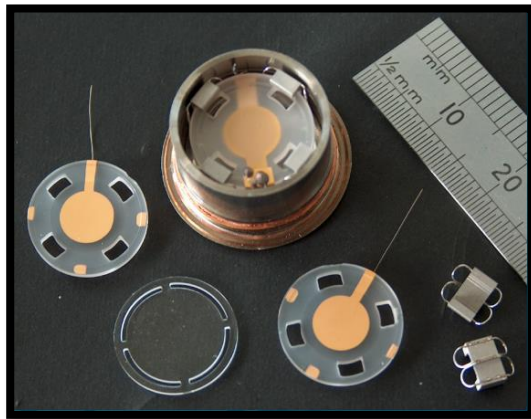


Precision Metrology for Dark Matter Detection



Will Campbell

William.Campbell@uwa.edu.au



Australian Government
Australian Research Council



THE UNIVERSITY
of ADELAIDE



Australian
National
University



THE UNIVERSITY OF
MELBOURNE



SWINBURNE
UNIVERSITY OF
TECHNOLOGY



THE UNIVERSITY OF
SYDNEY



THE UNIVERSITY OF
WESTERN
AUSTRALIA

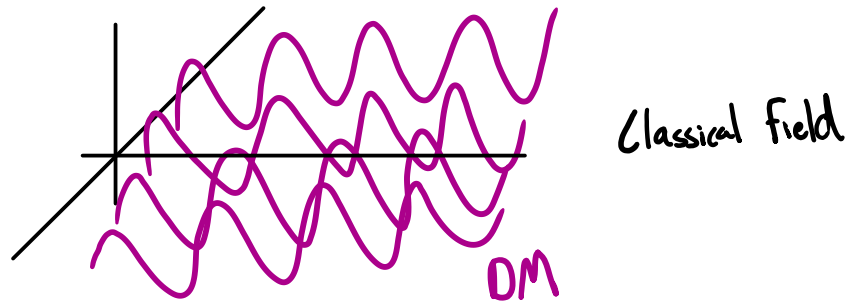
Outline

1. Ultralight dark matter, models and motivation
2. Precision metrology
3. Quartz bulk acoustic wave resonators, technology and dark matter
4. MAGE
5. Quartz bolometer
6. Other materials, TeO₂ and LiNbO₃ BAWs.

Ultralight Dark Matter

Mass:

$10^{-24} \text{ eV} < m_\phi < 1 \text{ eV}$ \longrightarrow Large occupation numbers, DM is bosonic



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QCD Axion, ALPs, Light Scalars, Vector DM, Fuzzy DM

