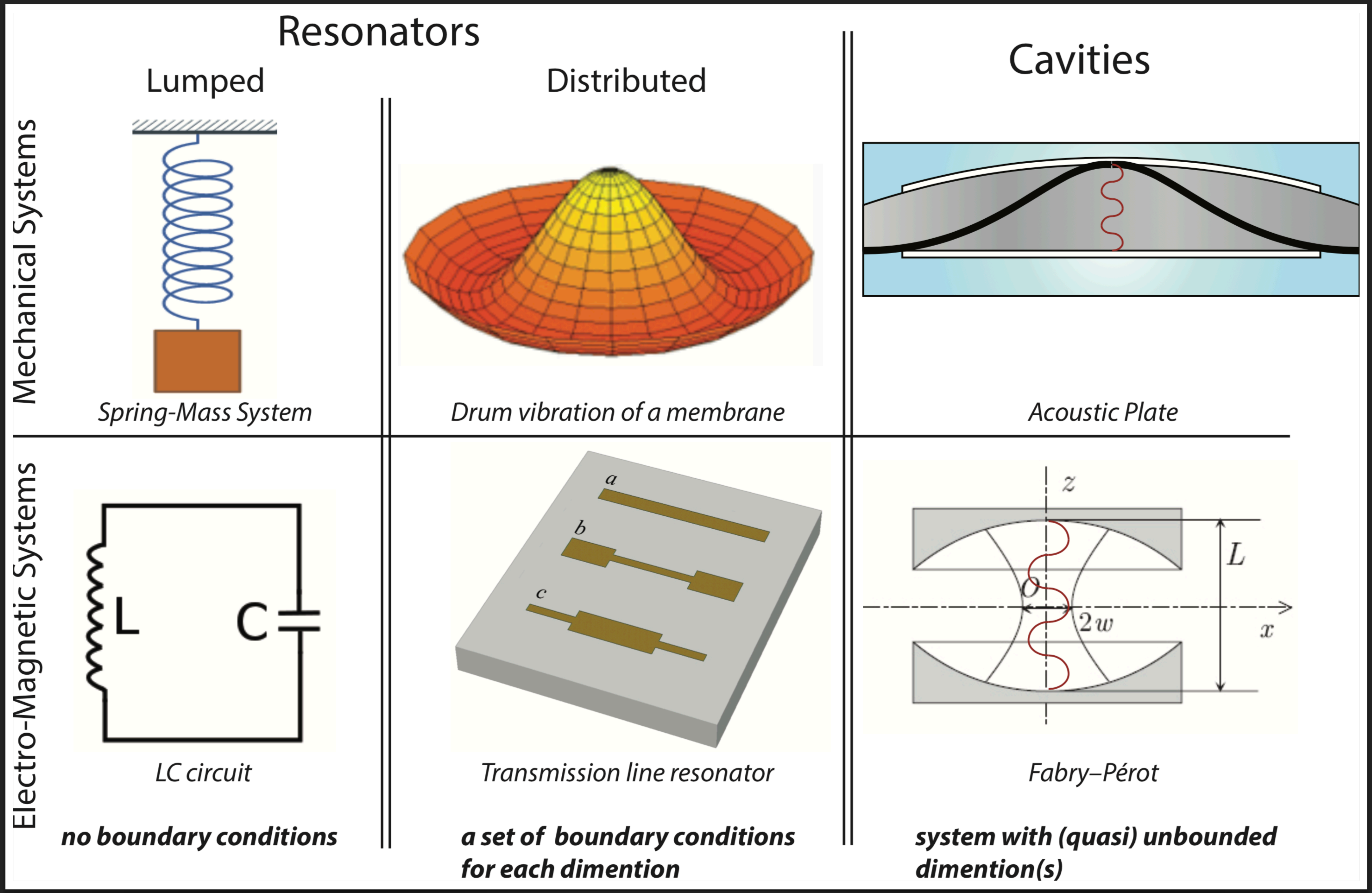
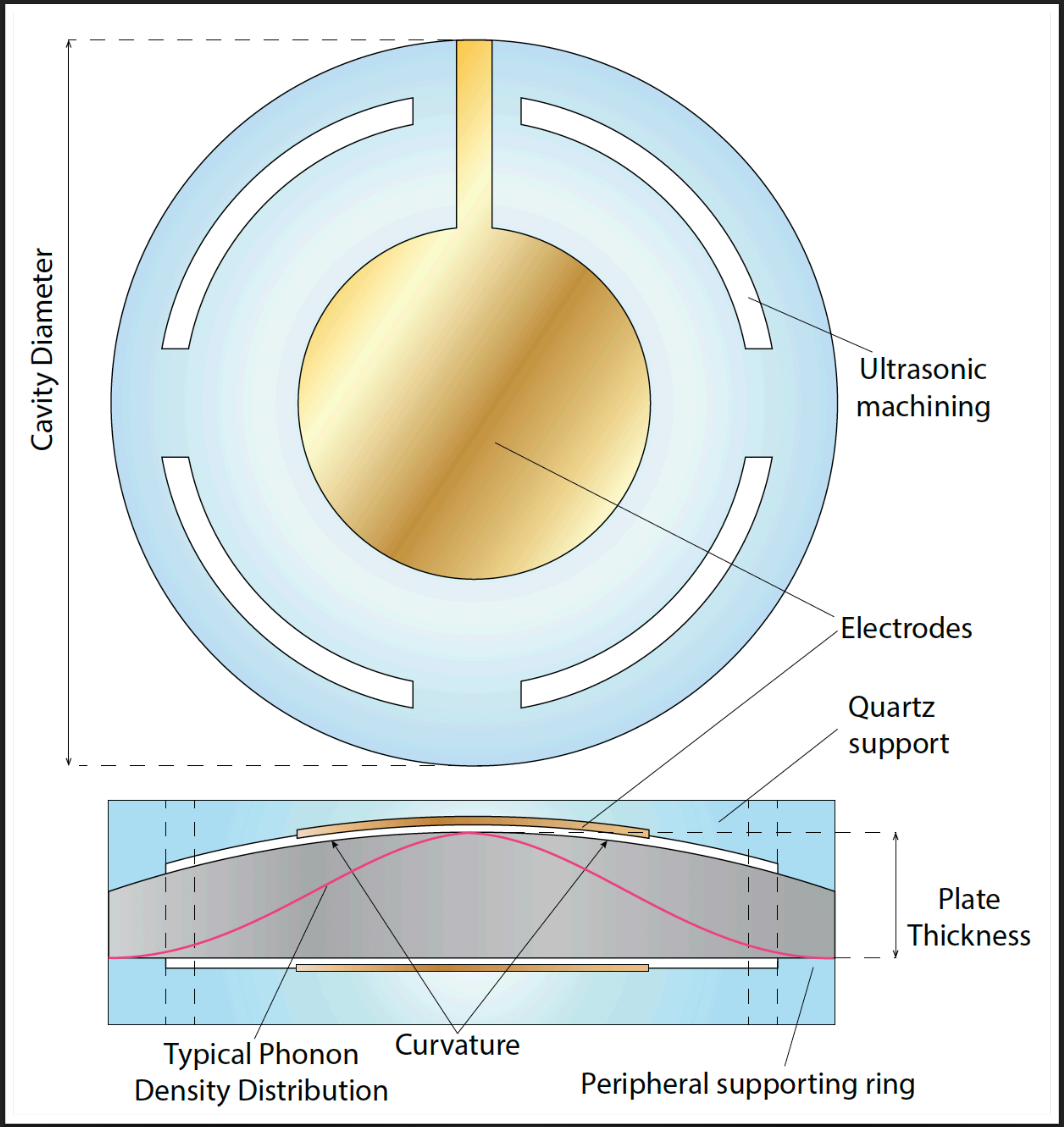
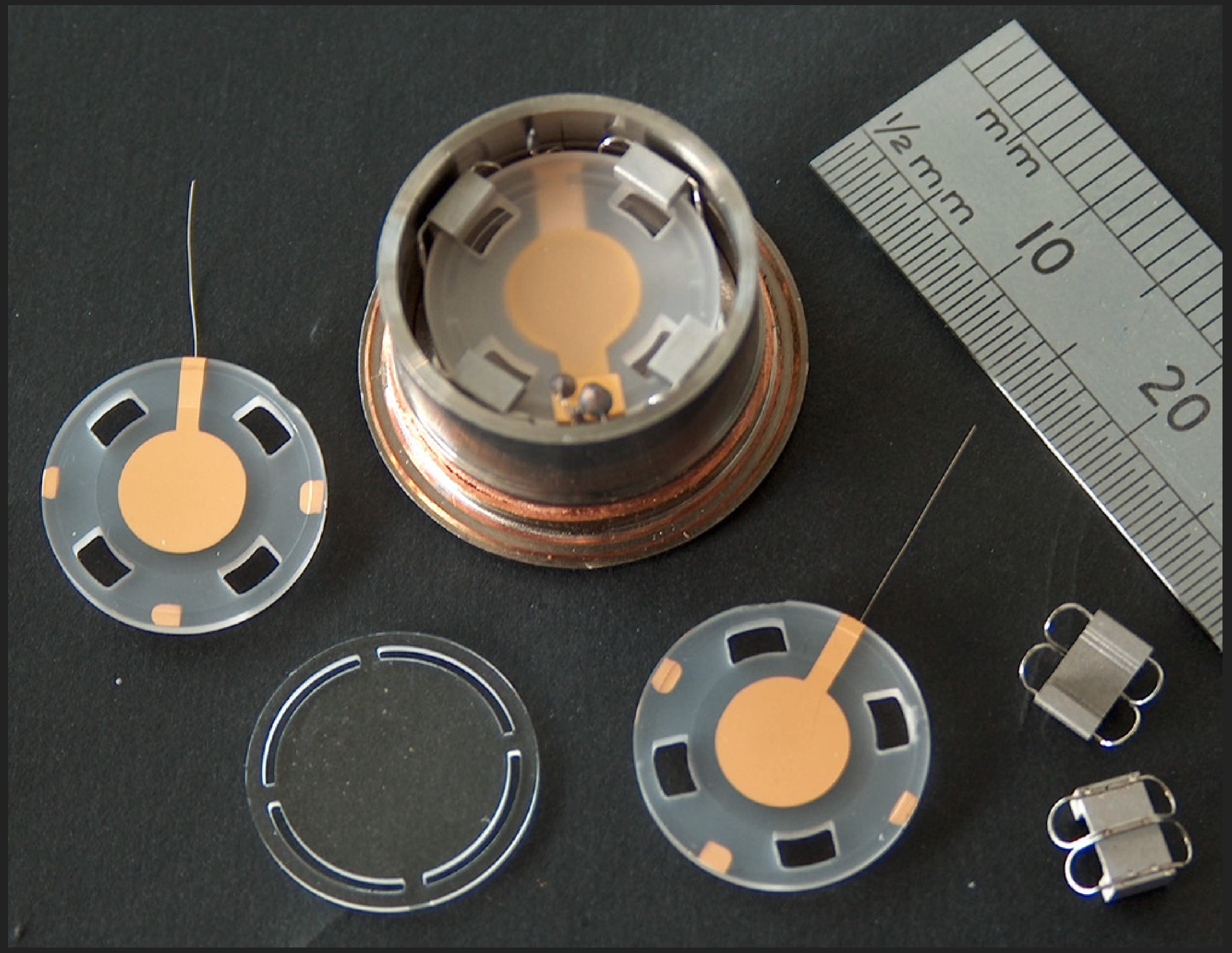
BAW Cavities

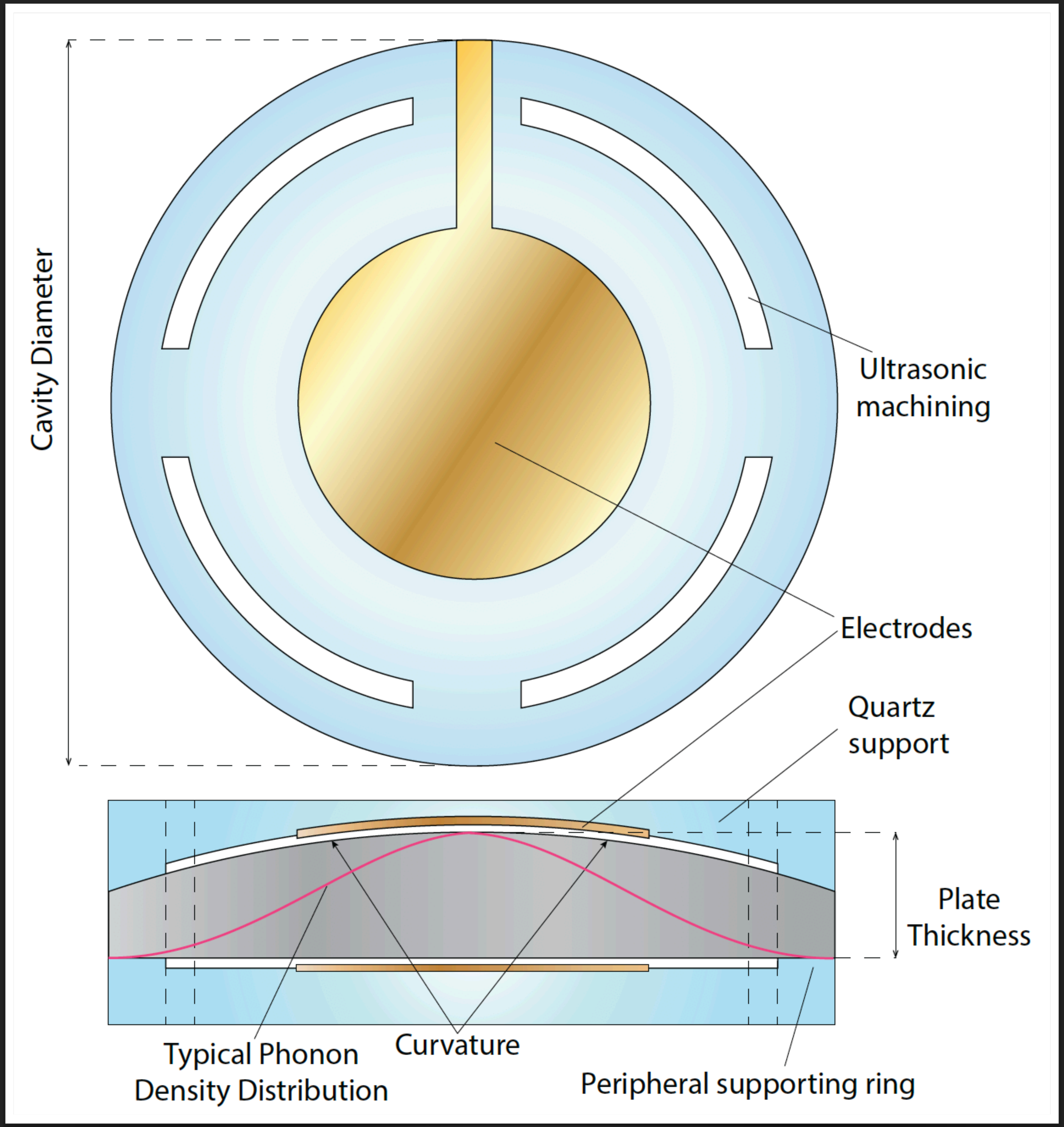




Scientific Reports Vol. 3, 2132 (2013)

BAW Cavities





- Frequency range: 1-1000 MHz
- Tree mode family types: 2 transverse and 1 longitudinal
- Piezoelectric Coupling

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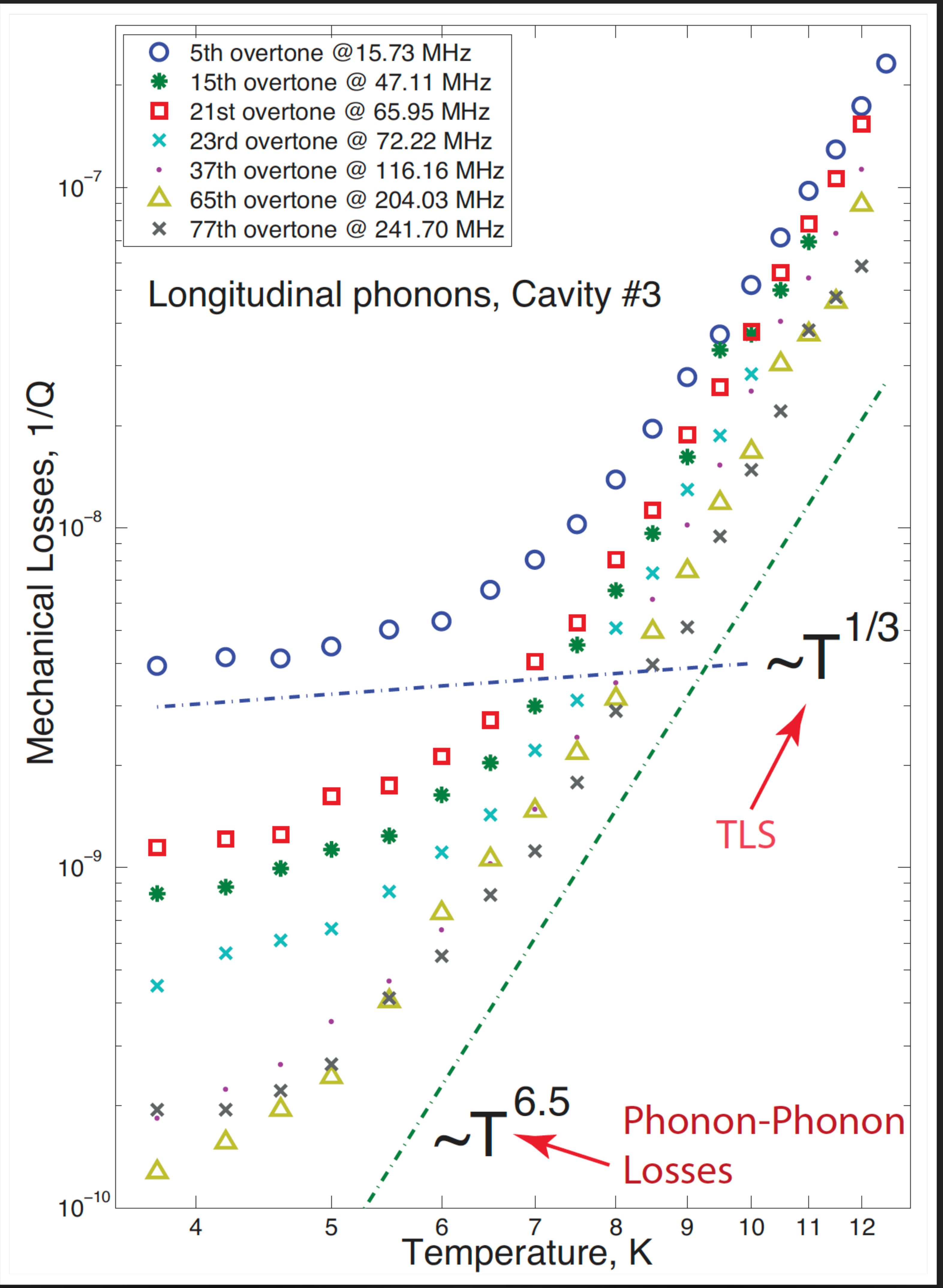
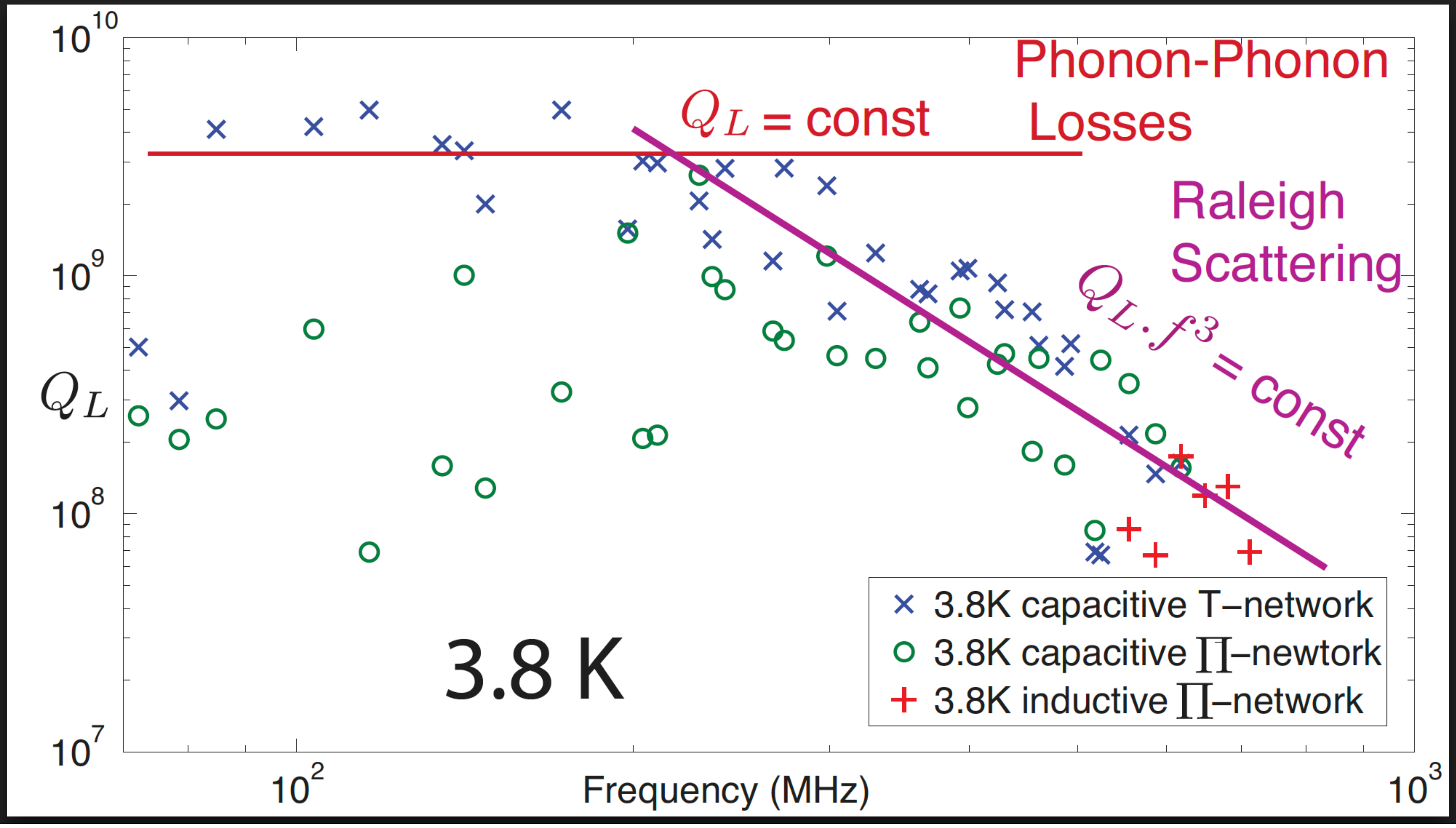
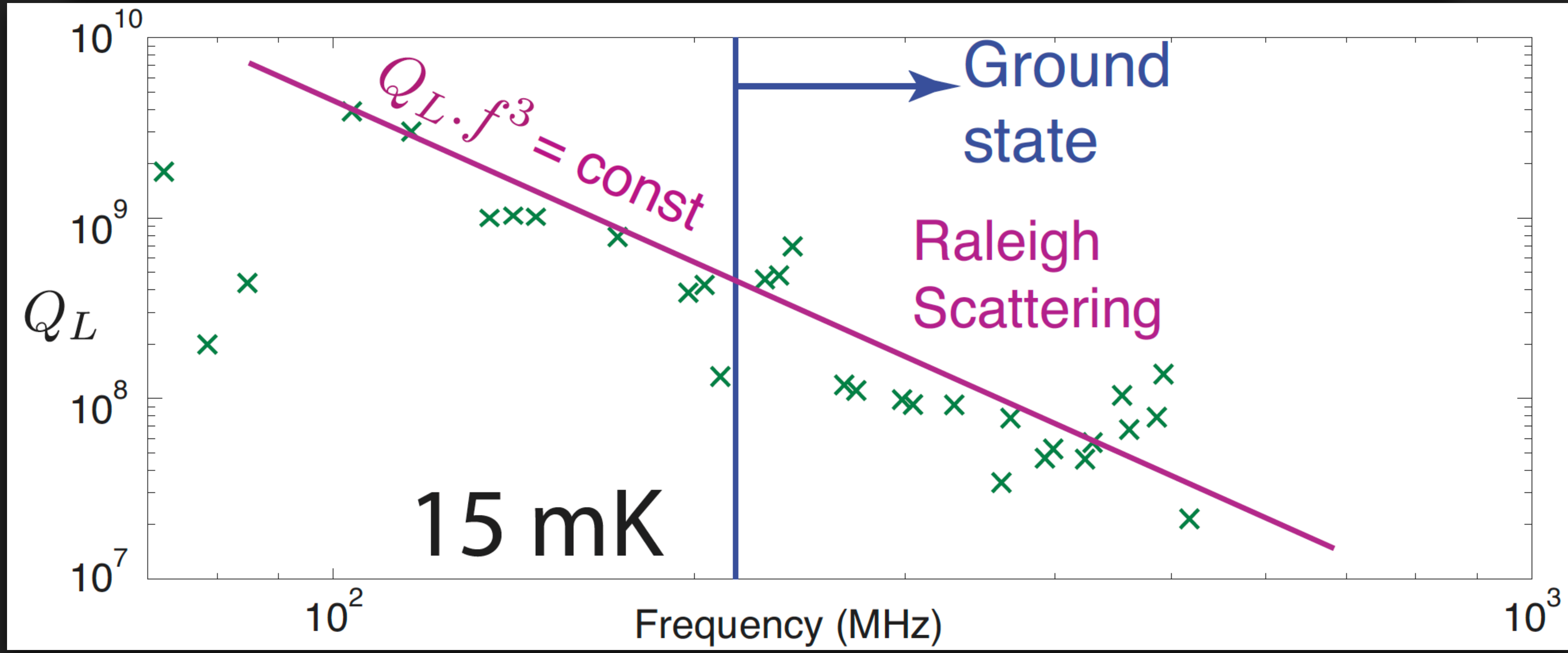
Observation of Different Types of Losses







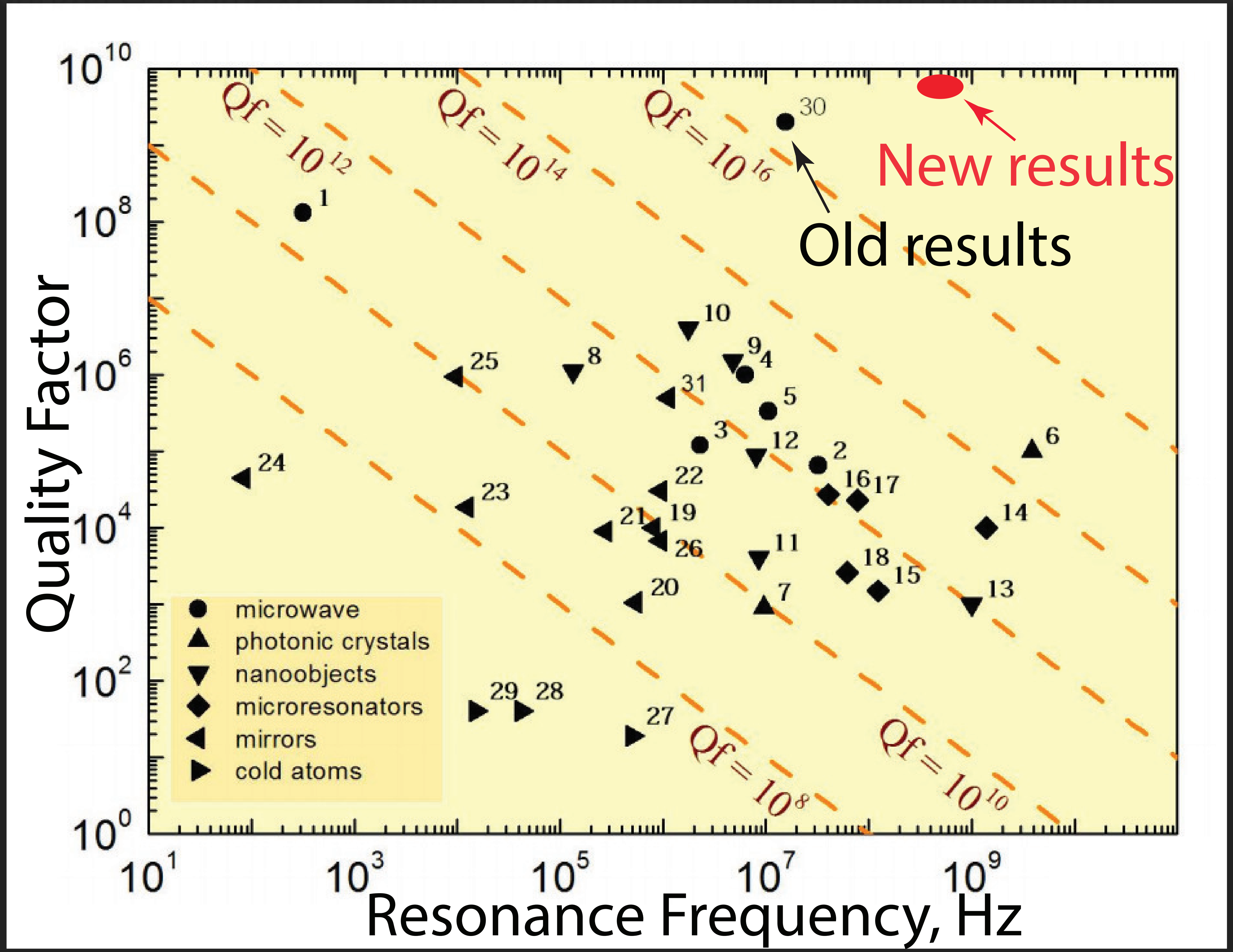
Q = 8x10⁹

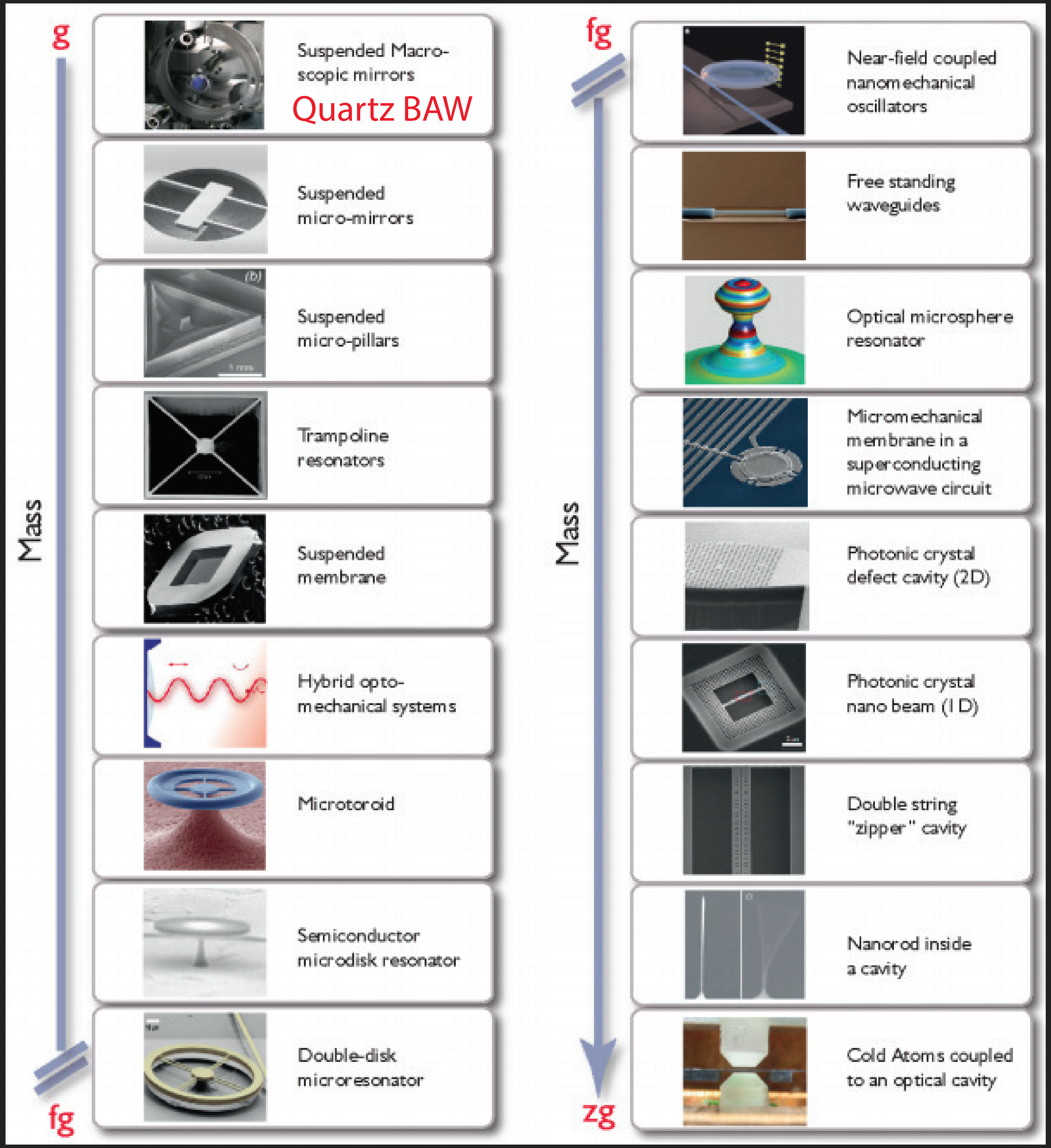
Physical Review Letters 111 (8), 085502

Comparing to Other Technologies

Cavity optomechanics

Markus Aspelmeyer, Tobias J. Kippenberg, and Florian Marquardt
Rev. Mod. Phys. **86**, 1391 – Published 30 December 2014





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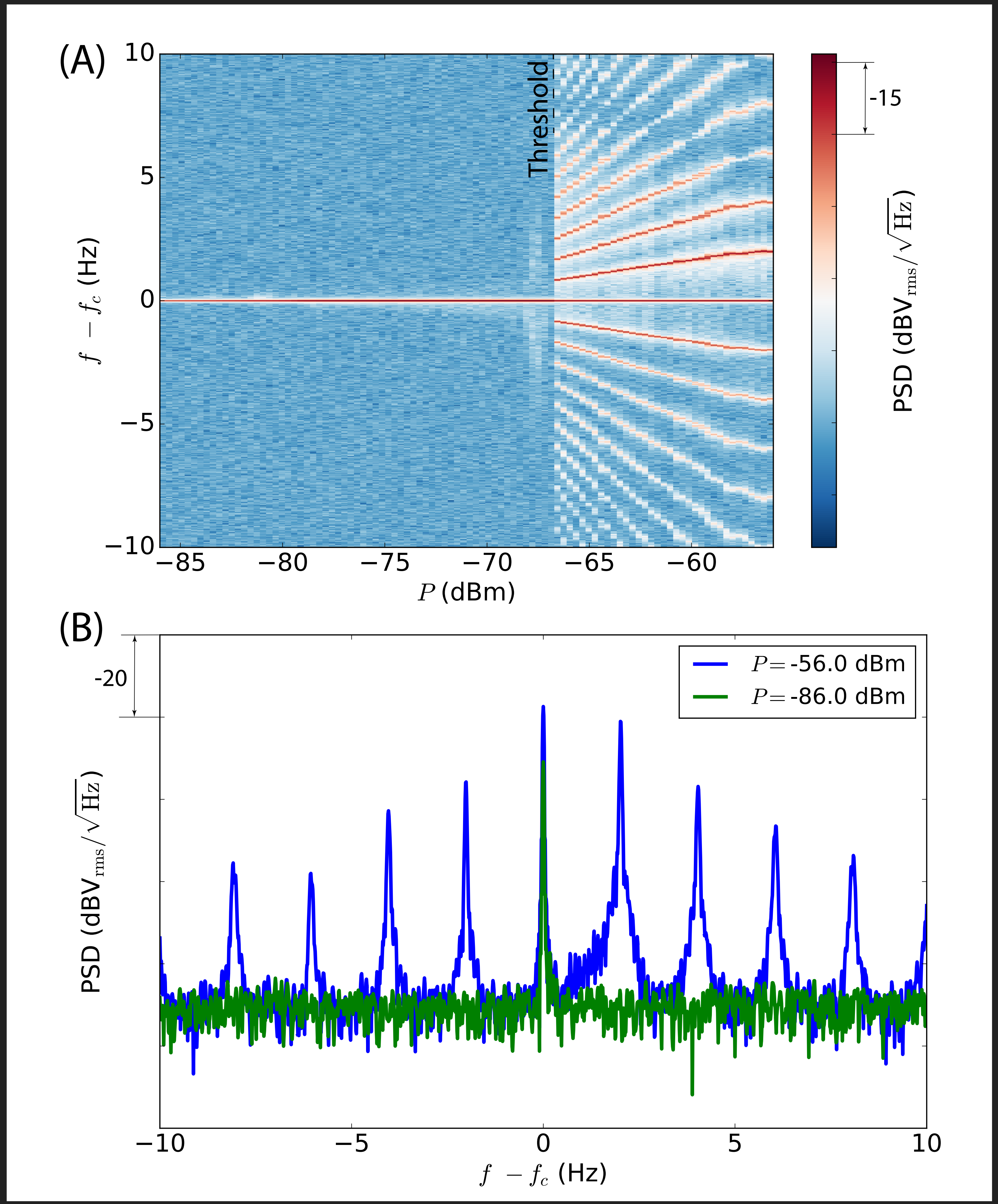
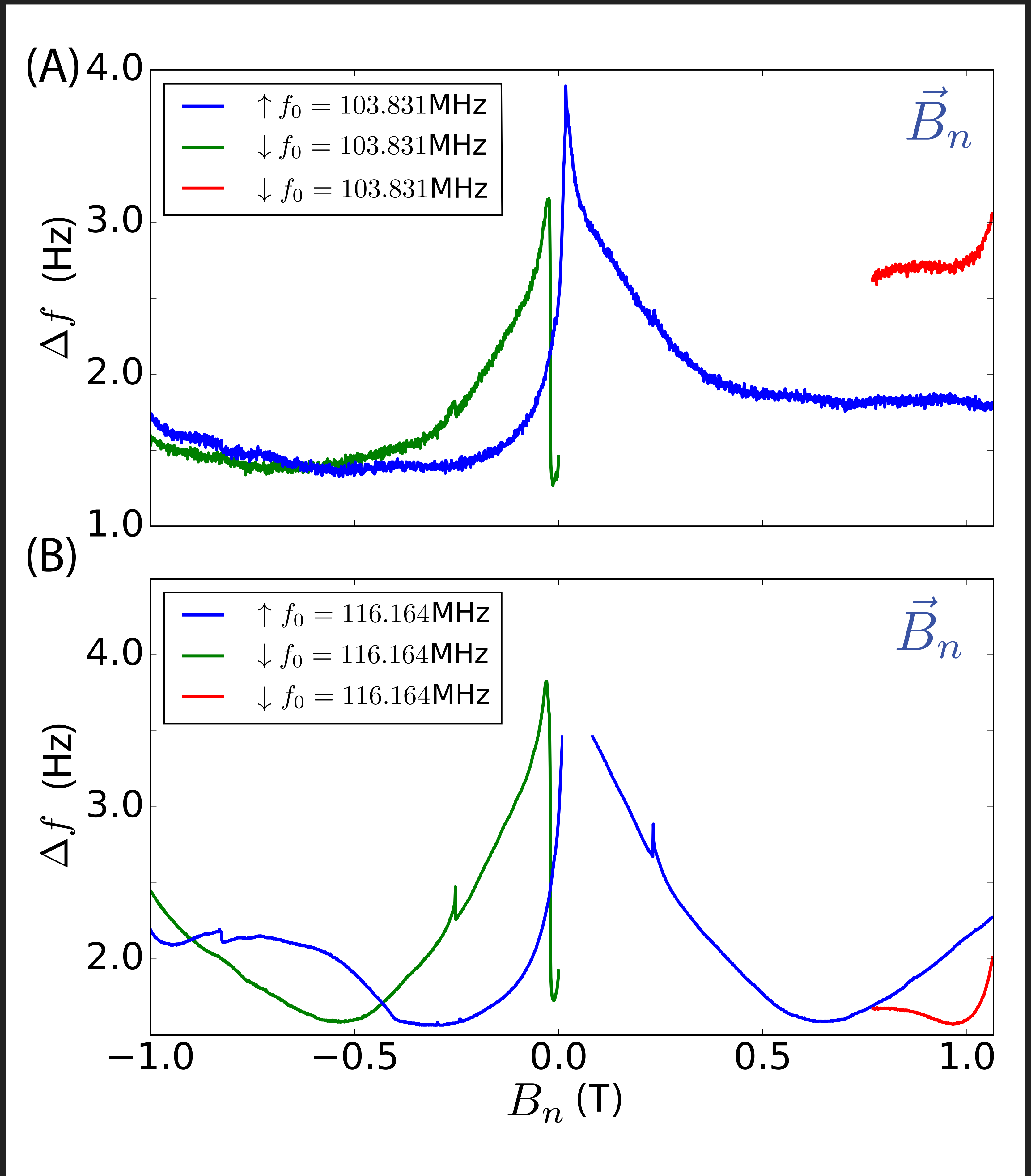
Looking Deeper with Phonons



Strong Duffing Nonlinearity (<1K)

Physical Review Research 2 (2), 023035



Unusual behaviour
Magnetic field sensitivity

Physical Review B 100 (17), 174108

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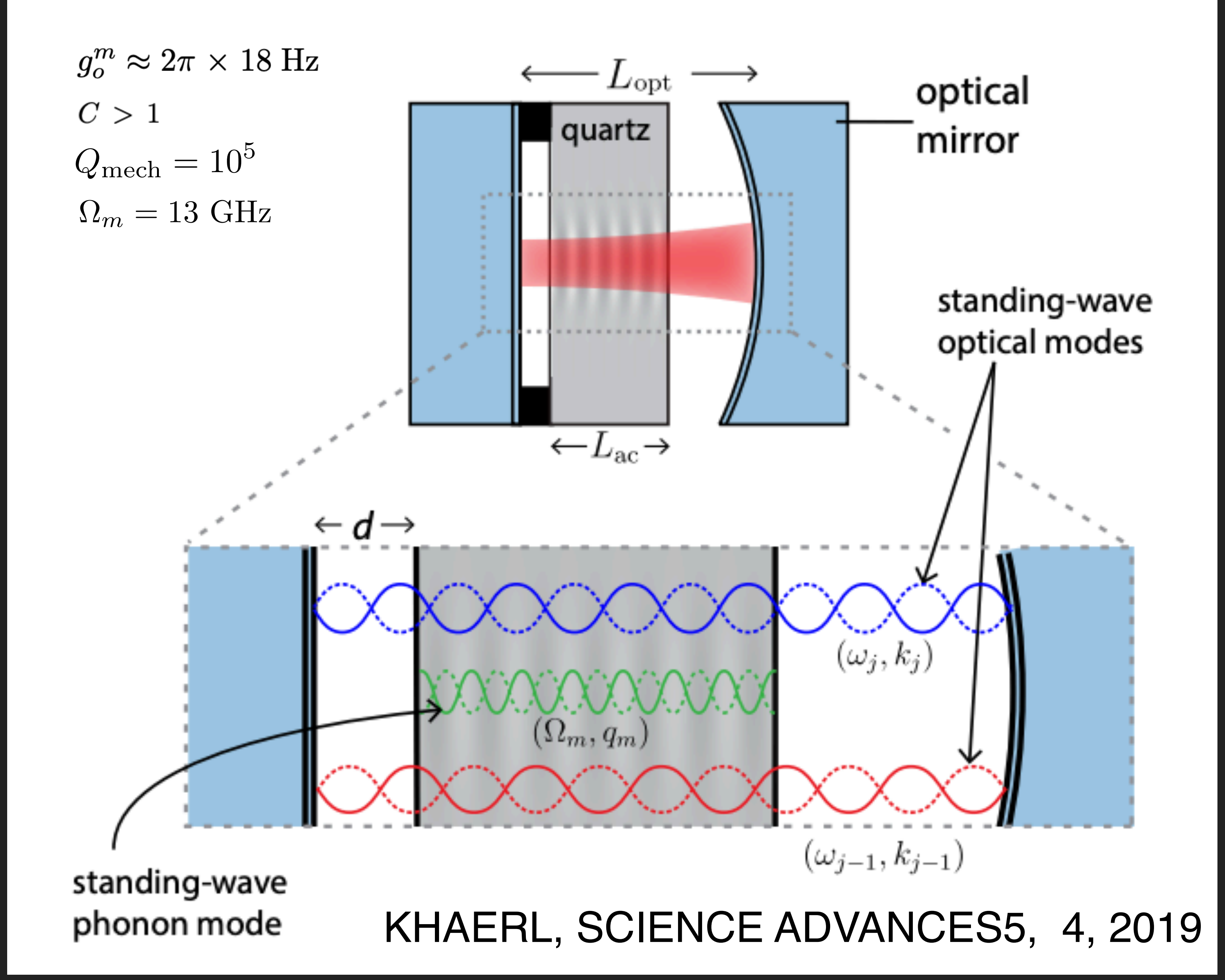
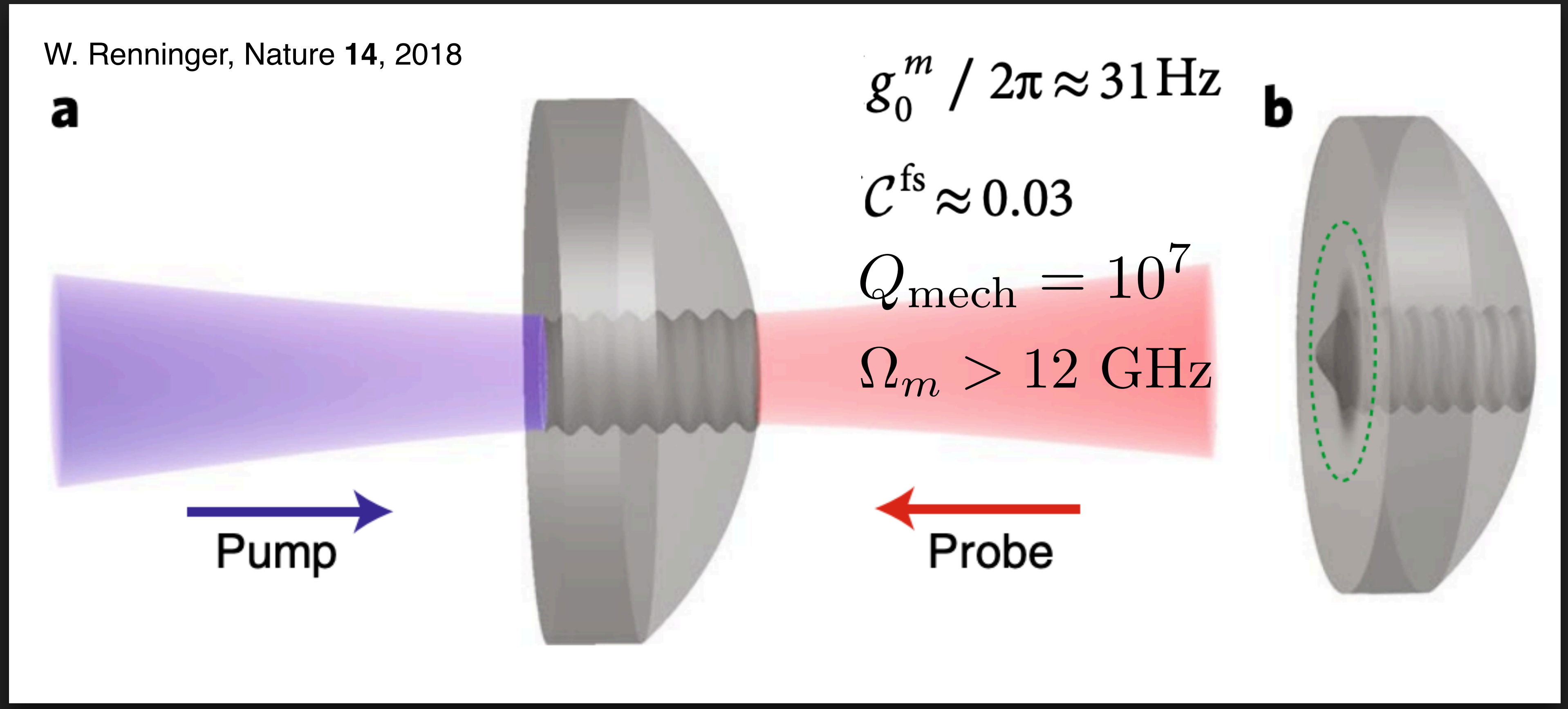
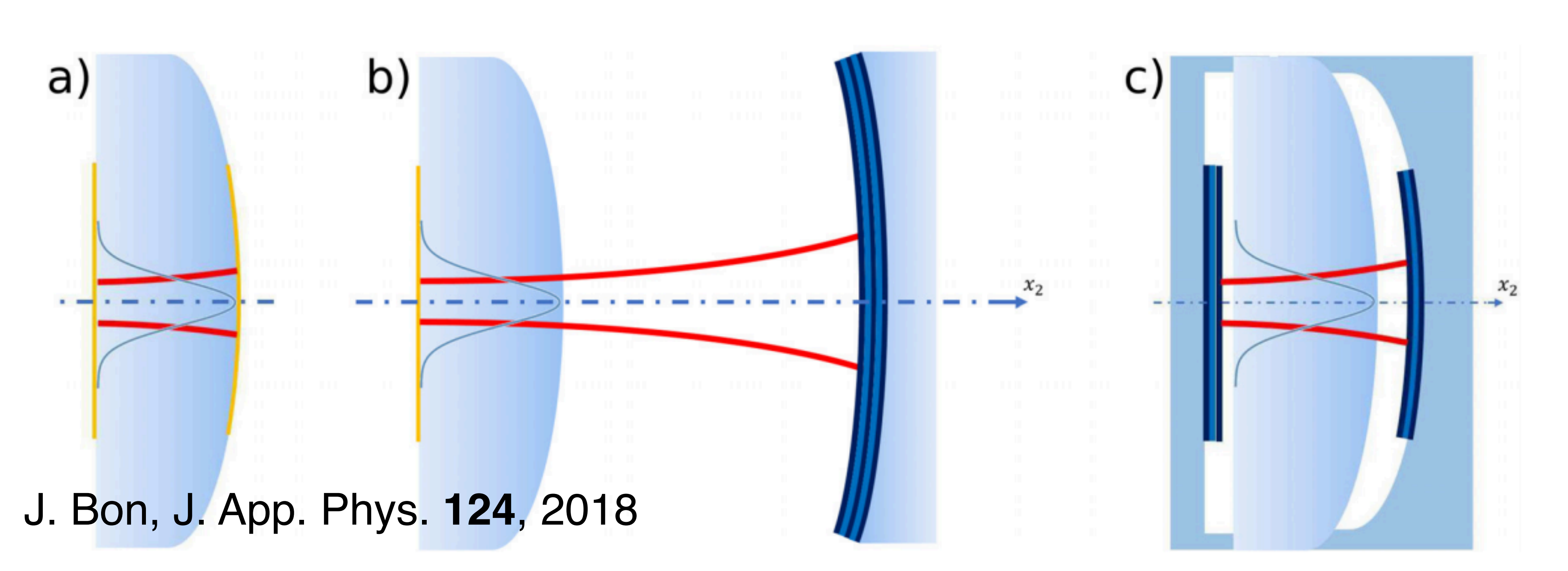
BAW Hybrid Quantum Systems