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Ultralight Dark Matter

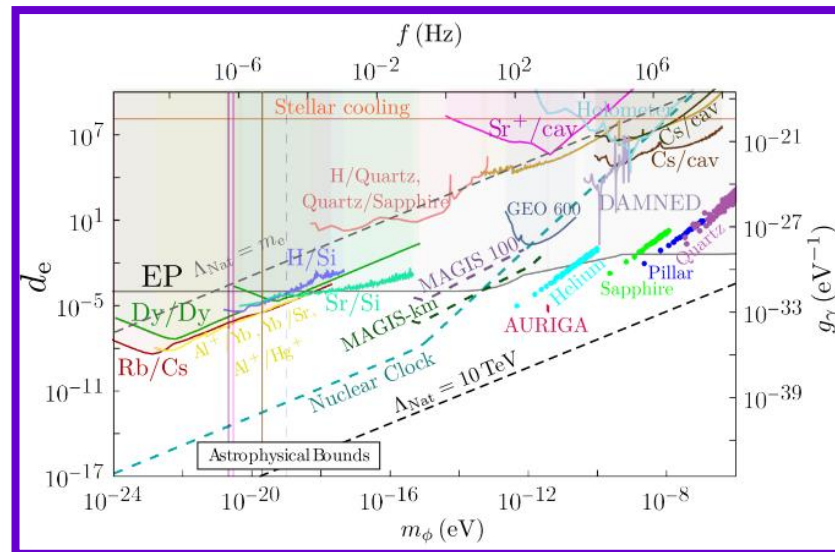
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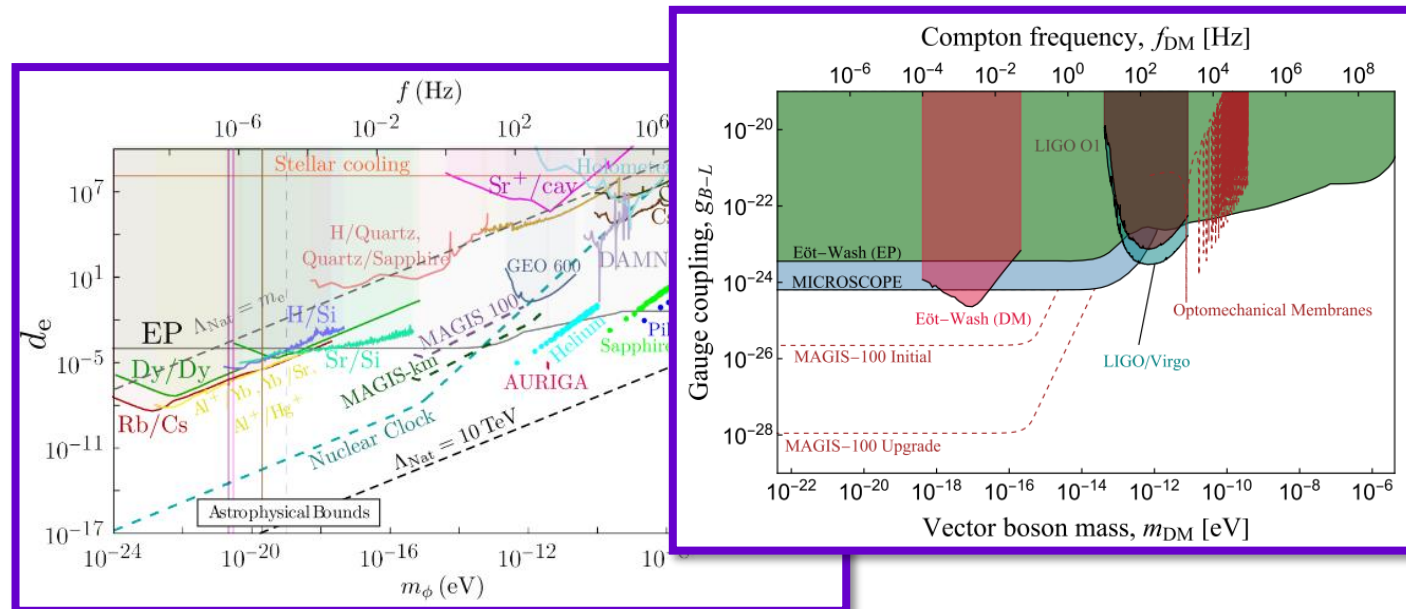