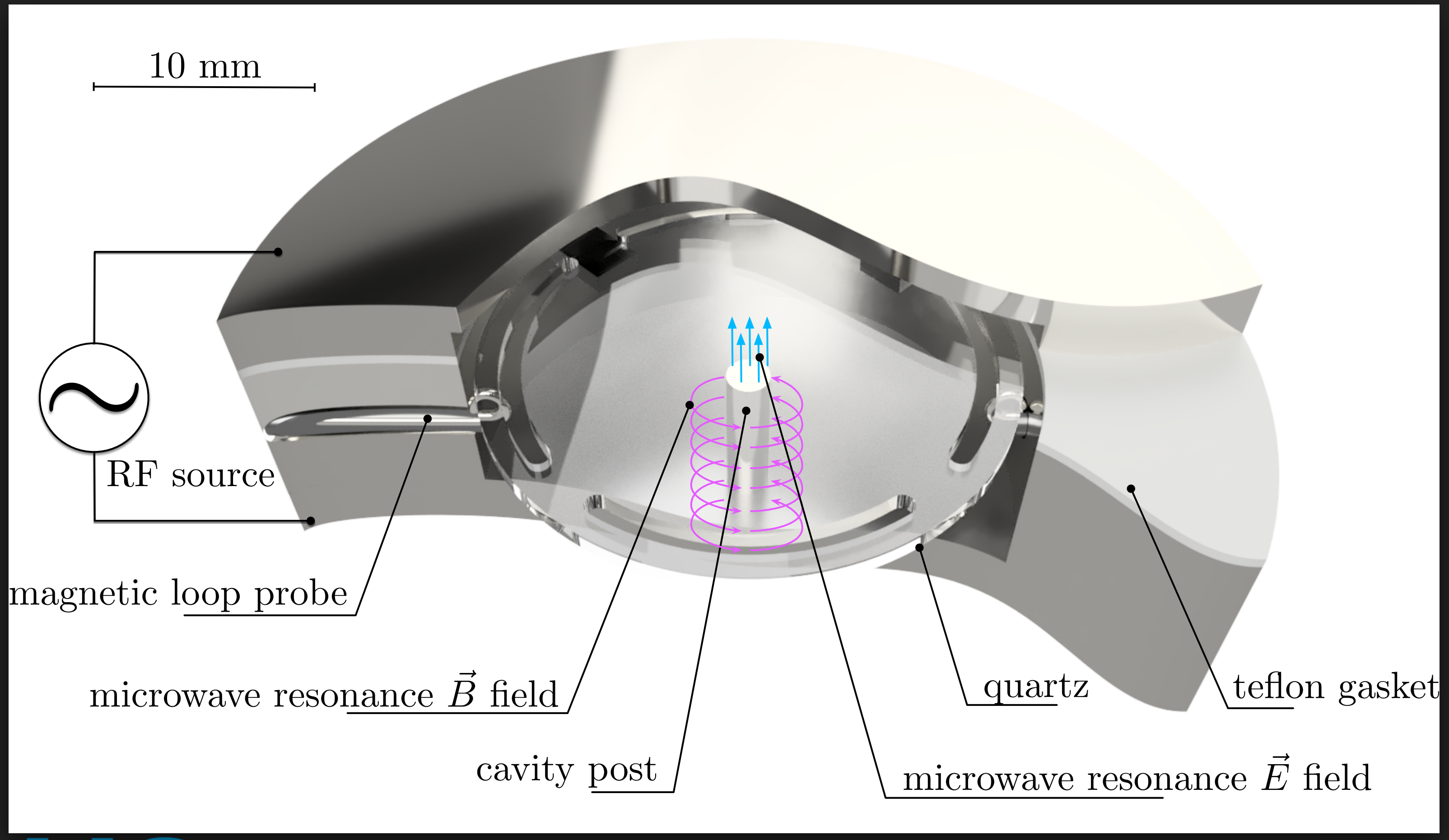
KHAERL, SCIENCE ADVANCES5, 4, 2019

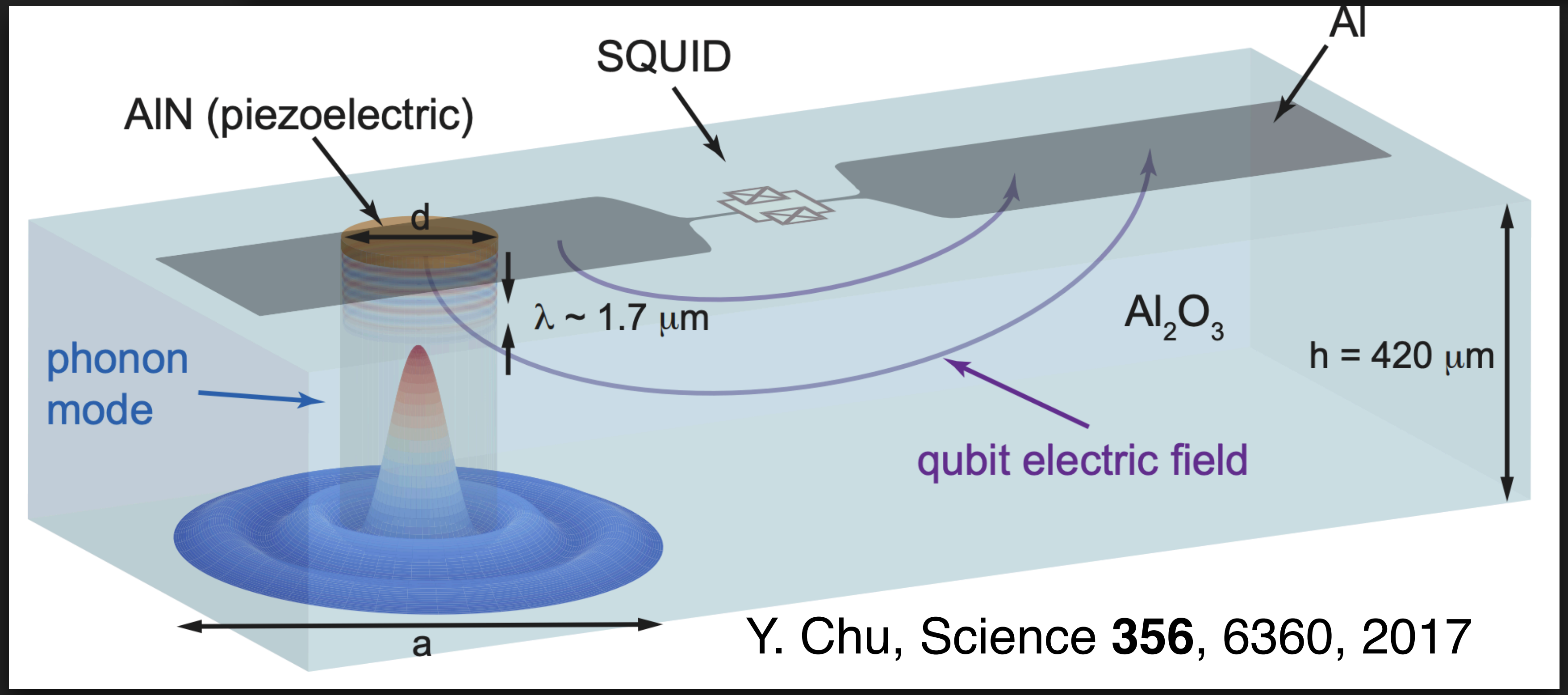


W. Renninger, Nature **14**, 2018



J. Bon, J. App. Phys. **124**, 2018





Y. Chu, Science **356**, 6360, 2017

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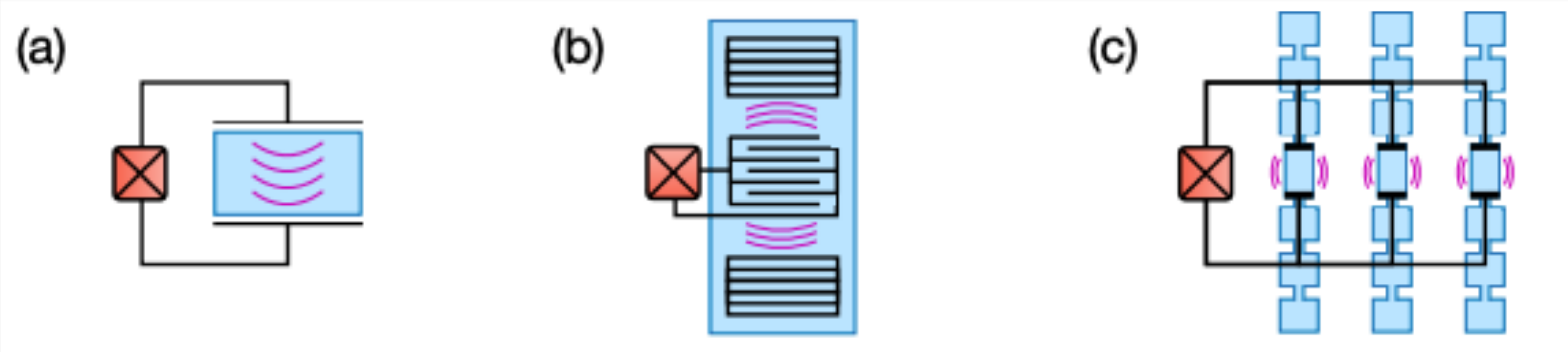
Hybrid Quantum Acoustic System

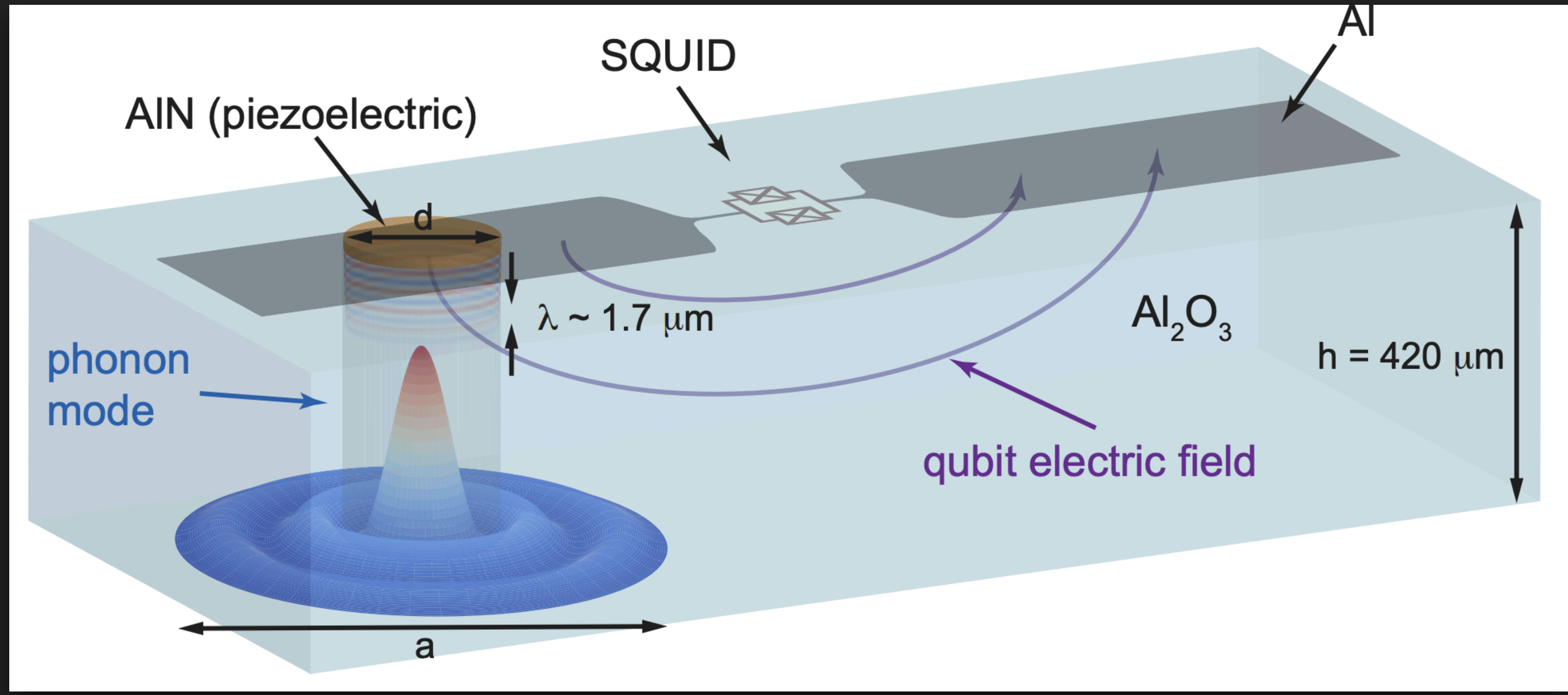
Hardware-efficient quantum random access memory with hybrid quantum acoustic systems

Connor T. Hann,[1] Chang-Ling Zou,[2] Yaxing Zhang,[1] Yiwen Chu,[3]
Robert J. Schoelkopf,[1] Steven M. Girvin,[1] and Liang Jiang[1]

[1] *Departments of Applied Physics and Physics, Yale University, New Haven, Connecticut 06511, USA*
[2] *Key Laboratory of Quantum Information, CAS, University of Science and Technology of China, Hefei, China.*
[3] *Department of Physics, ETH Zürich, 8093 Zürich, Switzerland*

Hybrid quantum systems in which acoustic resonators couple to superconducting qubits are promising quantum information platforms. High quality factors and small mode volumes make acoustic modes ideal quantum memories, while the qubit-phonon coupling enables the initialization and manipulation of quantum states. We present a scheme for quantum computing with multimode quantum acoustic systems, and based on this scheme, propose a hardware-efficient implementation of a quantum random access memory (qRAM). Quantum information is stored in high-Q phonon modes, and couplings between modes are engineered by applying off-resonant drives to a transmon qubit. In comparison to existing proposals that involve directly exciting the qubit, this scheme can offer a substantial improvement in gate fidelity for long-lived acoustic modes. We show how these engineered phonon-phonon couplings can be used to access data in superposition according to the state of designated address modes—implementing a qRAM on a single chip.





Y. Chu, Science **356**, 6360, 2017

Will Quantum Computer include acoustic memory?

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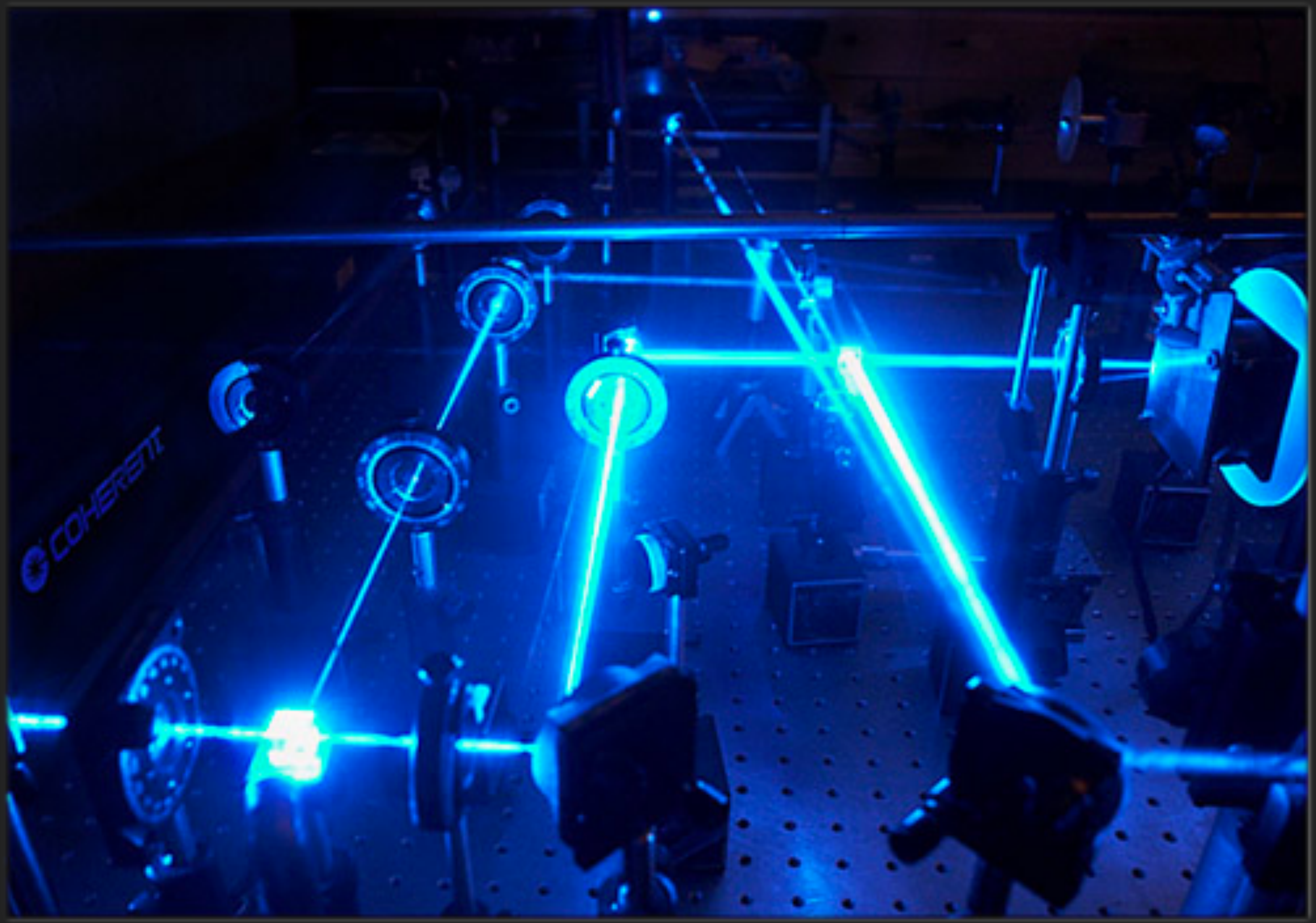
Fundamental Physics with Phonons?



Physics with Light

Physics with Sound

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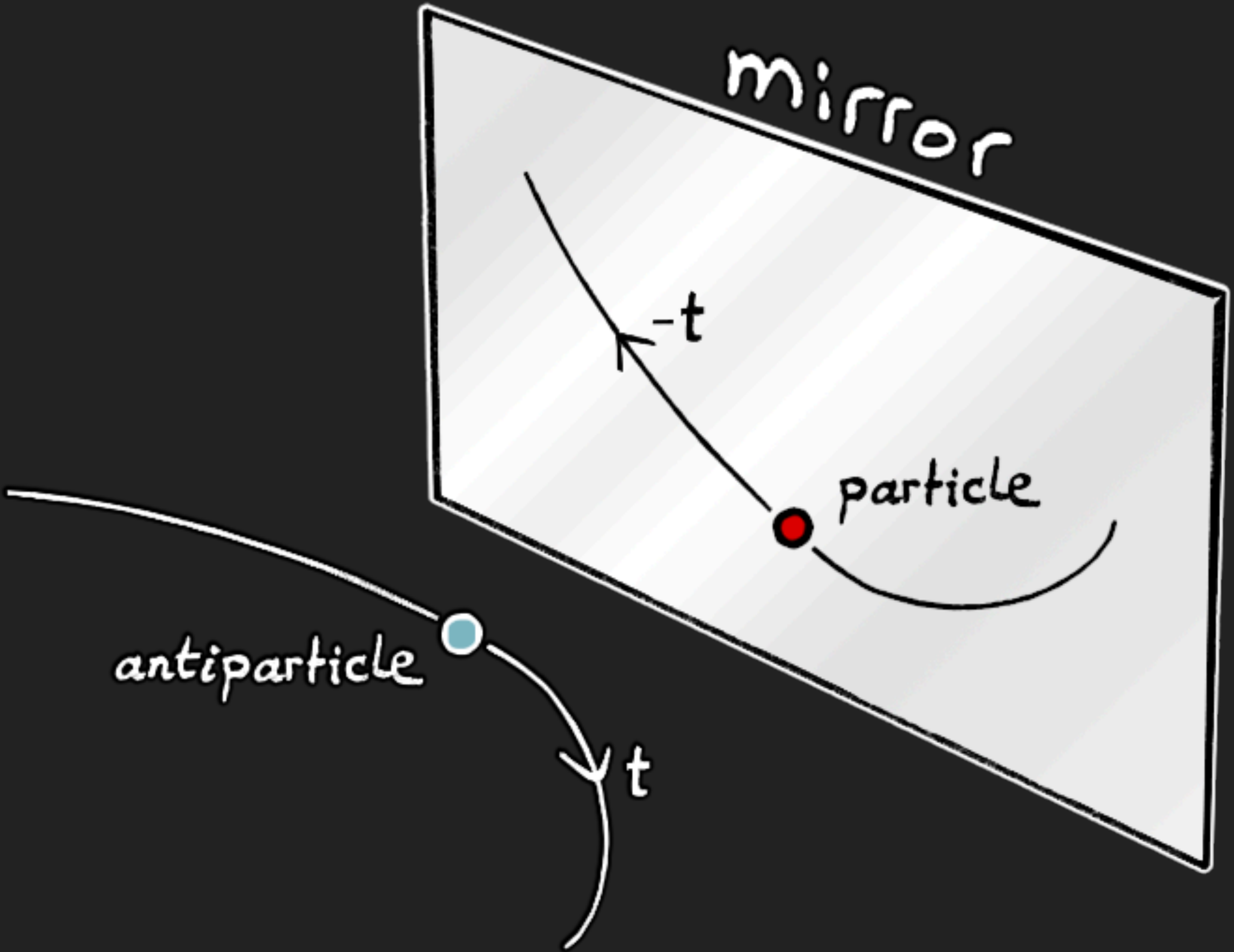
Lorentz Violations



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Lorentz Violations

Standard Model Extension (SME) is an effective Field Theory that includes SM, GR and all possible operators that break Lorentz symmetry.

CPT violation and the standard model

Don Colladay and V. Alan Kostelecký
Department of Physics, Indiana University, Bloomington, Indiana 47405

(Received 22 January 1997)

Spontaneous *CPT* breaking arising in string theory has been suggested as a possible observable experimental signature in neutral-meson systems. We provide a theoretical framework for the treatment of low-energy effects of spontaneous *CPT* violation and the attendant partial Lorentz breaking. The analysis is within the context of conventional relativistic quantum mechanics and quantum field theory in four dimensions. We use the framework to develop a *CPT*-violating extension to the minimal standard model that could serve as a basis for establishing quantitative *CPT* bounds.

Lorentz-violating extension of the standard model

D. Colladay and V. Alan Kostelecký
Physics Department, Indiana University, Bloomington, Indiana 47405

(Received 24 June 1998; published 26 October 1998)

In the context of conventional quantum field theory, we present a general Lorentz-violating extension of the minimal SU(3)×SU(2)×U(1) standard model including *CPT*-even and *CPT*-odd terms. It can be viewed as the low-energy limit of a physically relevant fundamental theory with Lorentz-covariant dynamics in which spontaneous Lorentz violation occurs. The extension has gauge invariance, energy-momentum conservation, and covariance under observer rotations and boosts, while covariance under particle rotations and boosts is broken. The quantized theory is Hermitian and power-counting renormalizable, and other desirable features such as microcausality, positivity of the energy, and the usual anomaly cancellation are expected. Spontaneous symmetry breaking to the electromagnetic U(1) is maintained, although the Higgs expectation is shifted by a small amount relative to its usual value and the Z^0 field acquires a small expectation. A general Lorentz-breaking extension of quantum electrodynamics is extracted from the theory, and some experimental tests are considered. In particular, we study modifications to photon behavior. One possible effect is vacuum birefringence, which could be bounded from cosmological observations by experiments using existing techniques. Radiative corrections to the photon propagator are examined. They are compatible with spontaneous Lorentz and *CPT* violation in the fermion sector at levels suggested by Planck-scale physics and accessible to other terrestrial laboratory experiments. [S0556-2821(99)01601-X]

Searches for violations of Lorentz and CPT symmetry may give a hint for new physics, to provide direction in the quest for a unified theory of QM and GR

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Lorentz Violations

Standard Model Extension (SME) is an effective Field Theory that includes SM, GR and all possible operators that break Lorentz symmetry.

ARTICLE

Received 17 Jan 2015 | Accepted 25 Jul 2015 | Published 1 Sep 2015 DOI: 10.1038/ncomms9174 OPEN

Direct terrestrial test of Lorentz symmetry in electrodynamics to 10^{-18}

Moritz Nagel[1,*], Stephen R. Parker[2,*], Evgeny V. Kovalchuk[1], Paul L. Stanwix[2], John G. Hartnett[2,3], Eugene N. Ivanov[2], Achim Peters[1] & Michael E. Tobar[2]

Lorentz symmetry is a foundational property of modern physics, underlying the standard model of particles and general relativity. It is anticipated that these two theories are low-energy approximations of a single theory that is unified and consistent at the Planck scale. Many unifying proposals allow Lorentz symmetry to be broken, with observable effects appearing at Planck-suppressed levels; thus, precision tests of Lorentz invariance are needed to assess and guide theoretical efforts. Here we use ultrastable oscillator frequency sources to perform a modern Michelson-Morley experiment and make the most precise direct terrestrial test to date of Lorentz symmetry for the photon, constraining Lorentz violating orientation-dependent relative frequency changes $\Delta\nu/\nu$ to $9.2 \pm 10.7 \times 10^{-19}$ (95% confidence interval). This order of magnitude improvement over previous Michelson-Morley experiments allows us to set comprehensive simultaneous bounds on nine boost and rotation anisotropies of the speed of light, finding no significant violations of Lorentz symmetry.

Data Tables for Lorentz and CPT Violation

V. Alan Kostelecký[a] and Neil Russell[b]
[a] *Physics Department, Indiana University, Bloomington, IN 47405*
[b] *Physics Department, Northern Michigan University, Marquette, MI 49855*

IUHET 608; February 2016 update to *Reviews of Modern Physics* **83**, 11 (2011) [arXiv:0801.0287]

This work tabulates measured and derived values of coefficients for Lorentz and CPT violation in the Standard-Model Extension. Summary tables are extracted listing maximal attained sensitivities in the matter, photon, neutrino, and gravity sectors. Tables presenting definitions and properties are also compiled.

Searches for violations of Lorentz and CPT symmetry may give a hint for new physics, to provide direction in the quest for a unified theory of QM and GR

Lorentz Violations

Standard Model Extension (SME) is an effective Field Theory that includes SM, GR and all possible operators that break Lorentz symmetry.

4 Summary Tables
S2-S5

- Matter
- Photon
- Neutrino
- Gravity

30 Data Tables
D6-D35
(nonminimal dimension)

Fermions:
- electron (5,6)
- proton (6)
- neutron

Photon (5,...,9)
Charged leptons:
- muon (5,...,9)
- tau (5,6)

Neutrino (5,6,...)
Quark (6)
Electroweak
Gluon
Gravity (6)

14 Properties Tables
P36-P49

Minimal QED lagrangian
C,P,T properties
Fermion observables
Photon combinations
Full SME (Riemann-Cartan):
- fermion, boson sectors

Neutrinos:
- coefficients, definitions

Nonminimal fermion:
- Lagrange density, coeffs

Nonminimal photon:
- Lagrange density, coeffs

Nonminimal neutrino coeffs

Data Tables for Lorentz and CPT Violation

V. Alan Kostelecký[a] and Neil Russell[b]
[a] *Physics Department, Indiana University, Bloomington, IN 47405*
[b] *Physics Department, Northern Michigan University, Marquette, MI 49855*

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Searches for violations of Lorentz and CPT symmetry may give a hint for new physics, to provide direction in the quest for a unified theory of QM and GR

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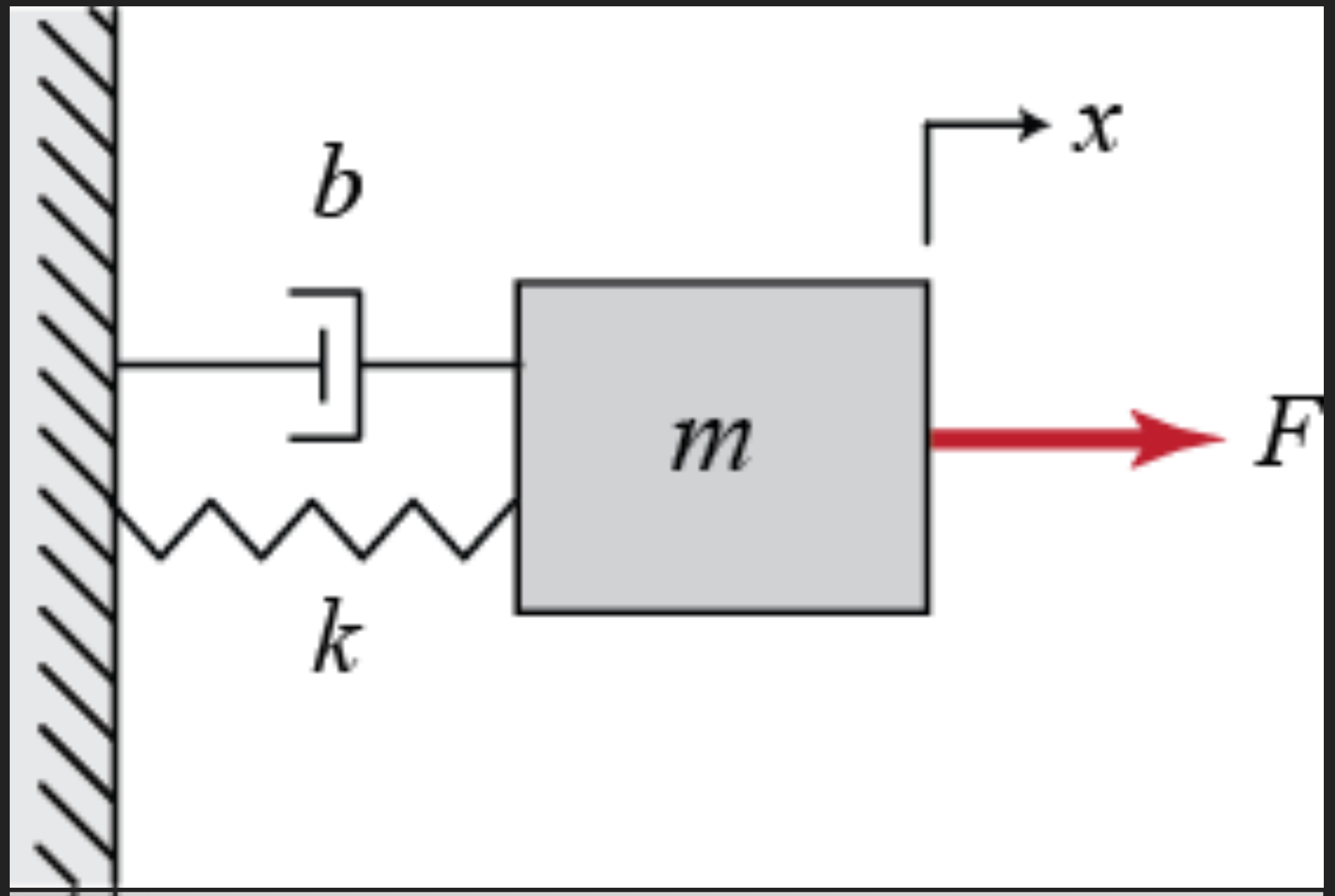
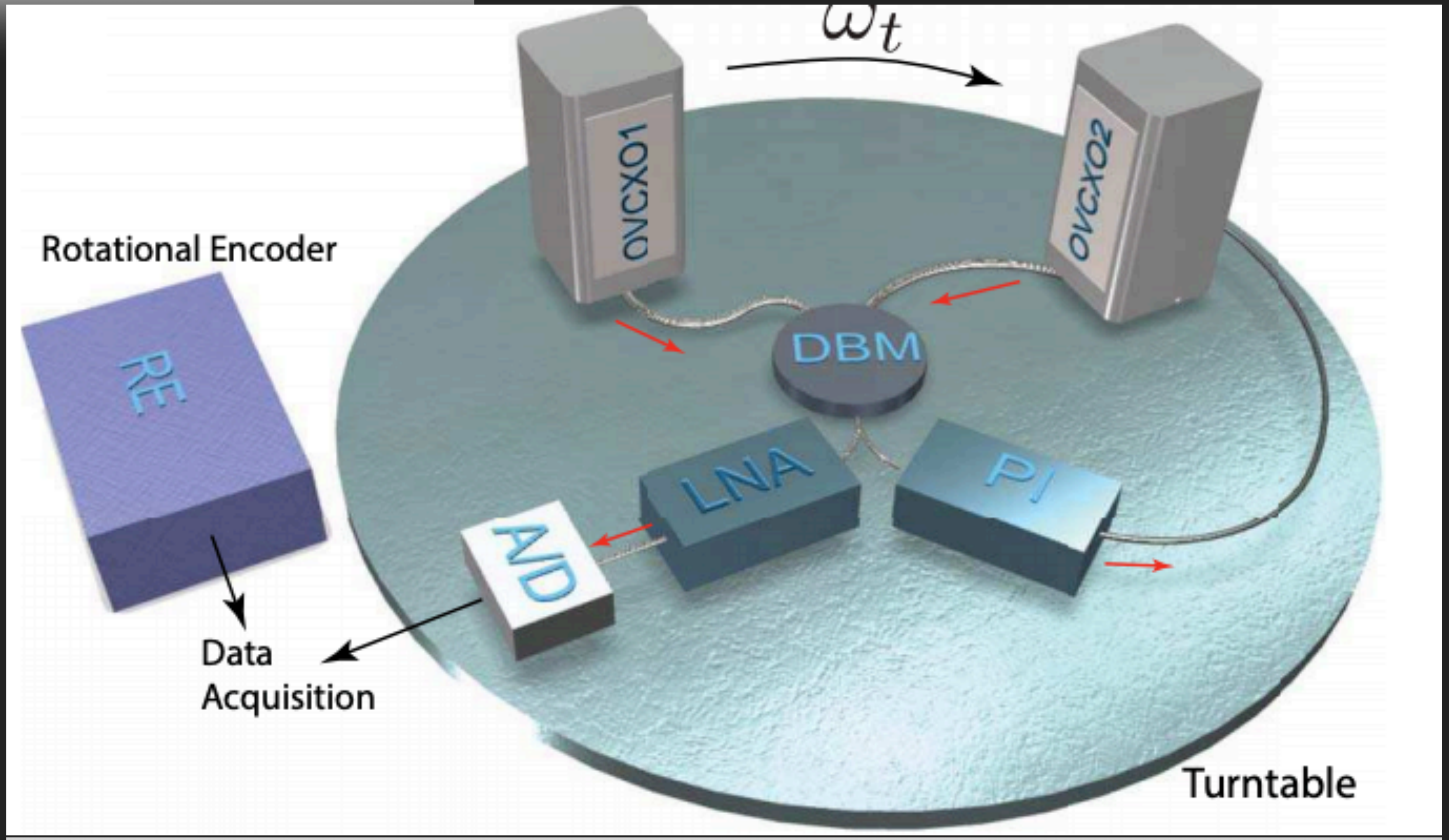
Lorentz Invariance

Acoustic Tests of Lorentz Symmetry Using Quartz Oscillators

Anthony Lo, Philipp Haslinger, Eli Mizrachi, Loïc Anderegg, Holger Müller, Michael Hohensee, Maxim Goryachev, and Michael E. Tobar

Phys. Rev. X **6**, 011018 – Published 24 February 2016





$$f(m) \rightarrow f(\hat{X}, \hat{Y}, \hat{Z})$$

$$\frac{\delta \nu}{\nu} = -\frac{1}{2}\frac{\delta m}{m} = -\frac{1}{2}\left(2c^{Q}_{[xx]} + c^{Q}_{00}\right)$$

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Lorentz Invariance

Acoustic Tests of Lorentz Symmetry Using Quartz Oscillators

Anthony Lo, Philipp Haslinger, Eli Mizrachi, Loïc Anderegg, Holger Müller, Michael Hohensee, Maxim Goryachev, and Michael E. Tobar

Phys. Rev. X **6**, 011018 – Published 24 February 2016

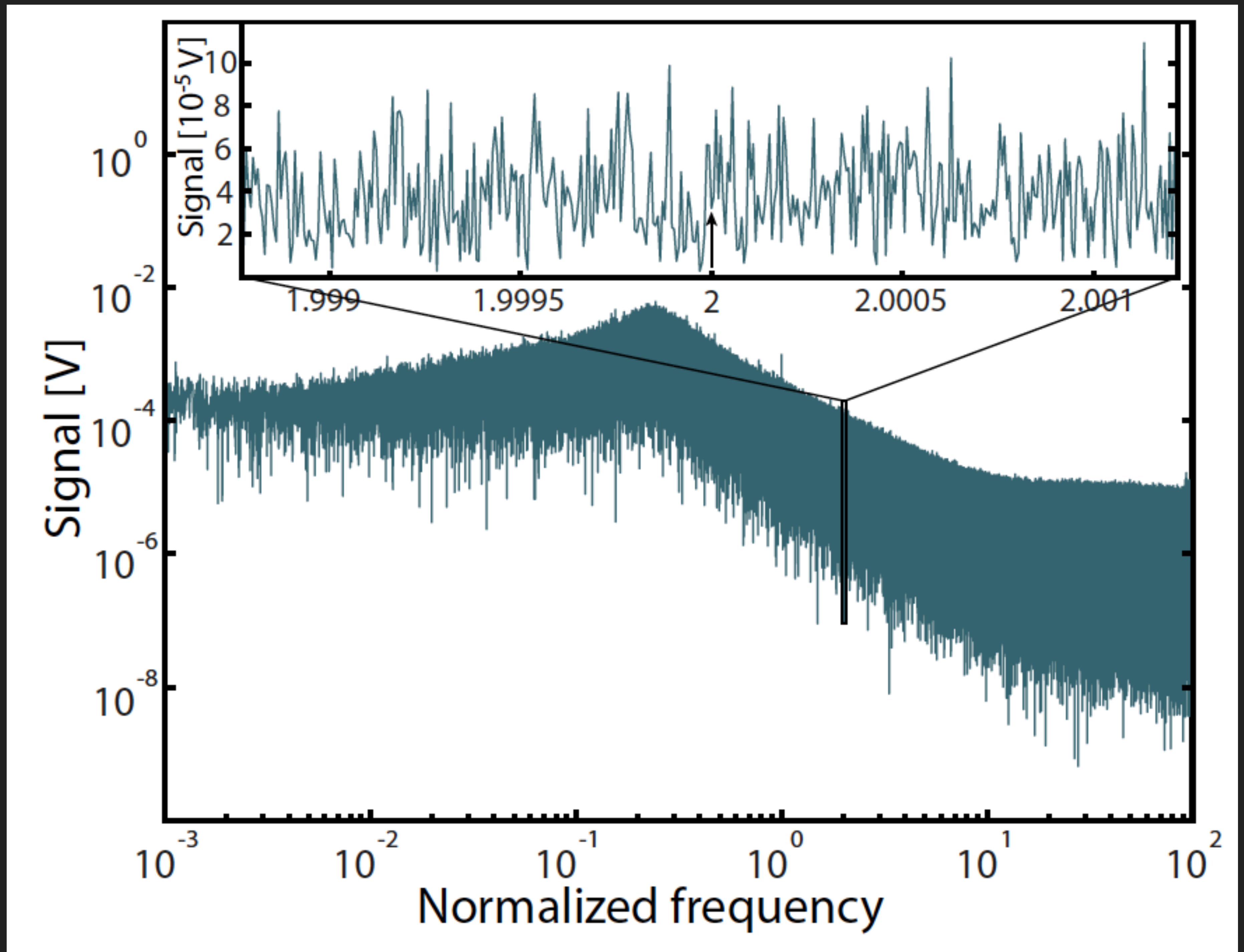
Phys. Rev. X 6, 011018 – Published 24 February 2016

Level of Frequency Deviations:

$$\frac{\delta\nu}{\nu} = (-2 \pm 2.4) \times 10^{-15}$$

Neutron sector coefficient:

$$\tilde{c}_Q^n = (-1.8 \pm 2.2) \times 10^{-14}\text{GeV}$$



120 HOURS OF OBSERVATIONS

This rules out all possibilities for Lorentz violating anisotropies in the inertial mass of neutrons, protons, and electron at the ~10^{-14} GeV level. A few orders of magnitude improvement over previous laboratory test and astrophysical bounds

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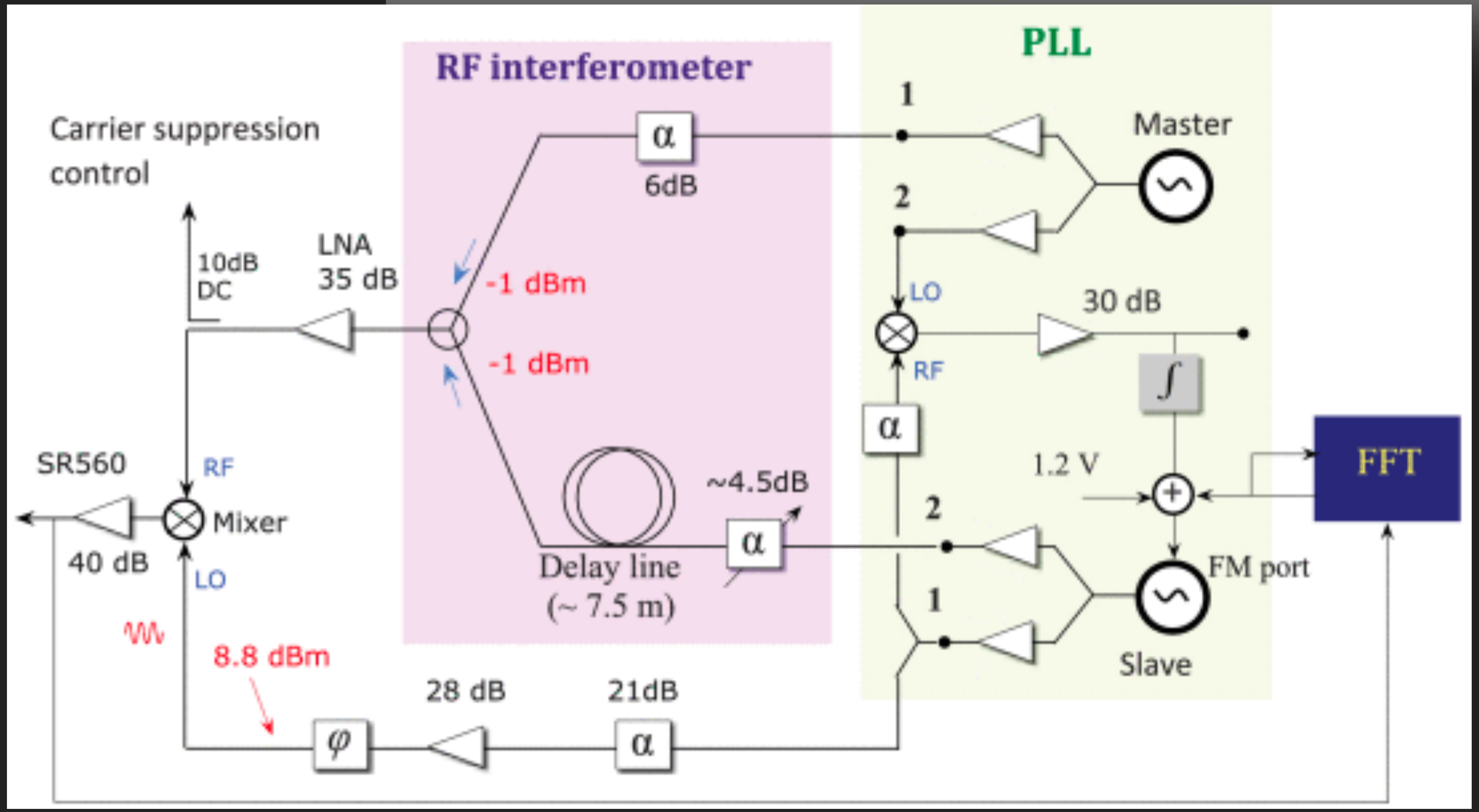
Lorentz Invariance: Next Generation

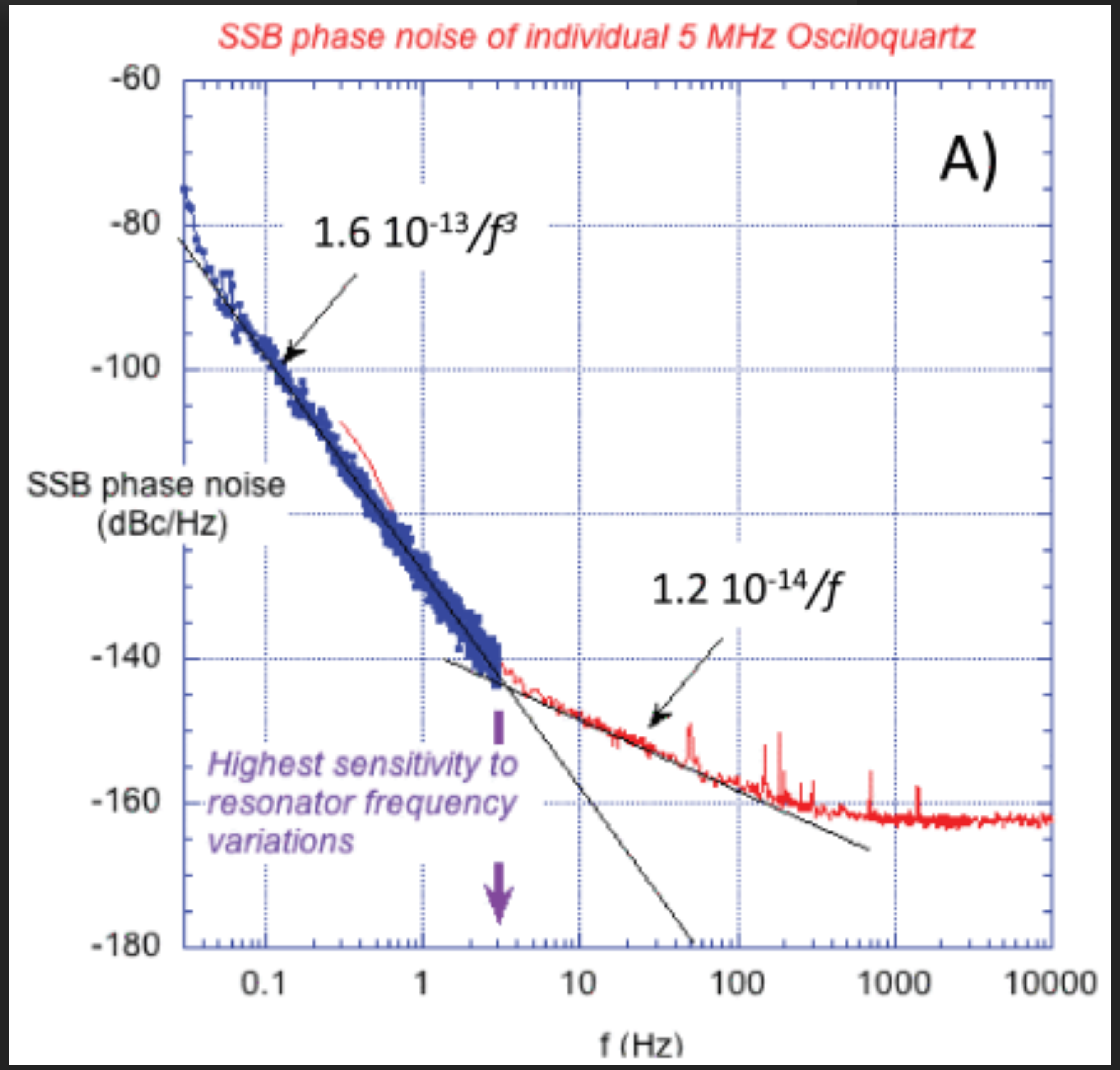
Next Generation of Phonon Tests of Lorentz Invariance Using Quartz BAW Resonators

Publisher: IEEE

Cite This | PDF

Maxim Goryachev ; Zeyu Kuang ; Eugene N. Ivanov ; Philipp Haslinger ; Holger Müller ; Michael E. Tobar   All Authors





Better phase noise/frequency stability ($\sim 10^{-13}$)
Improved measurement scheme
More stable rotating stage
Better shielding

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>1.5 YEARS OF OBSERVATIONS COMING SOON

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Quantum Gravity

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Quantum Gravity

Testing the generalized uncertainty principle with macroscopic mechanical oscillators and pendulums

P. A. Bushev, J. Bourhill, M. Goryachev, N. Kukharchyk, E. Ivanov, S. Galliou, M. E. Tobar, and S. Danilishin
Phys. Rev. D **100**, 066020 – Published 20 September 2019

Quantum Gravity Models

↓

Fundamental Minimal Length Scale $\sim l_{\text{Planck}}$

↓

Modified Commutation Relationship

$$[\hat{x}, \hat{p}] = i\hbar\left(1 + \beta_0\left(\frac{l_{\text{Planck}}}{\hbar}\hat{p}\right)^2\right)$$

Recent progress in observing and manipulating mechanical oscillators at quantum regime provides new opportunities of studying fundamental physics, for example to search for low energy signatures of quantum gravity. For example, it was recently proposed that such devices can be used to test quantum gravity effects, by detecting the change in the $[\hat{x}, \hat{p}]$ commutation relation that could result from quantum gravity corrections. We show that such a correction results in a dependence of a resonant frequency of a mechanical oscillator on its amplitude, which is known as the amplitude-frequency effect. By implementing this new method we measure the amplitude-frequency effect for a 0.3 kg ultra-high-Q sapphire split-bar mechanical resonator and for an $\sim 10^{-5}$ kg quartz bulk acoustic wave resonator. Our experiments with a sapphire resonator have established the upper limit on a quantum gravity correction constant of β_0 to not exceed 5.2×10^6, which is a factor of 6 better than previously measured. The reasonable estimates of β_0 from experiments with quartz resonators yields $\beta_0 < 4 \times 10^4$. The datasets of 1936 measurements of a physical pendulum period by Atkinson [E.C. Atkinson, Proc. Phys. Soc. London **48**, 606 (1936).] could potentially lead to significantly stronger limitations on $\beta_0 \ll 1$. Yet, due to the lack of proper pendulum frequency stability measurement in these experiments the exact upper bound on β_0 cannot be reliably established. Moreover, pendulum based systems only allow one to test a specific form of the modified commutator that depends on the mean value of momentum. The electromechanical oscillators to the contrary enable testing of any form of generalized uncertainty principle directly due to a much higher stability and a higher degree of control.