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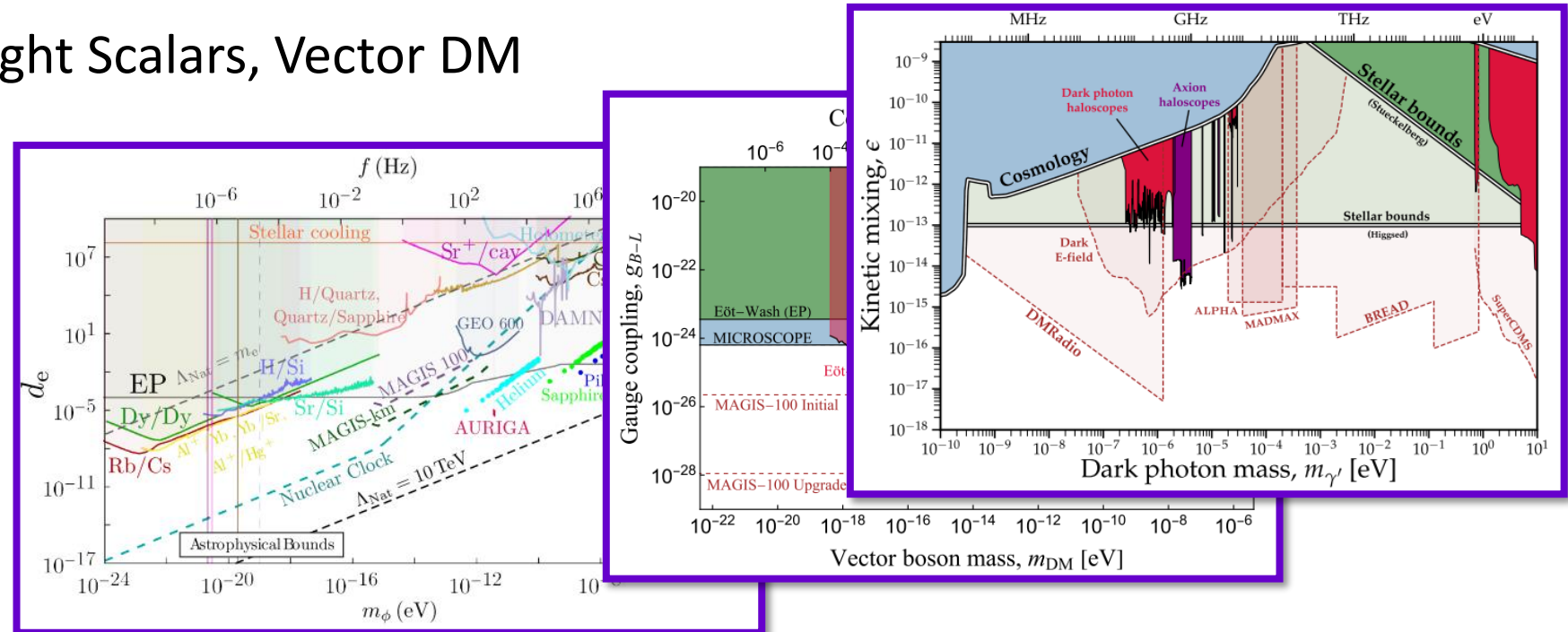
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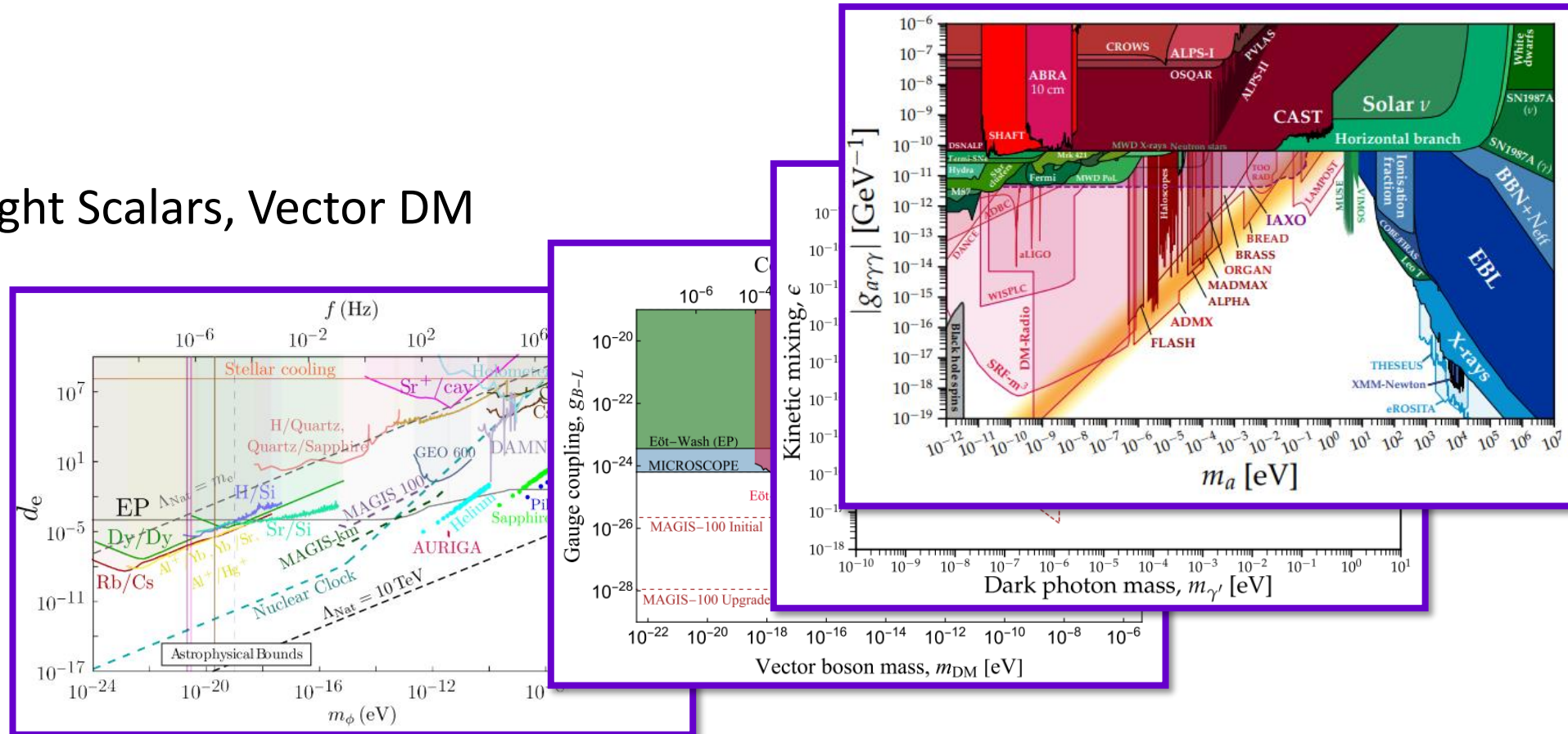
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Snowmass 2021:

2203.14923

2203.14915



Precision Metrology

Science of precise measurement



Physics at low energies

Precision Metrology

Science of precise measurement



Physics at low energies



Precision Metrology

Science of precise measurement



Physics at low energies



Metrology helps us search for physics beyond the standard model

Lorentz violation, fundamental constant variation, tests of general relativity & gravitation, violations of quantum statistics
+ more

Precision Metrology

Science of precise measurement

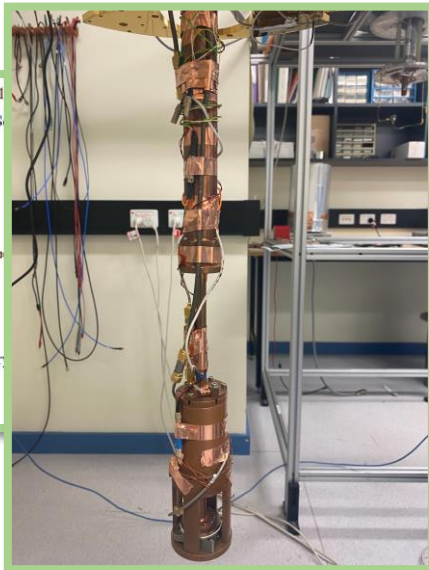
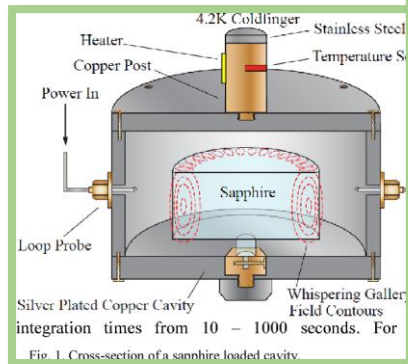


Physics at low energies

Metrological Systems:

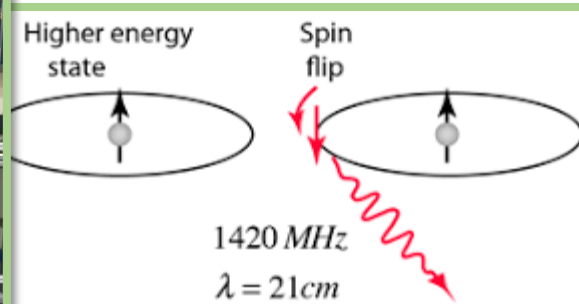
Photonic

- WGM Resonators
- Microwave Cavities



Atomic

- H - Maser
- Atomic Clocks



Acoustic

- Superfluid
- BAW Resonator



Precision Metrology

Science of precise measurement

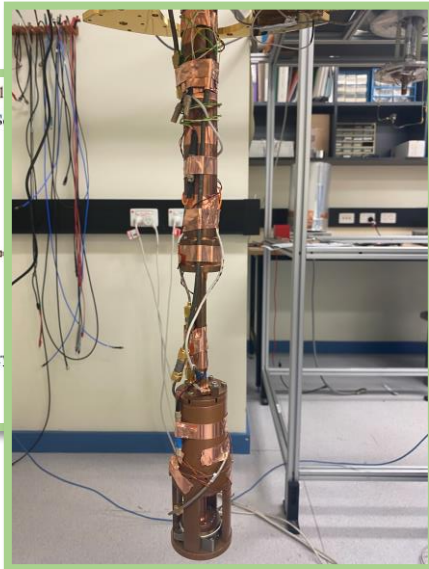
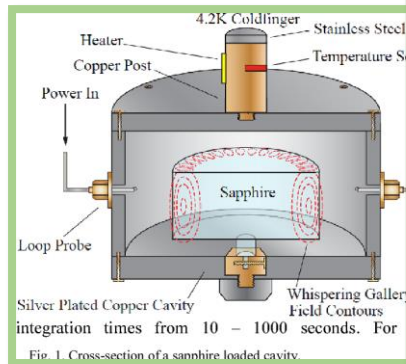


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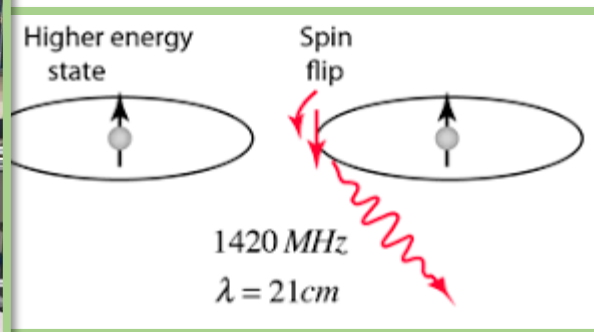
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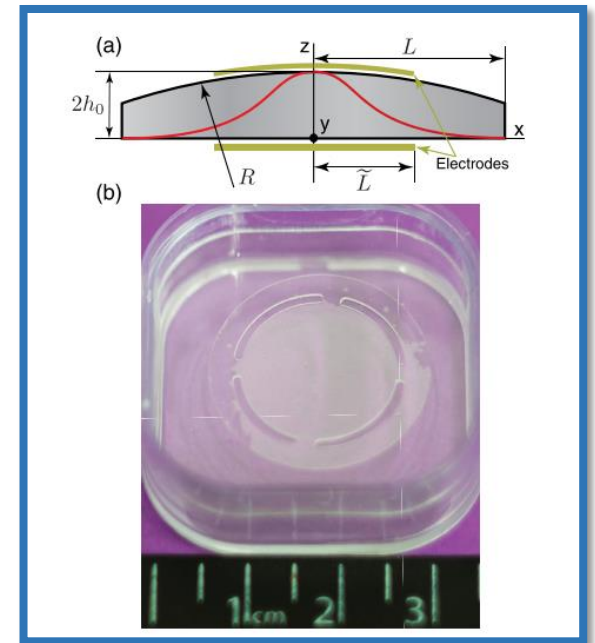
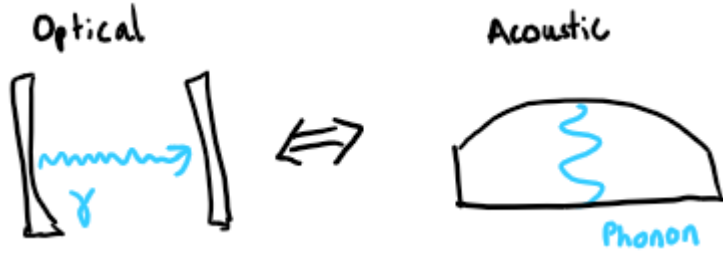
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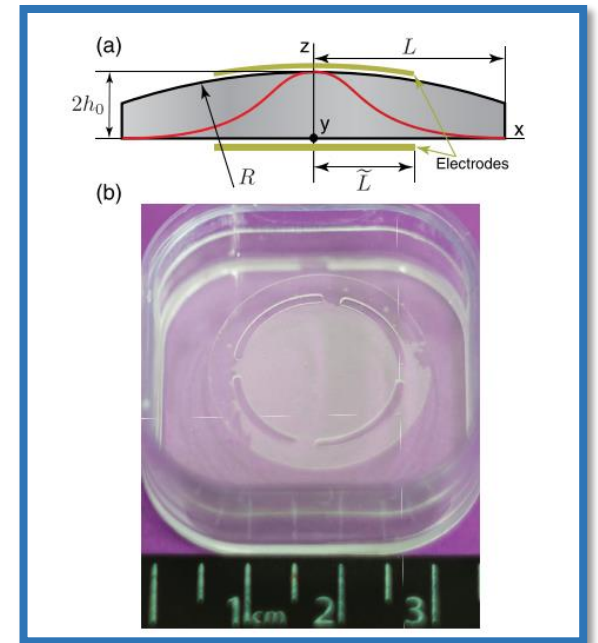
Quartz Bulk Acoustic Wave Resonators