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Quantum Gravity

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P. A. Bushev, J. Bourhill, M. Goryachev, N. Kukharchyk, E. Ivanov, S. Galliou, M. E. Tobar, and S. Danilishin
Phys. Rev. D **100**, 066020 – Published 20 September 2019

Modified Commutation Relationship

$$[\hat{x},\hat{p}] = i\hbar\left(1+\beta_0\left(\frac{l_{\text{Planck}}}{\hbar}\hat{p}\right)^2\right)$$

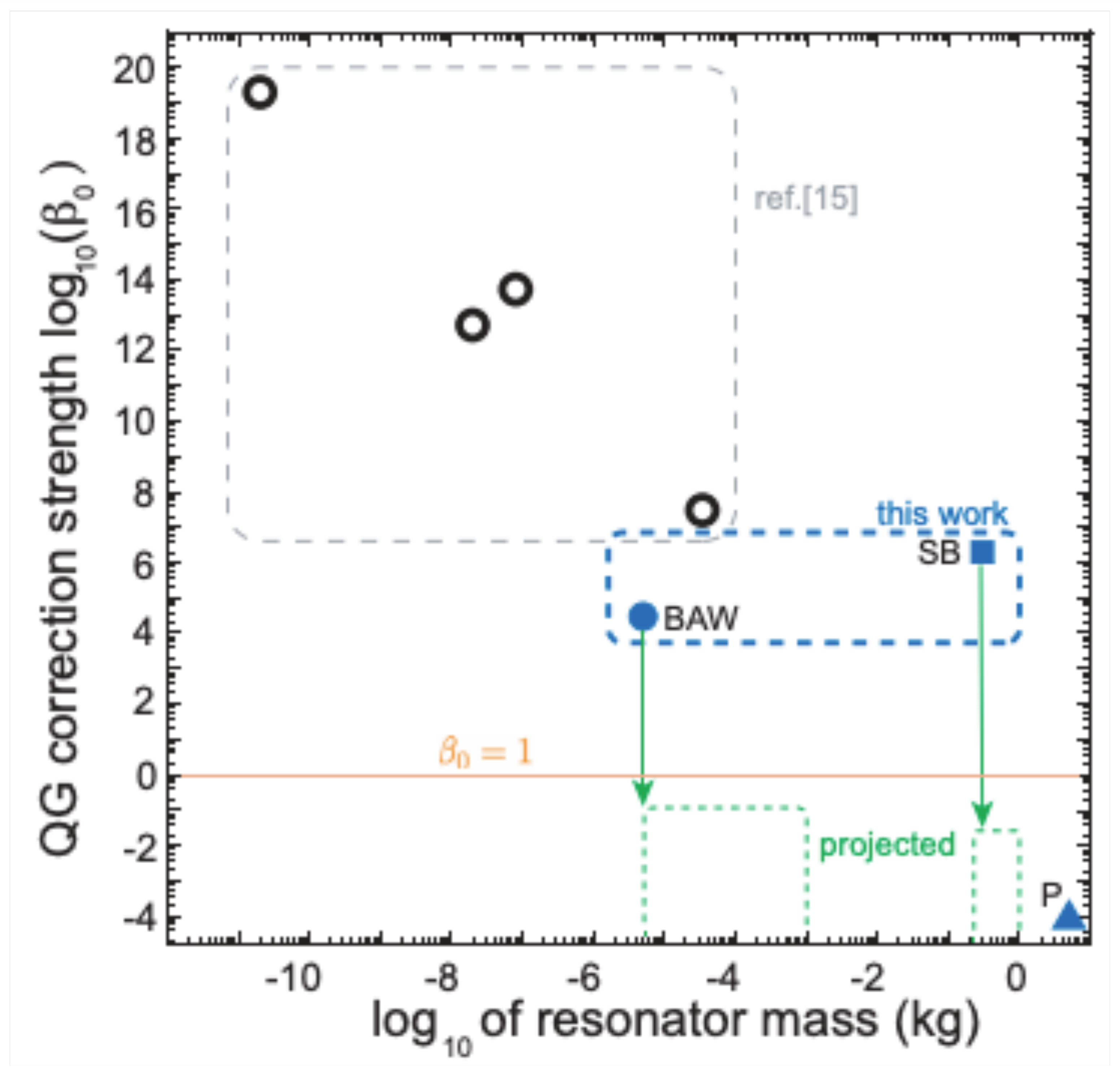
Generalised Uncertainty Principle

$$\Delta x \Delta p \geq \frac{\hbar}{2}\left[1+\beta_0\frac{\Delta p^2+\langle p\rangle^2}{M_{\text{Planck}}^2 c^2}\right]$$

Nonlinear Dynamics

$$\hat{H} \rightarrow \hat{H}_0 + \Delta\hat{H} = \frac{\hat{p}^2}{2m} + m\Omega_0^2\frac{\hat{x}^2}{2} + \beta_0\frac{\hat{p}^4}{3m\left(M_{\text{Planck}}c\right)^2}$$

$$M_{\text{Planck}} \sim 21.8\mu g$$



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Quantum Gravity

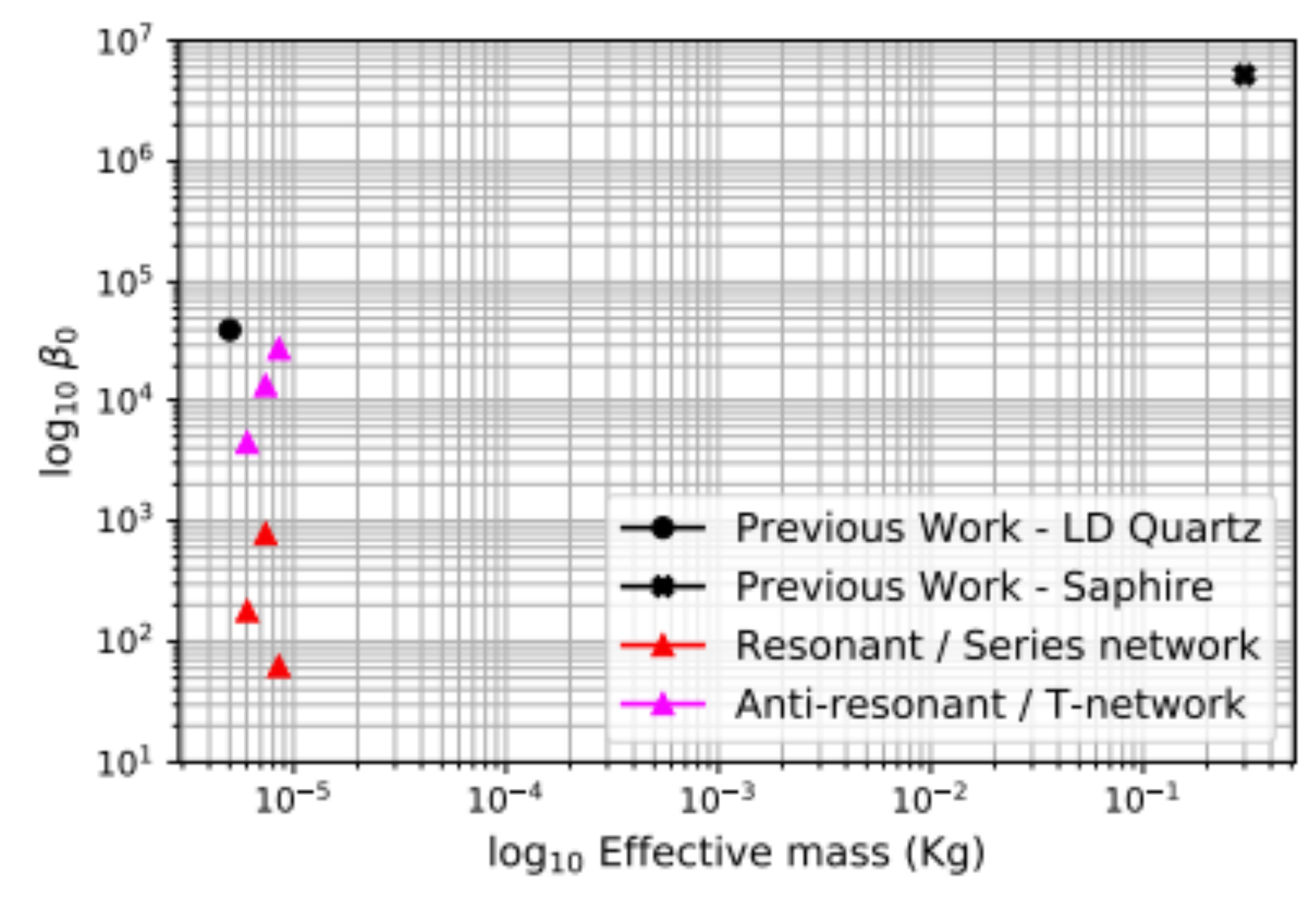
Improved Constraints on the Minimum Length with a Macroscopic Low Loss Phonon Cavity

William M. Campbell,* Michael E. Tobar, and Maxim Goryachev†
Quantum Technologies and Dark Matter Labs, Department of Physics, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia.

Serge Galliou
FEMTO-ST Institute, Univ. Bourgogne Franche-Comté, CNRS, ENSMM, 26 Rue de l'Épitaphe 25000 Besançon, France

(Dated: April 4, 2023)

arXiv:2304.00688v1



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High Frequency Gravitational Waves

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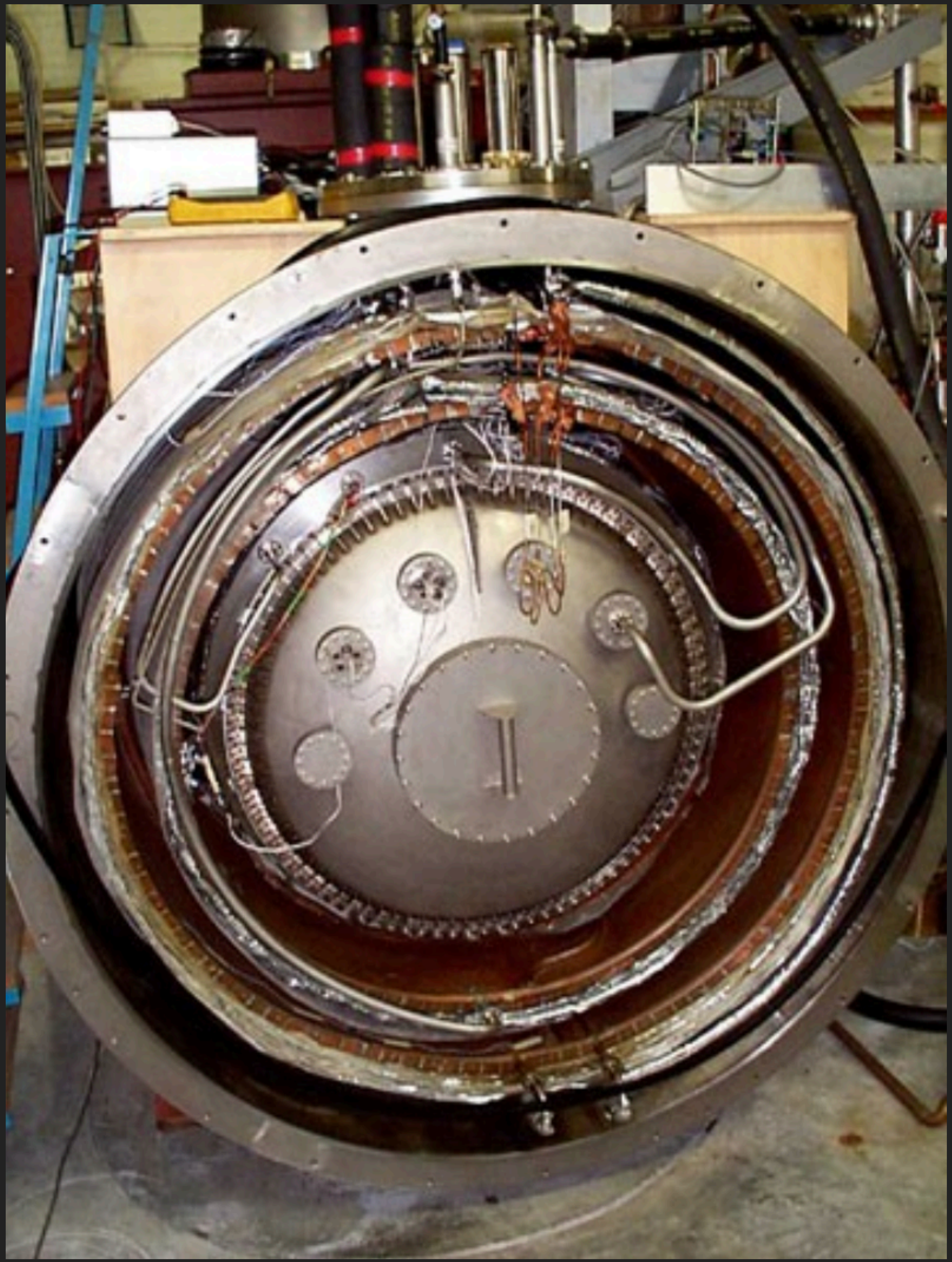
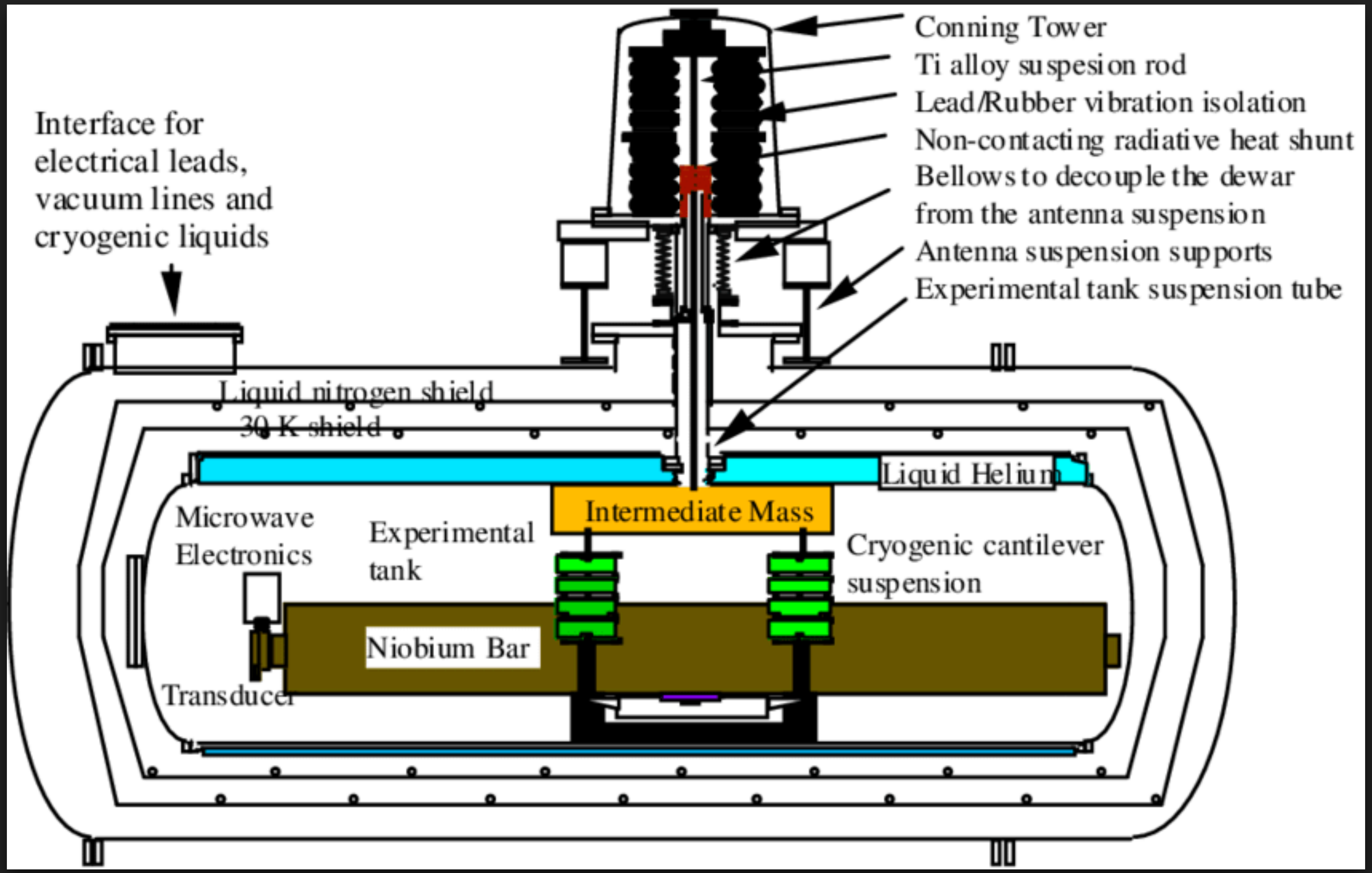
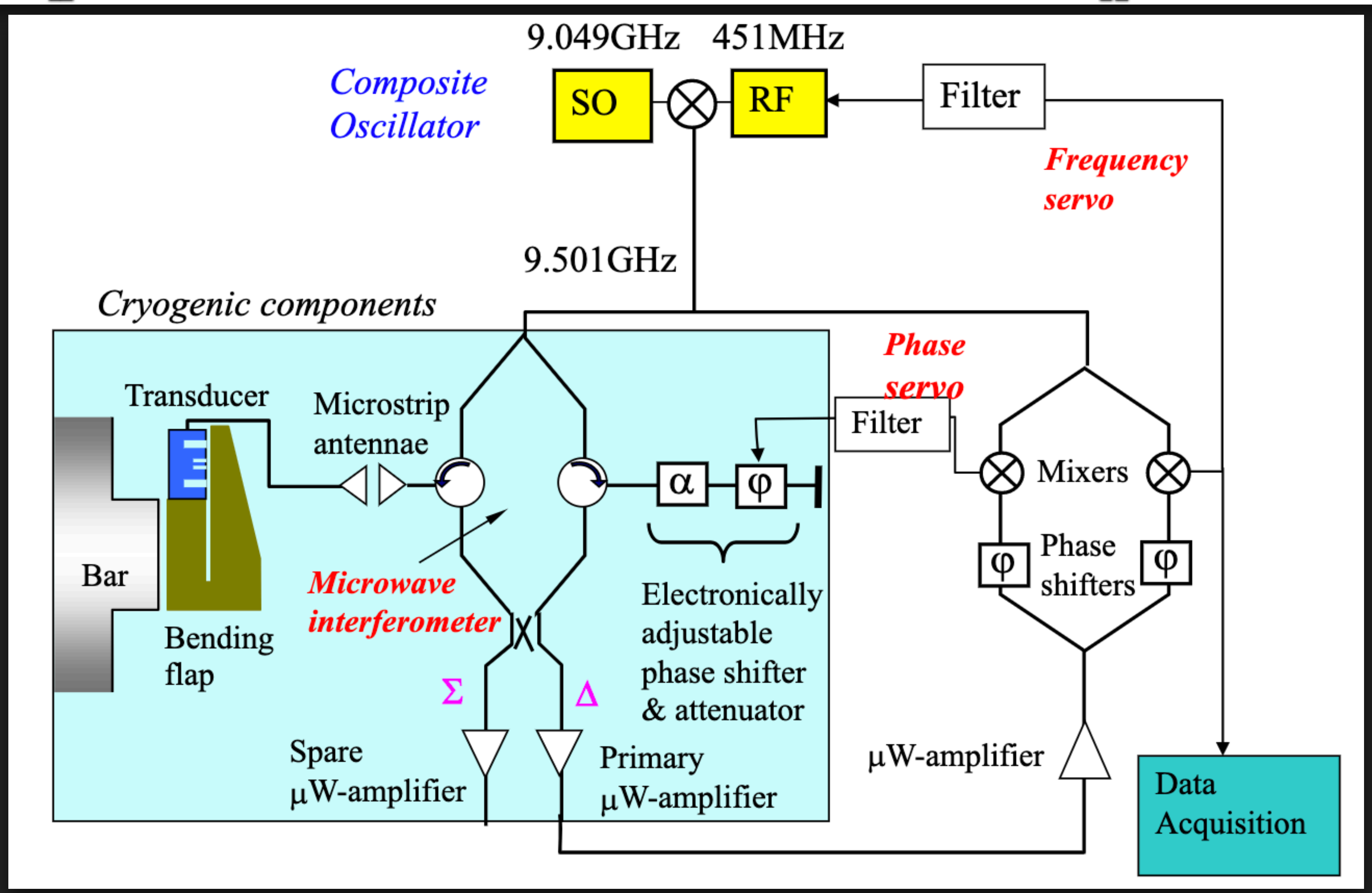
Resonant Bar GW Detectors







Phys. Rev. Lett 74, 1908 (1995)

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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

Phys. Rev. D **90**, 102005 – Published 24 November 2014
Maxim Goryachev and Michael E. Tobar

There are a number of theoretical predictions for astrophysical and cosmological objects, which emit high frequency ($10^6 - 10^9$ Hz) gravitation waves (GW) or contribute somehow to the stochastic high frequency GW background. Here we propose a new sensitive detector in this frequency band, which is based on existing cryogenic ultrahigh quality factor quartz bulk acoustic wave cavity technology, coupled to near-quantum-limited SQUID amplifiers at 20 mK. We show that spectral strain sensitivities reaching 10^{-22} per $\sqrt{\mathrm{Hz}}$ per mode is possible, which in principle can cover the frequency range with multiple (> 100) modes with quality factors varying between 10^6 and 10^{10} allowing wide bandwidth detection. Due to its compactness and well-established manufacturing process, the system is easily scalable into arrays and distributed networks that can also impact the overall sensitivity and introduce coincidence analysis to ensure no false detections.

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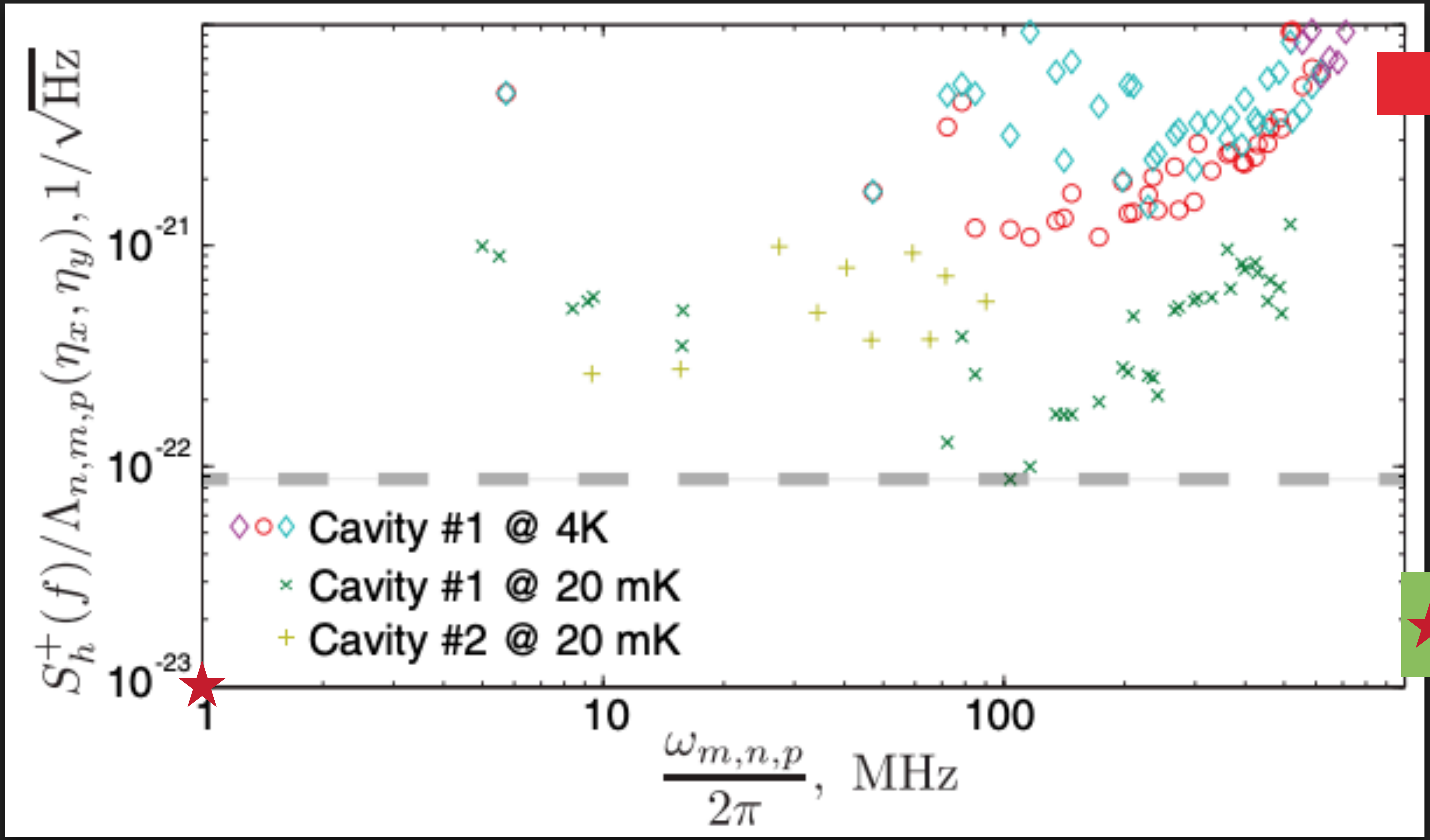

HAS TO BE CORRECTED

★ LIGO $\sim 10^{-23} 1/\sqrt{\text{Hz}}$

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High Frequency Gravitational Waves

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

REVIEW ARTICLE

Check for updates

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

Nancy Aggarwal[1] · Odylio D. Aguiar[2] · Andreas Bauswein[3] · Giancarlo Cella[4] · Sebastian Clesse[5] · Adrian Michael Cruise[6] · Valerie Domcke[7,8,9] · Daniel G. Figueroa[10] · Andrew Geraci[11] · Maxim Goryachev[12] · Hartmut Grote[13] · Mark Hindmarsh[14,15] · Francesco Muia[9,16] · Nikhil Mukund[17] · David Ottaway[18,19] · Marco Peloso[20,21] · Fernando Quevedo[16] · Angelo Ricciardone[20,21] · Jessica Steinlechner[22,23,24] · Sebastian Steinlechner[22,23] · Sichun Sun[25,26] · Michael E. Tobar[12] · Francisco Torrenti[27] · Caner Ünal[28] · Graham White[29]

There is a number of theories predicting GW cosmic sources for the frequencies above 1MHz

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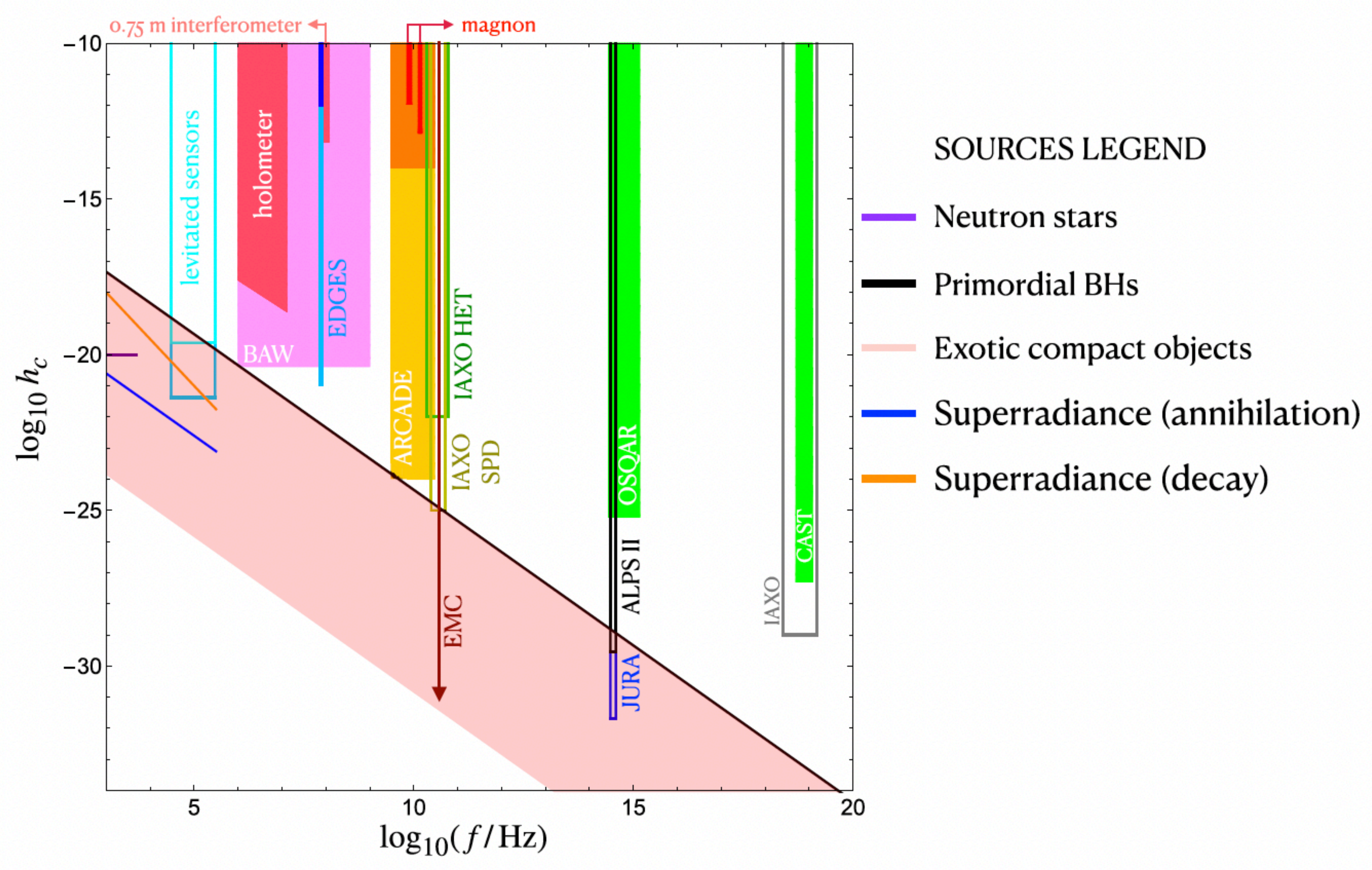
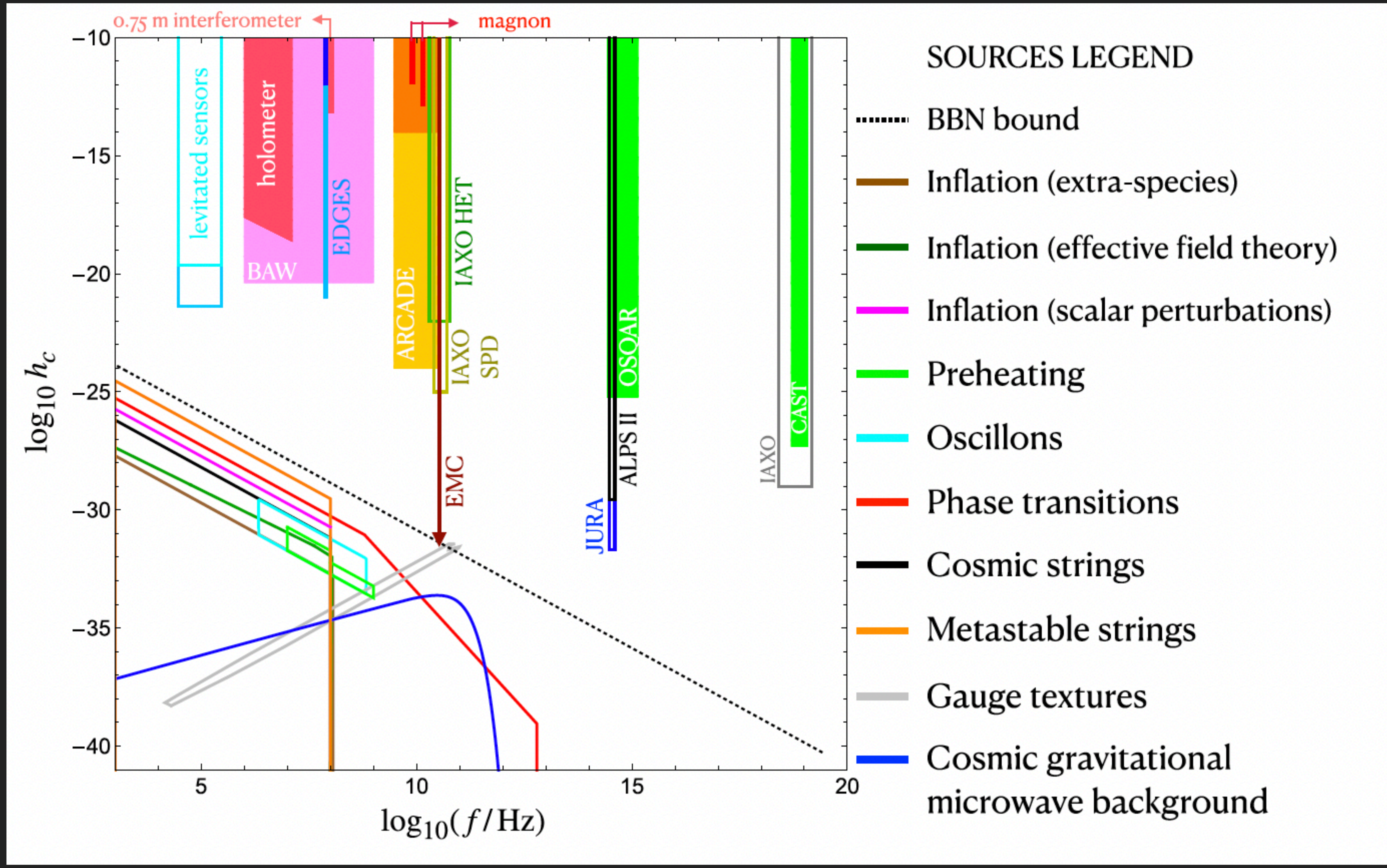
High Frequency Gravitational Waves





- *Neutron star mergers*
- *Light primordial black hole mergers*
- *Exotic compact objects*
- *Black hole superradiance*
- *Inflation*

- *Preheating*
- *Phase transitions*
- *Topological defects*
- *Evaporating primordial black holes*

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High Frequency Gravitational Waves

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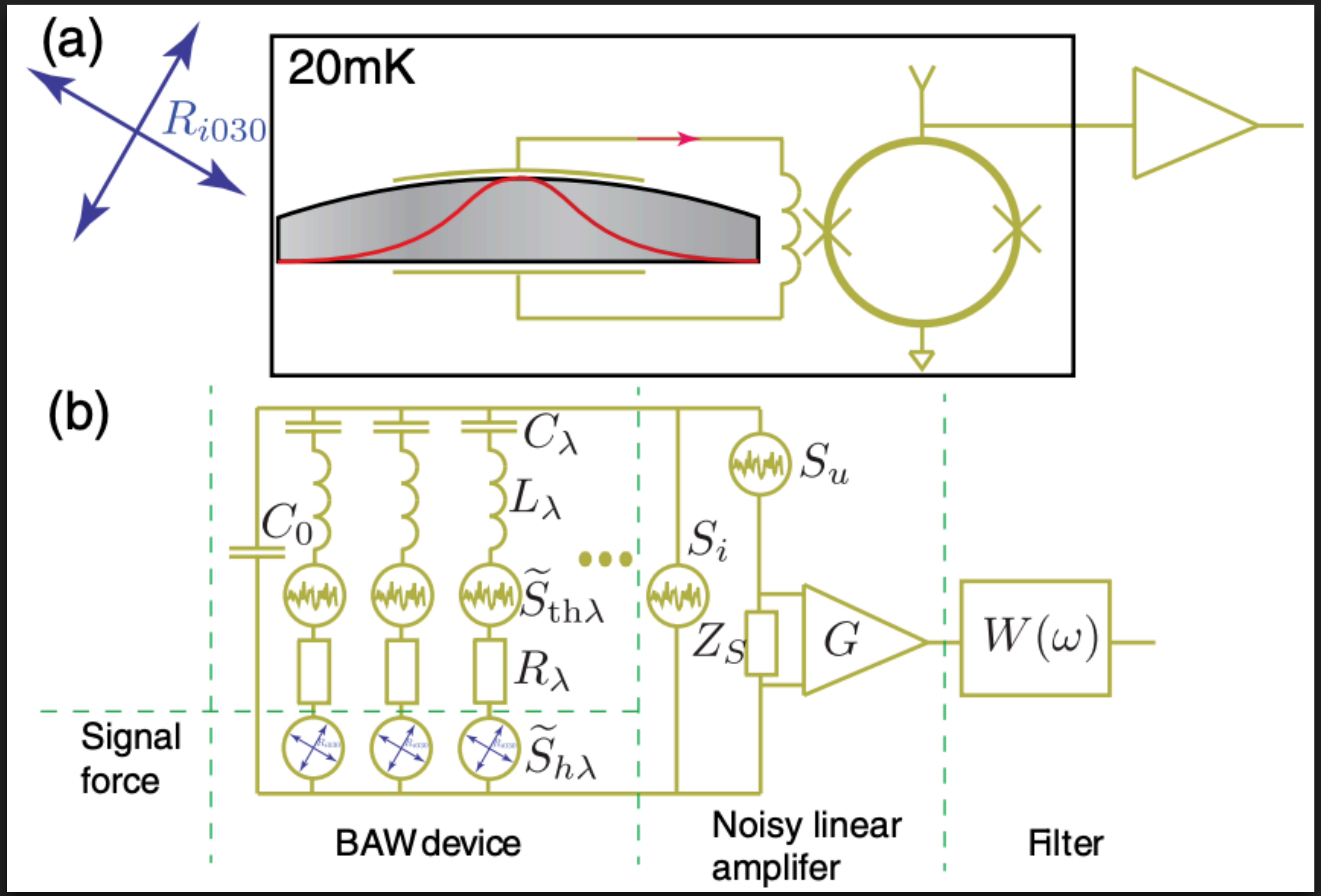
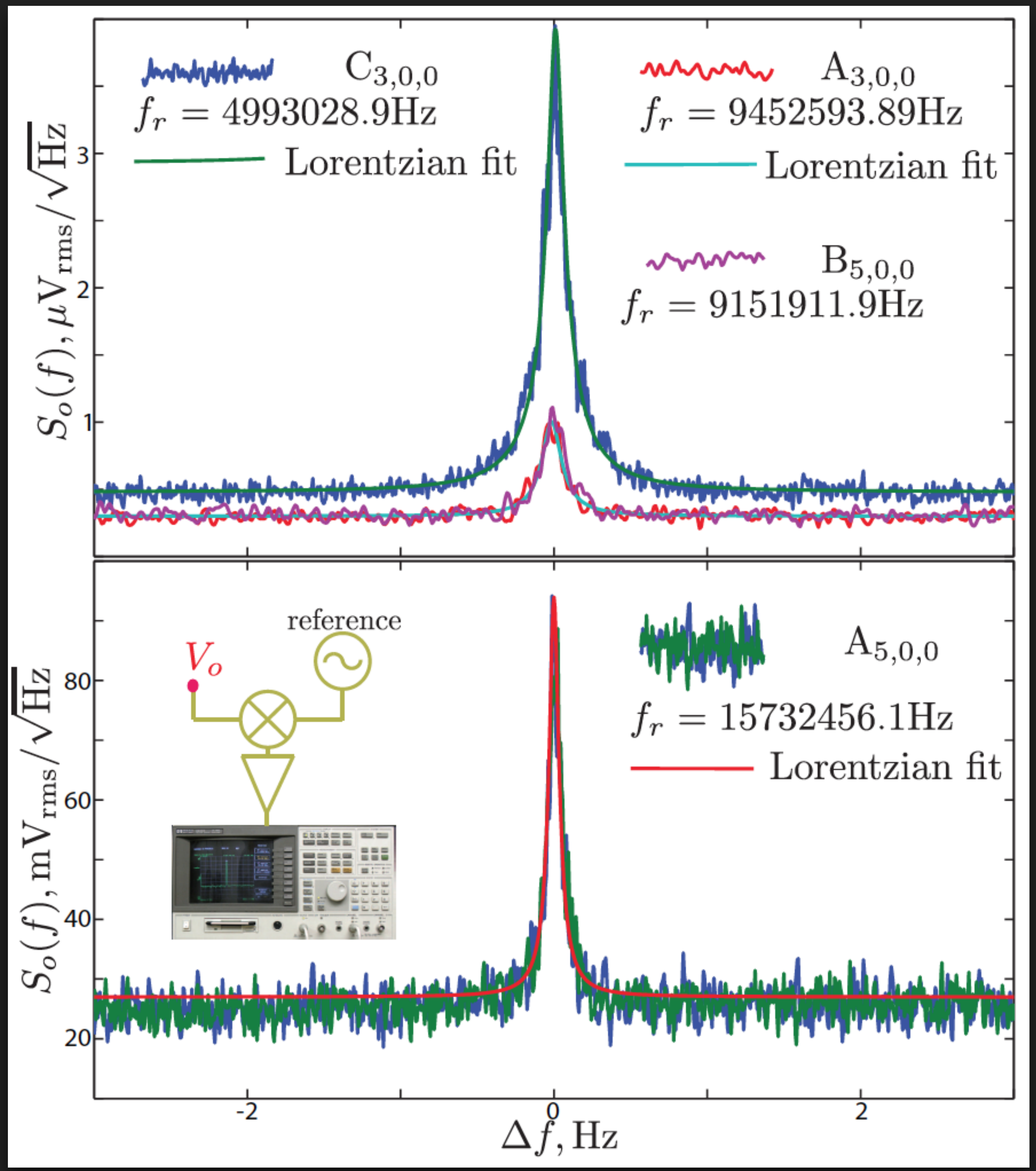
Phys. Rev. D **90**, 102005 – Published 24 November 2014





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

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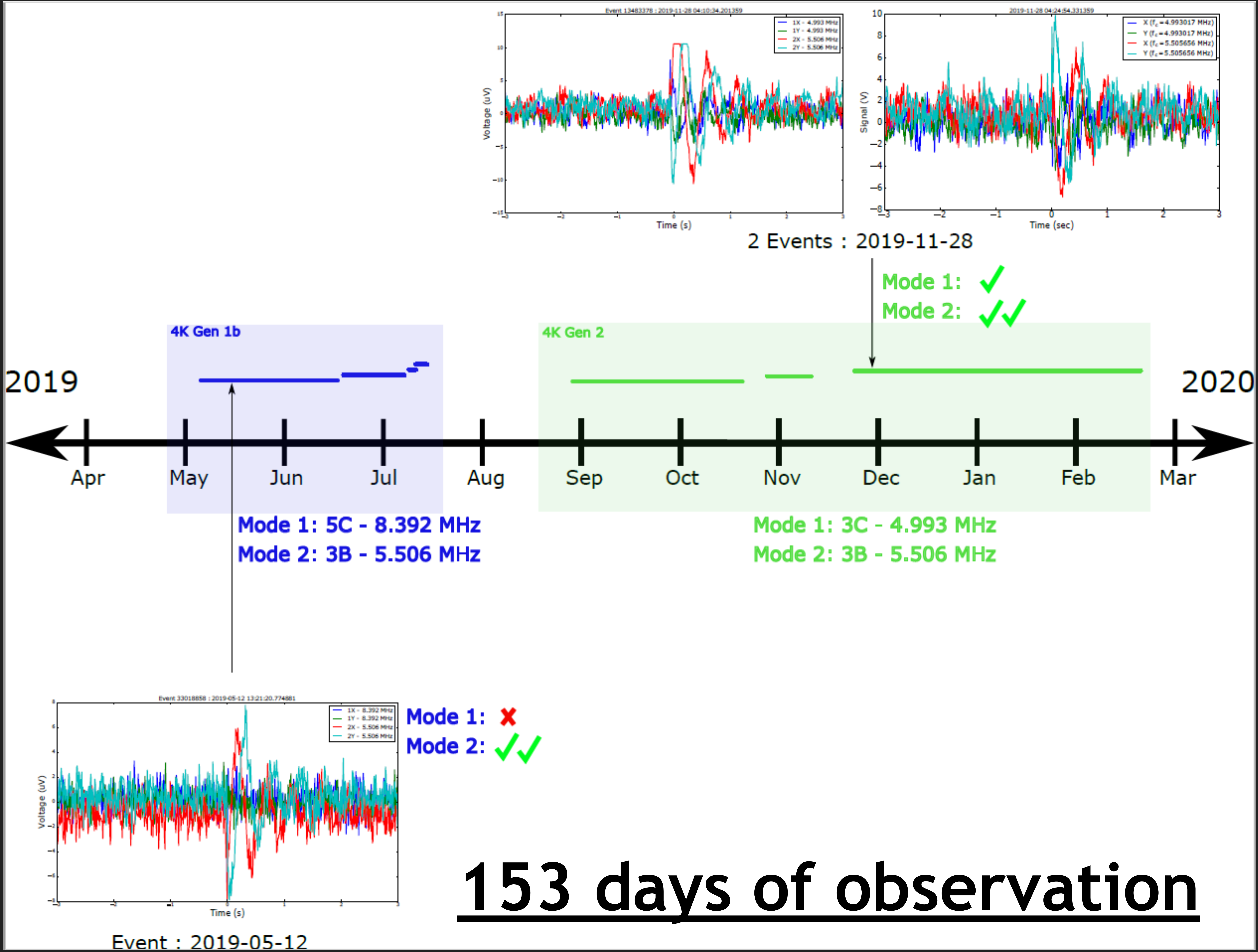
First Detection



153 days of observation

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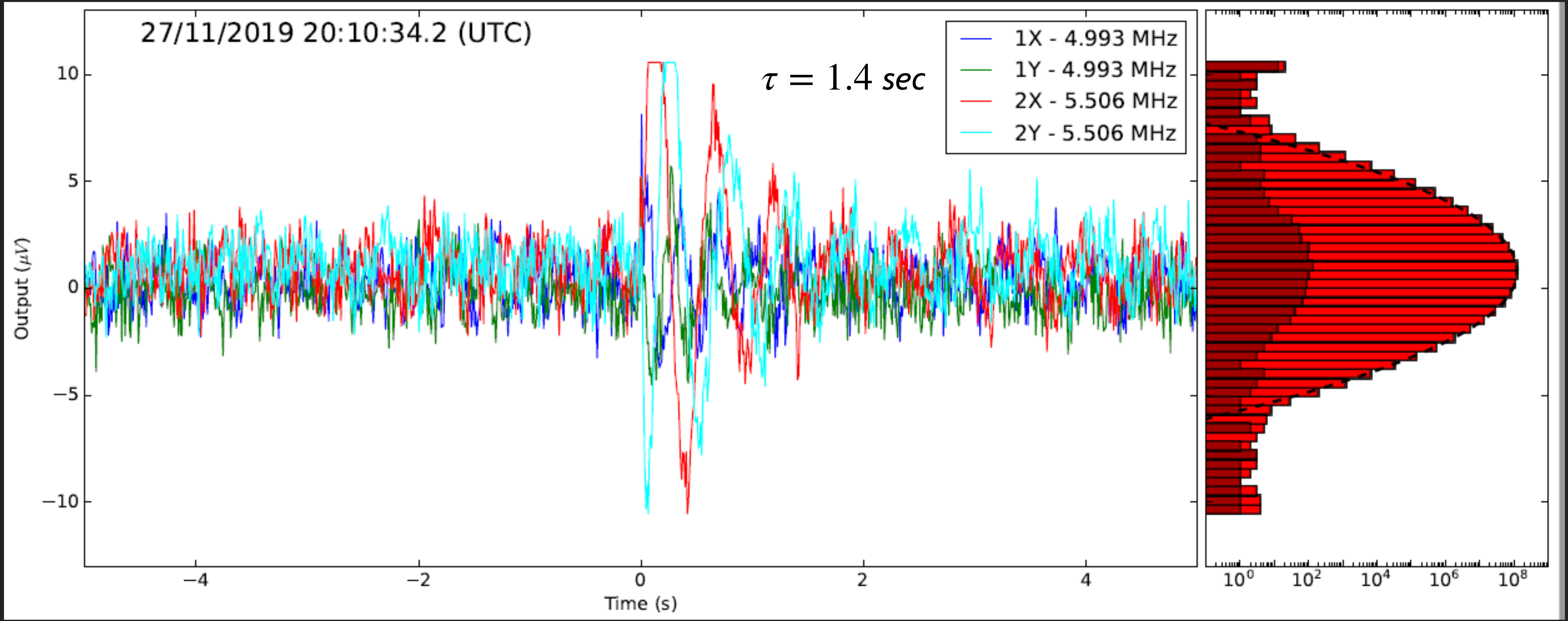
First Detection



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

Maxim Goryachev, William M. Campbell, Ik Siong Heng, Serge Galliou, Eugene N. Ivanov, and Michael E. Tobar
Phys. Rev. Lett. **127**, 071102 – Published 12 August 2021

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

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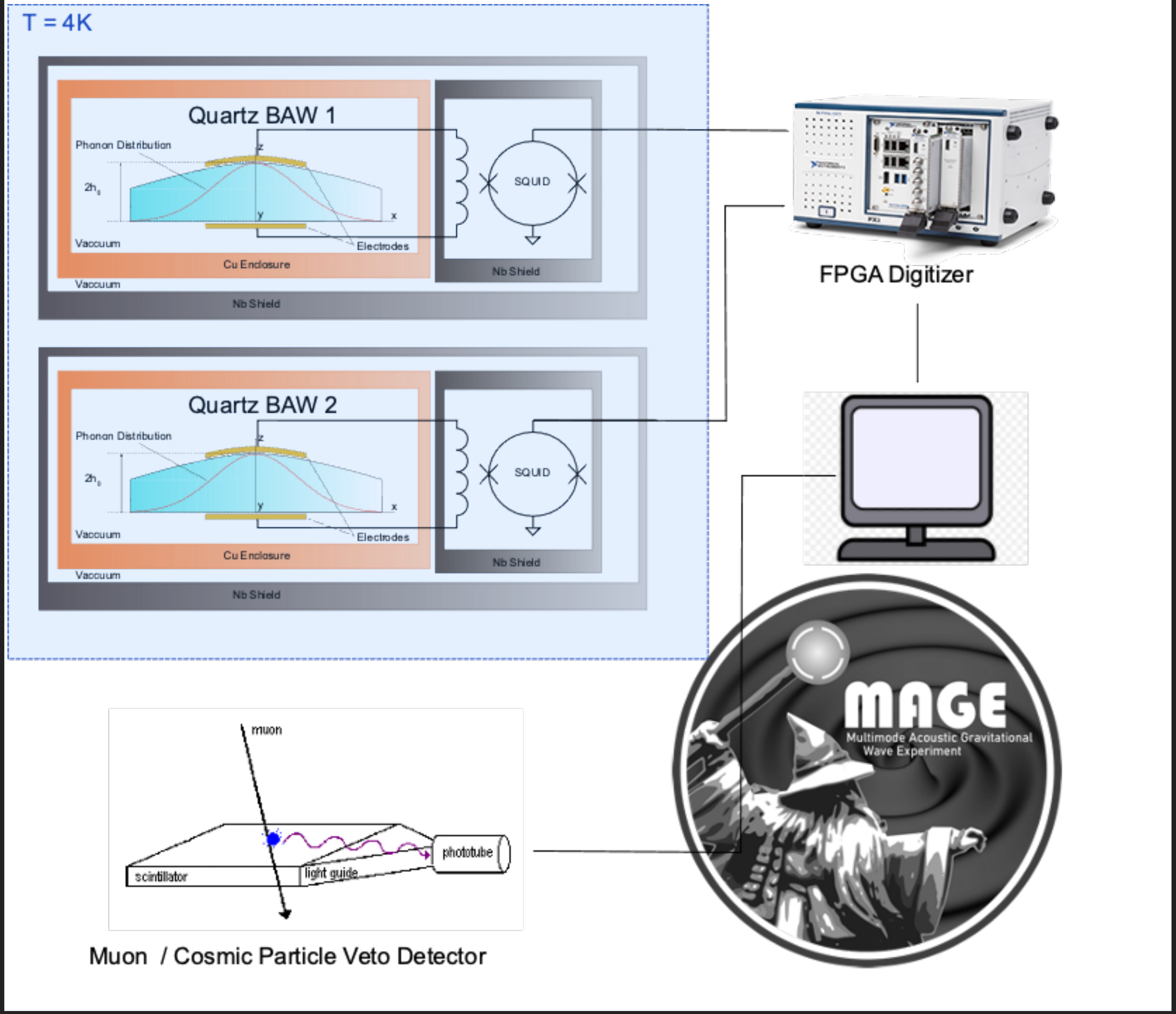
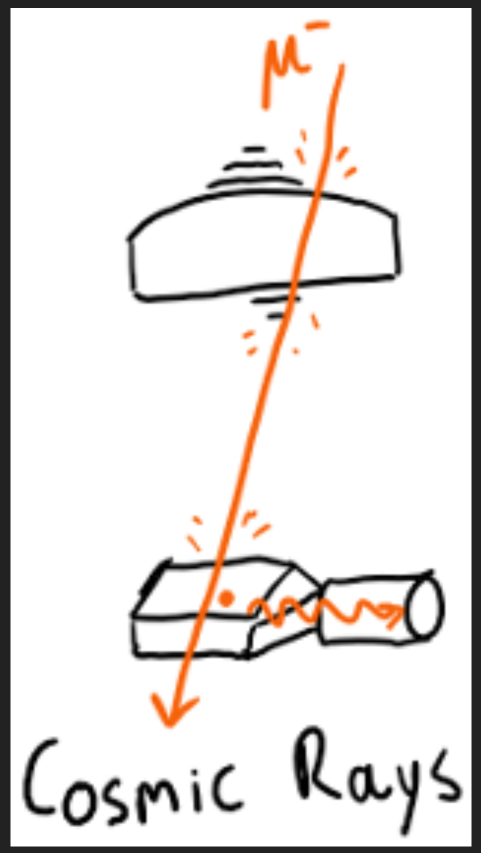
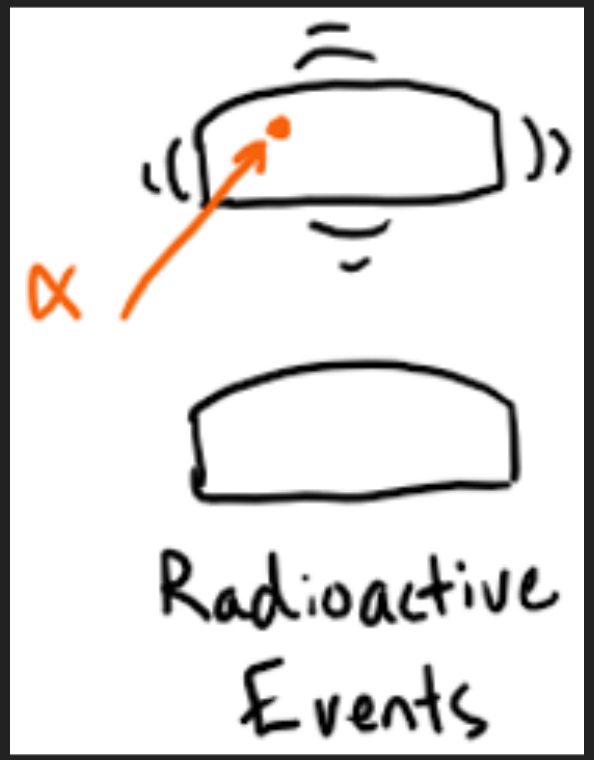
Multimode Acoustic Gravitational Wave Experiment



- 2 x Quartz BAW crystals
- 2 x DC SQUID amplifiers
- FPGA DAQ
- Cosmic particle veto (coming soon)





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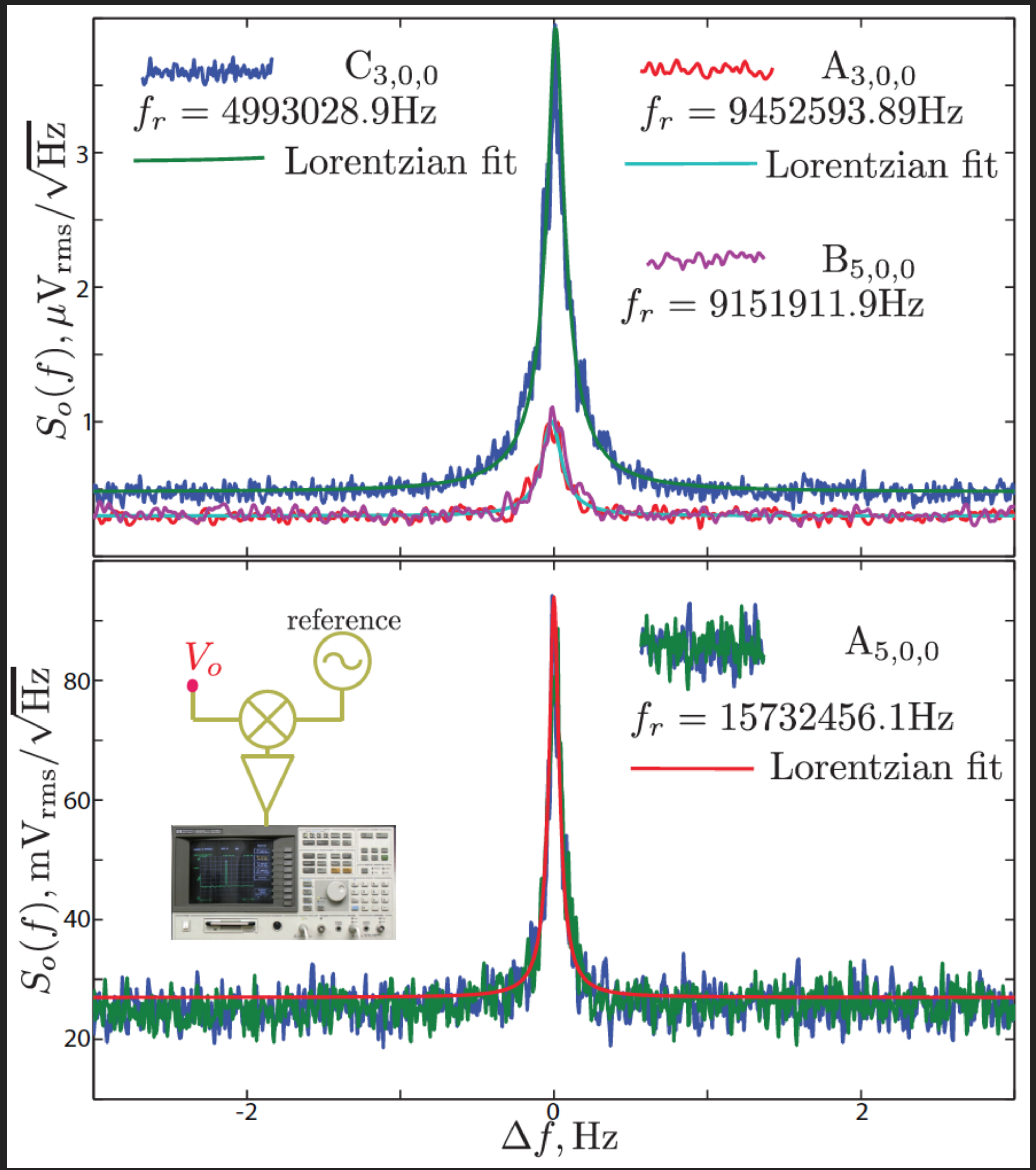
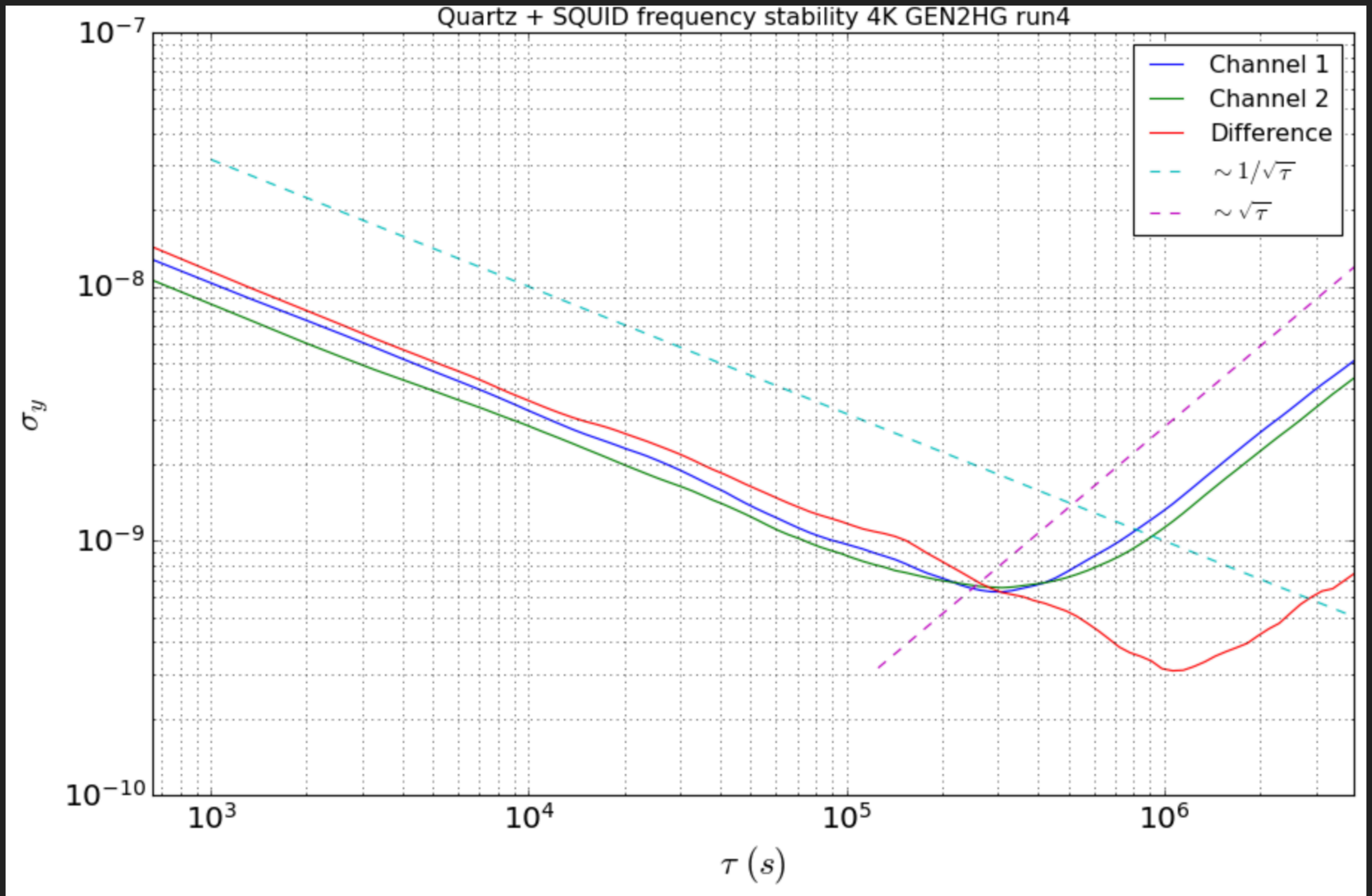
MAGE as a Clock





Scalar Dark Matter

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Scalar Dark Matter

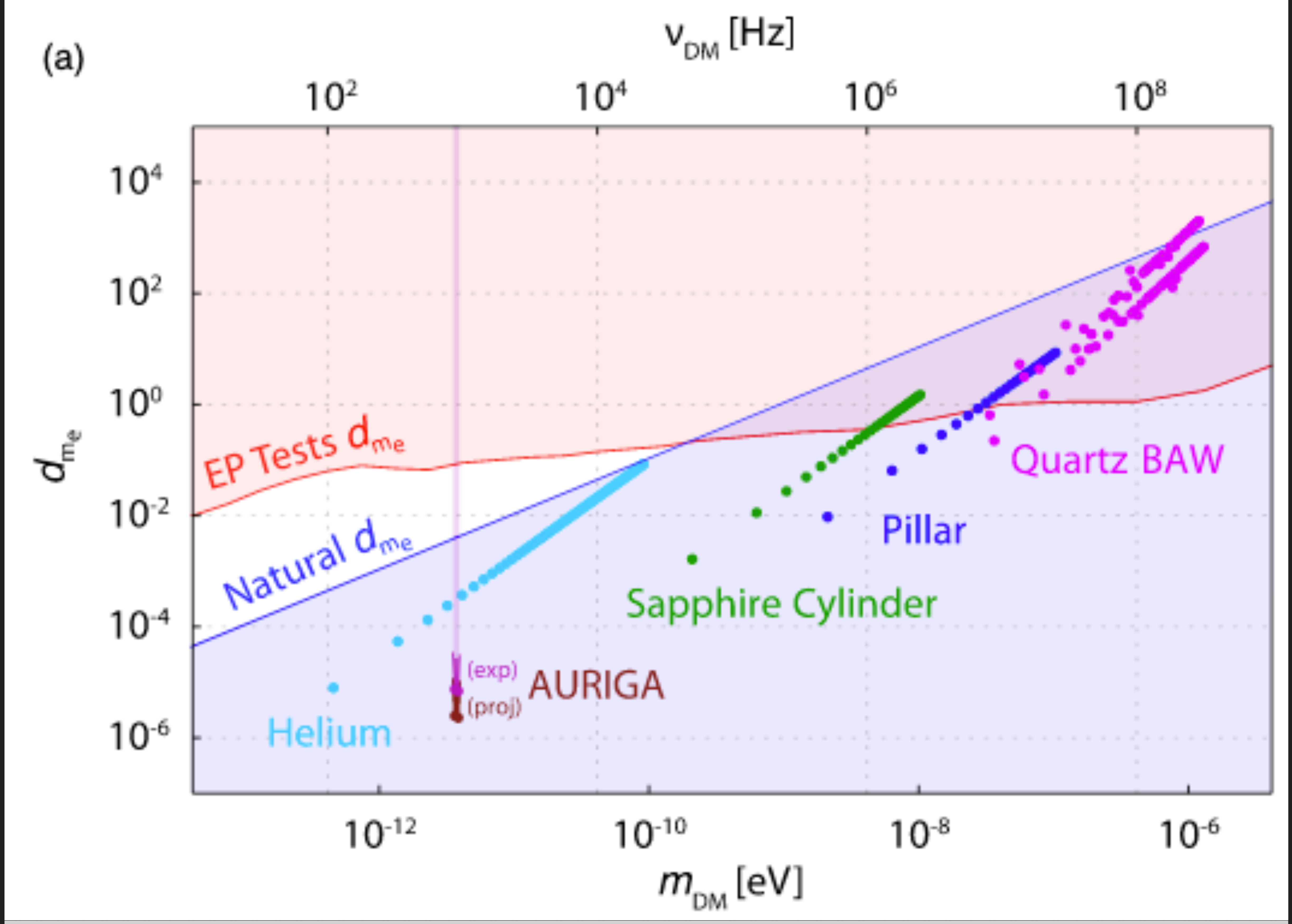
Searching for Scalar Dark Matter with Compact Mechanical Resonators

Jack Manley,[1] Dalziel J. Wilson,[2] Russell Stump,[1] Daniel Grin,[3] and Swati Singh[1,*]
[1]*Department of Electrical and Computer Engineering, University of Delaware, Newark, Delaware 19716, USA*
[2]*College of Optical Sciences, University of Arizona, Tucson, Arizona 85721, USA*
[3]*Department of Physics and Astronomy, Haverford College, Haverford, Pennsylvania 19041, USA*

(Received 21 November 2019; accepted 18 March 2020; published 16 April 2020)

Ultralight scalars are an interesting dark matter candidate that may produce a mechanical signal by modulating the Bohr radius. Recently it has been proposed to search for this signal using resonant-mass antennas. Here, we extend that approach to a new class of existing and near term compact (gram to kilogram mass) acoustic resonators composed of superfluid helium or single crystal materials, producing displacements that are accessible with opto- or electromechanical readout techniques. We find that a large unprobed parameter space can be accessed using ultrahigh-Q, cryogenically cooled centimeter-scale mechanical resonators operating at 100 Hz–100 MHz frequencies, corresponding to 10^{-12}–10^{-6} eV scalar mass range.

DOI: 10.1103/PhysRevLett.124.151301



$$\left(d_{\mathrm{DM}}\right)_{\min} \approx \sqrt{\frac{c^2}{8\pi G\rho_{\mathrm{DM}}}}\,\omega_n h_{\min}$$

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Scalar Dark Matter

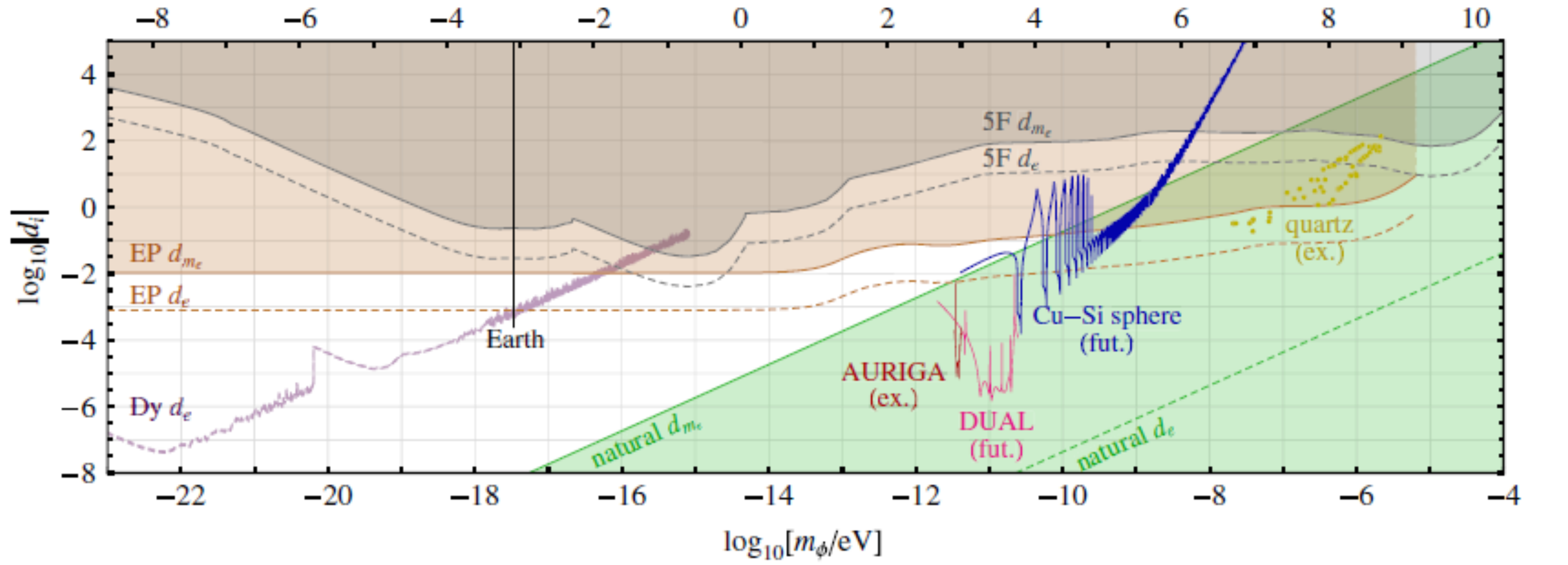
PRL 116, 031102 (2016) PHYSICAL REVIEW LETTERS week ending 22 JANUARY 2016

Sound of Dark Matter: Searching for Light Scalars with Resonant-Mass Detectors

Asimina Arvanitaki,[1,*] Savas Dimopoulos,[2,†] and Ken Van Tilburg[2,‡]
[1]*Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada*
[2]*Stanford Institute for Theoretical Physics, Stanford University, Stanford, California 94305, USA*
(Received 23 August 2015; revised manuscript received 17 October 2015; published 22 January 2016)

The fine-structure constant and the electron mass in string theory are determined by the values of scalar fields called moduli. If the dark matter takes on the form of such a light modulus, it oscillates with a frequency equal to its mass and an amplitude determined by the local dark-matter density. This translates into an oscillation of the size of a solid that can be observed by resonant-mass antennas. Existing and planned experiments, combined with a dedicated resonant-mass detector proposed in this Letter, can probe dark-matter moduli with frequencies between 1 kHz and 1 GHz, with much better sensitivity than searches for fifth forces.

DOI: 10.1103/PhysRevLett.116.031102



Scalar Dark Matter

SYSTEMATIC SEARCH?

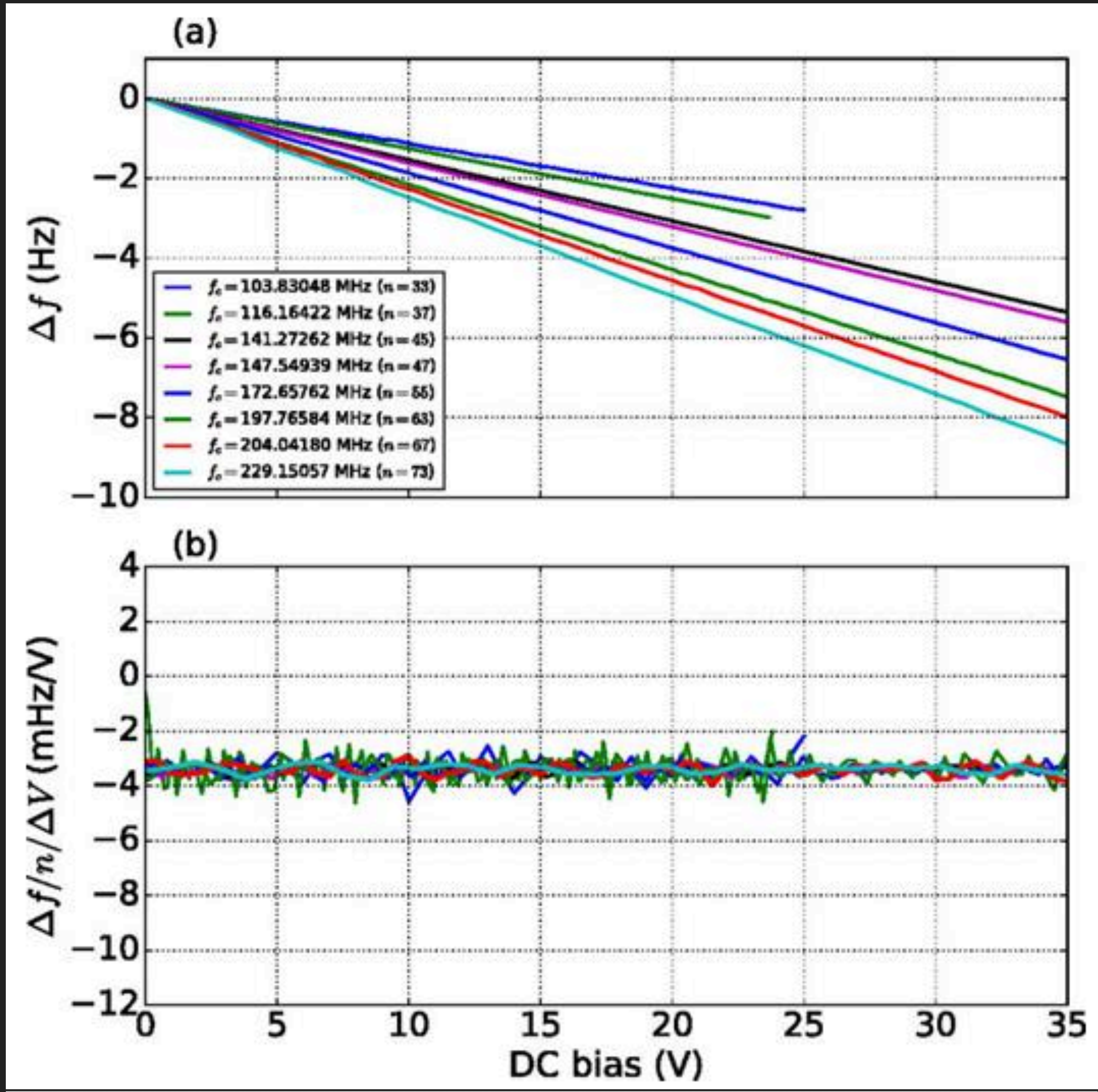
Electro-mechanical tuning of high-Q bulk acoustic phonon modes at cryogenic temperatures

William Campbell ; Serge Galliou ; Michael E. Tobar; Maxim Goryachev

Check for updates

+ Author & Article Information

Appl. Phys. Lett. 122, 032202 (2023)



DC Electrical tuning - 3.5 mHz/OT/V (e.g. 255mHz/V for n=73)
No Q degradation, no heating
Main mechanism - thickness change
Works at 20mK and 4K

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Scalar Dark Matter

Coupling of Scalar DM to SM

$$\mathscr{L}_{\text{int}} = \varphi \left[\frac{d_e}{4\mu_0} \left(F_{\mu\nu}\right)^2 - \frac{d_g \beta_g}{2g_3} \left(F^A_{\mu\nu}\right)^2 - c^2 \sum_{i=e,u,d} \left(d_{m_i} + \gamma_{m_i} d_g\right) m_i \bar{\psi}_i \psi_i \right],$$

Fundamental Constants Variation

$$\alpha_{\text{EM}}(\varphi) = \alpha_{\text{EM}} \left(1 + d_e^{(i)} \frac{\varphi^i}{i} \right)$$

Fine structure constant

$$m_j(\varphi) = m_j \left(1 + d_{m_j}^{(i)} \frac{\varphi^i}{i} \right) \quad \text{for } j = e, u, d$$

Masses of particles

$$\Lambda_3(\varphi) = \Lambda_3 \left(1 + d_g^{(i)} \frac{\varphi^i}{i} \right)$$

QCD mass scale

Phonons, Photons, Atoms
have nontrivial time variations

$$f_{\text{Q}} \propto m_e \alpha^2 \sqrt{\frac{m_e}{m_p}} \propto m_e \alpha^2 \sqrt{\frac{m_e}{\Lambda_{\text{QCD}}}}$$

$$f_{\text{CSO}} \propto m_e \alpha$$

$$f_{\text{HM}} \propto m_e \alpha^4 \left(\frac{m_e}{m_p} \right) \propto m_e \alpha^4 \left(\frac{m_e}{\Lambda_{\text{QCD}}} \right)$$

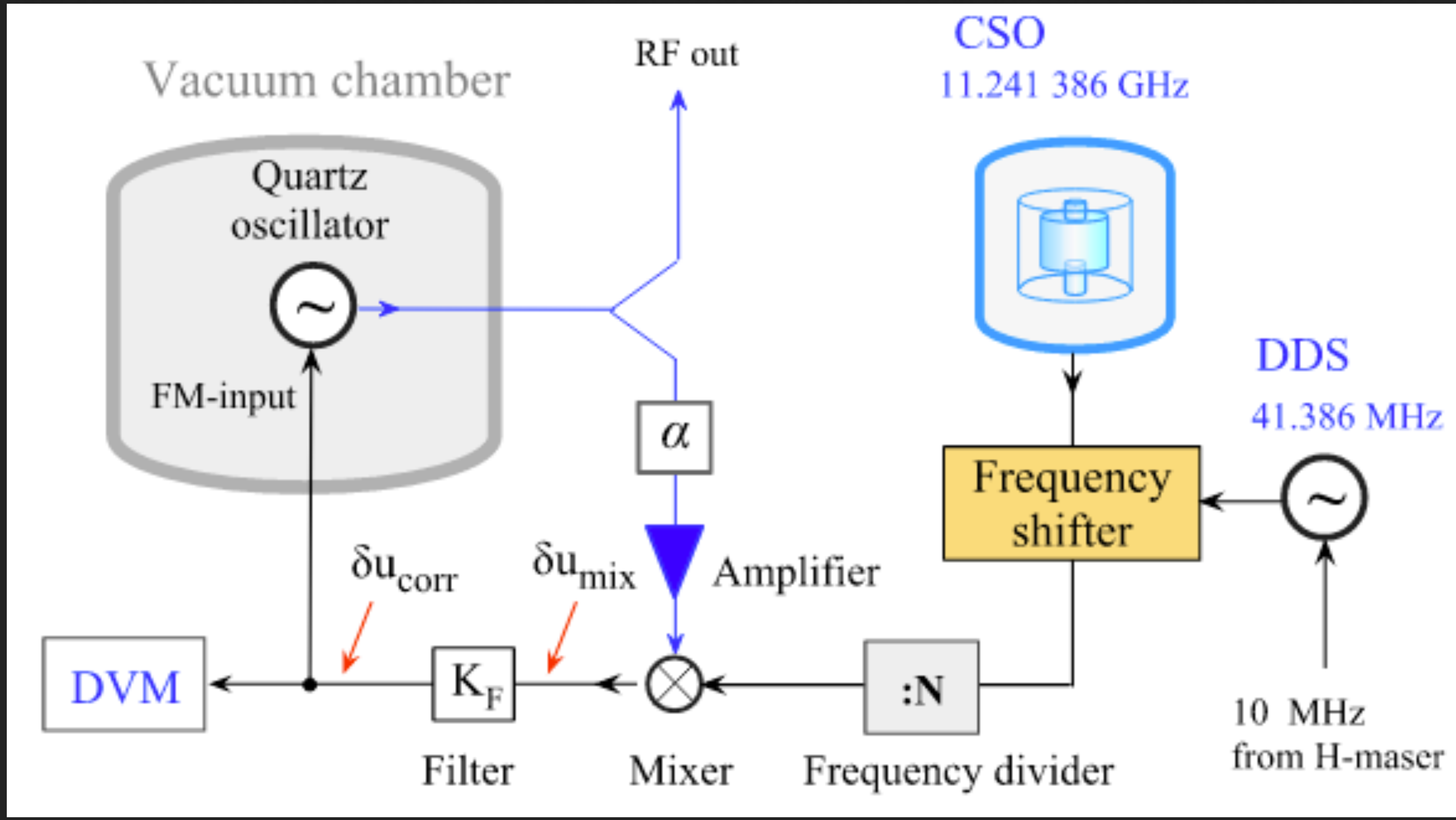
Damour T, et al, Phys. Rev. D. 82, 084033 (2010)
Hees A, et al, Phys. Rev. D. 98, 064051 (2010)

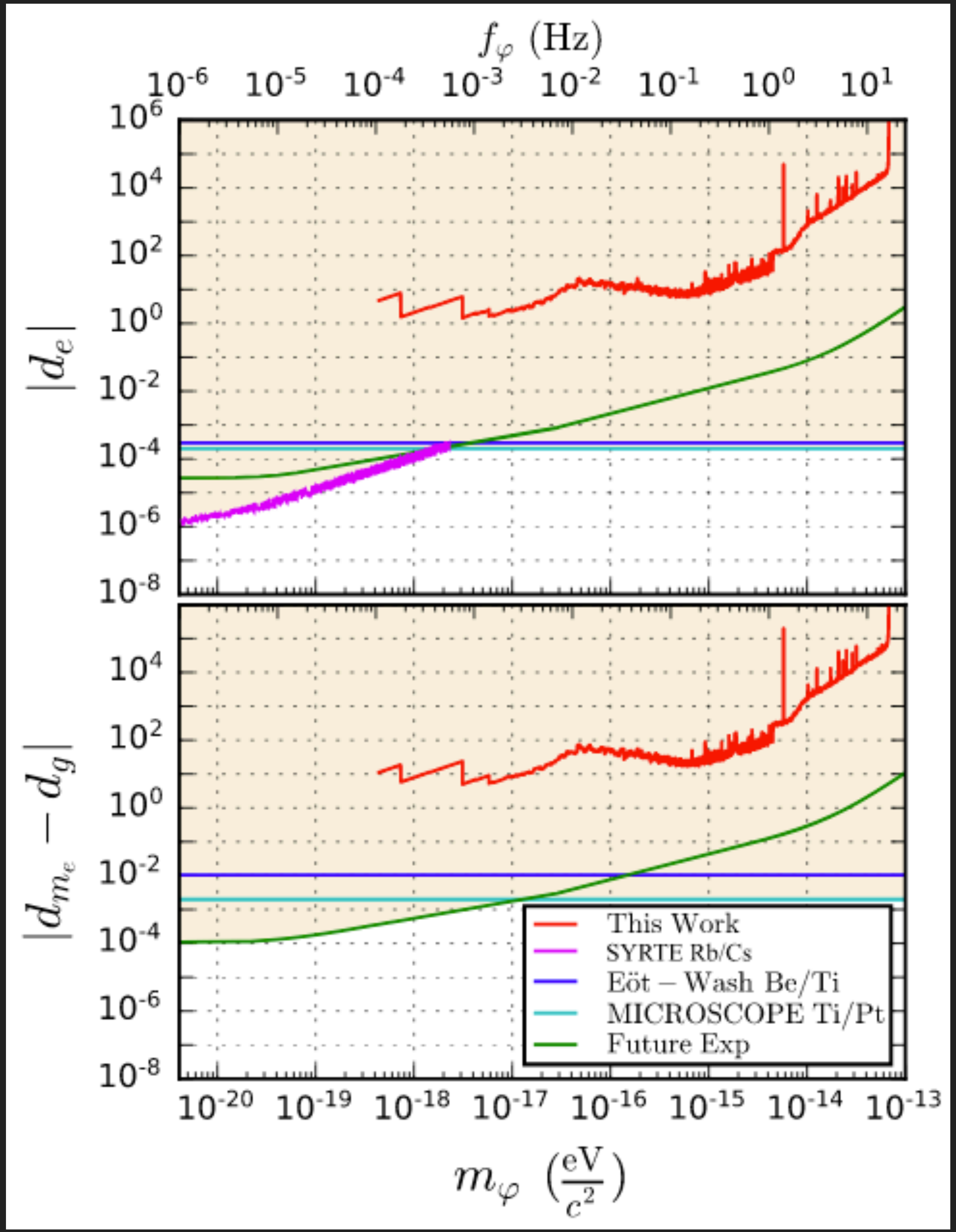
Scalar Dark Matter

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

Phys. Rev. Lett. **126**, 071301 – Published 18 February 2021





These limits do not rely on Maximum Reach Analysis. They employ the more general coefficient separation technique.

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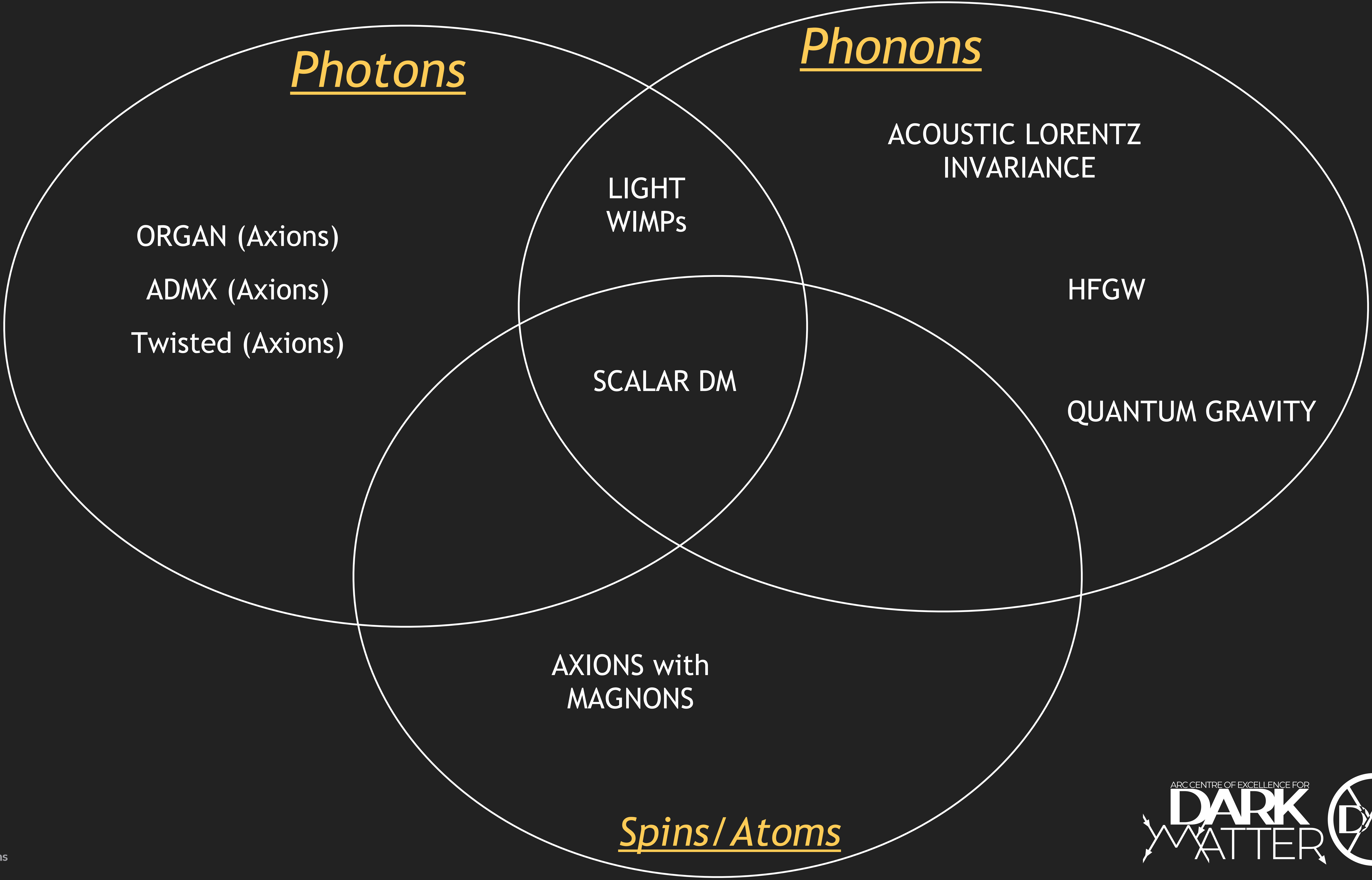
Fundamental Physics @ UWA



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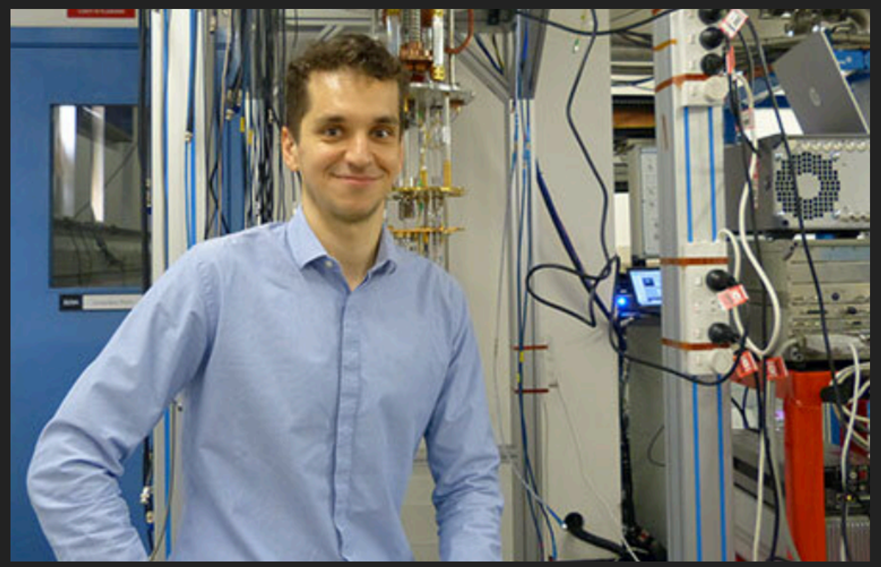
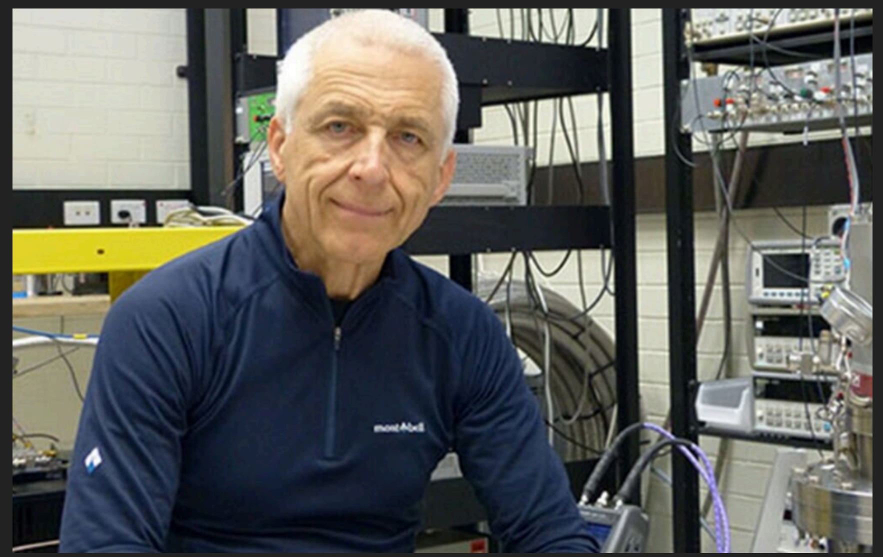
QDM Lab

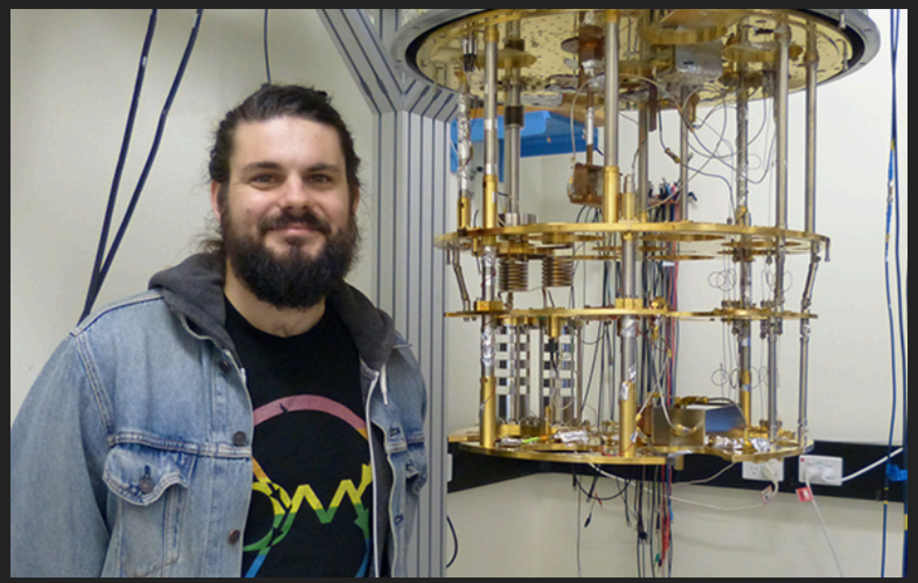
Michael Tobar



Maxim Goryachev



Eugene Ivanov



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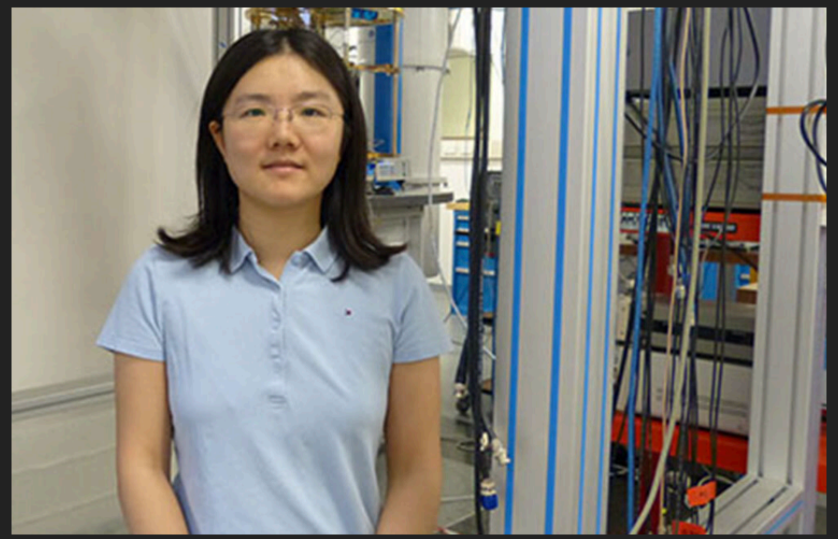
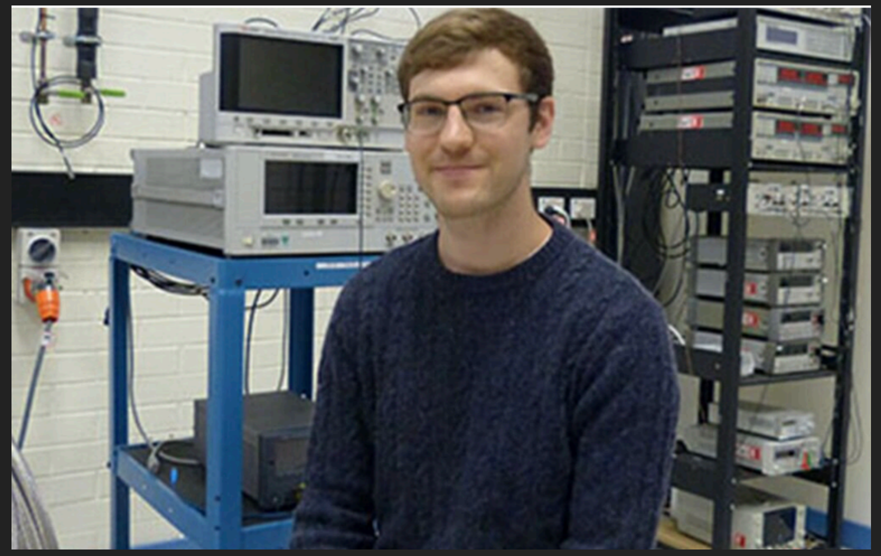
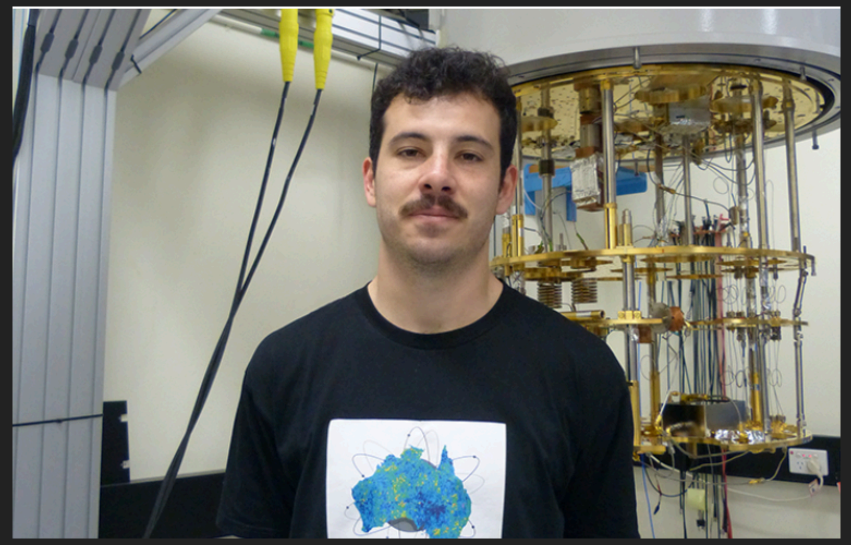


Cindy Zhao

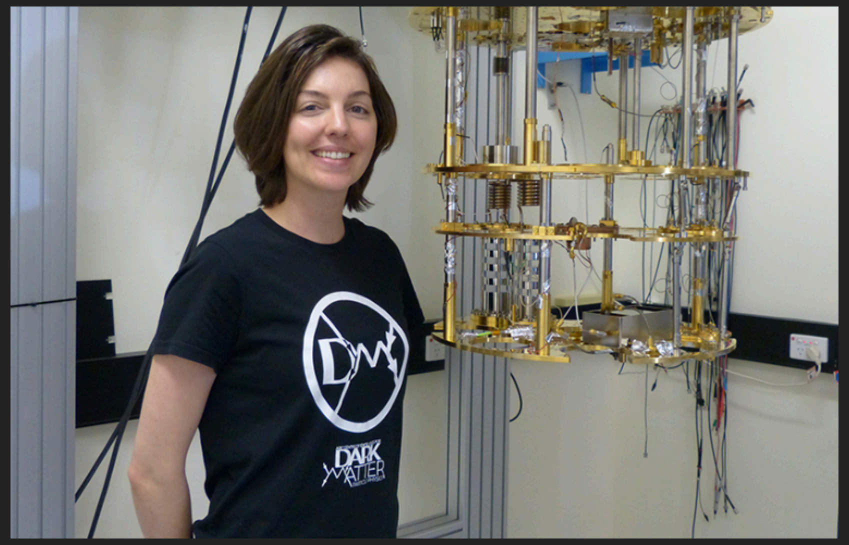


Graeme Flower

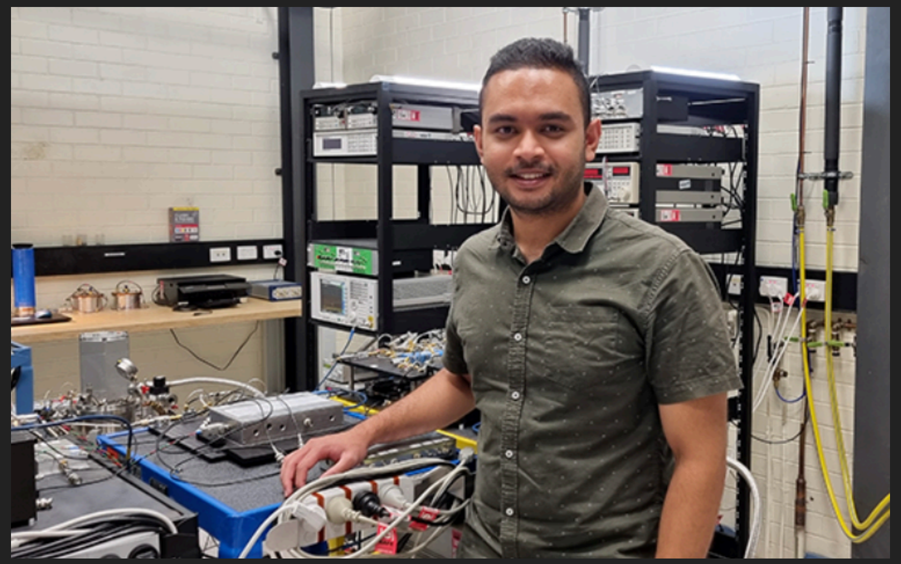


Will Campbell

Aaron Quiskamp

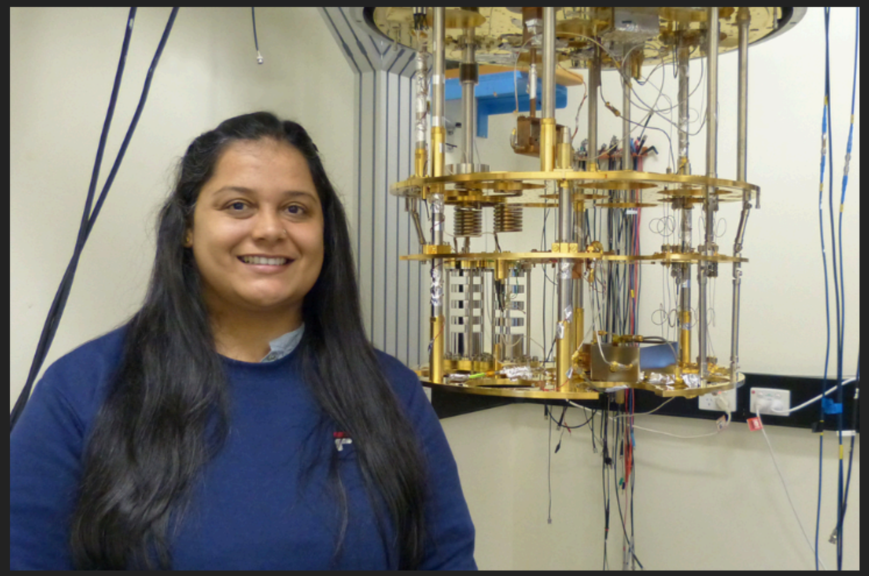


Elrina Hartman



Steven Samuels

Michael Hatzon



Sonali Parashar

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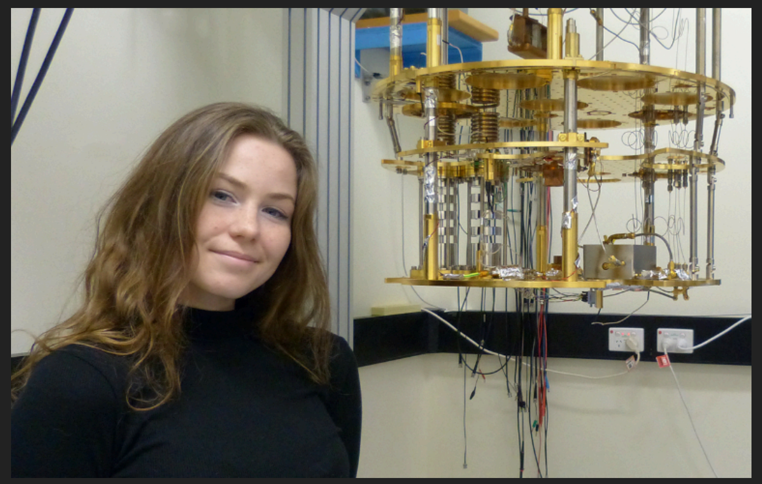
Linda Barbour



Emma Paterson

Robert Crew

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