- Acoustic analogue to a Optical Fabry-Perot cavity.



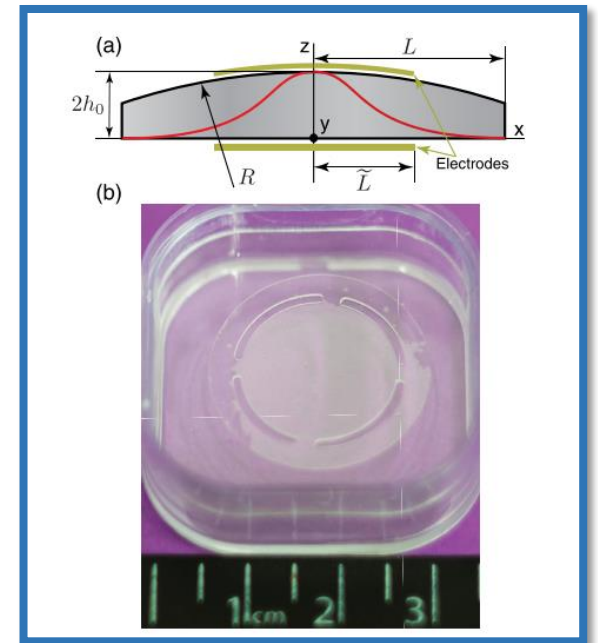
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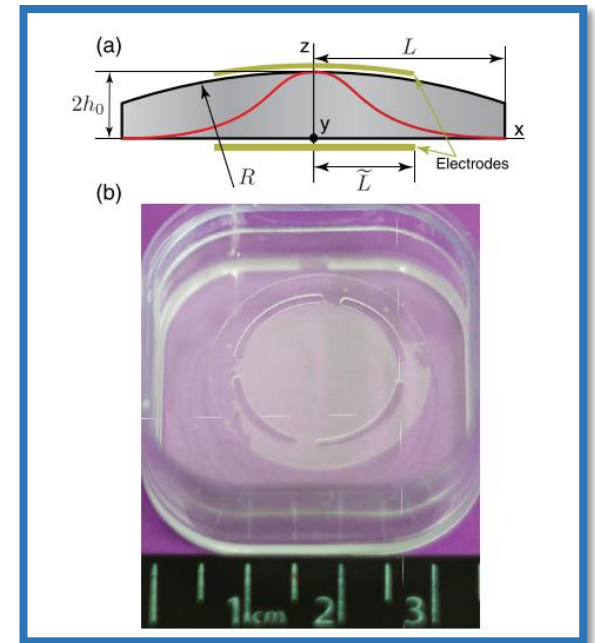
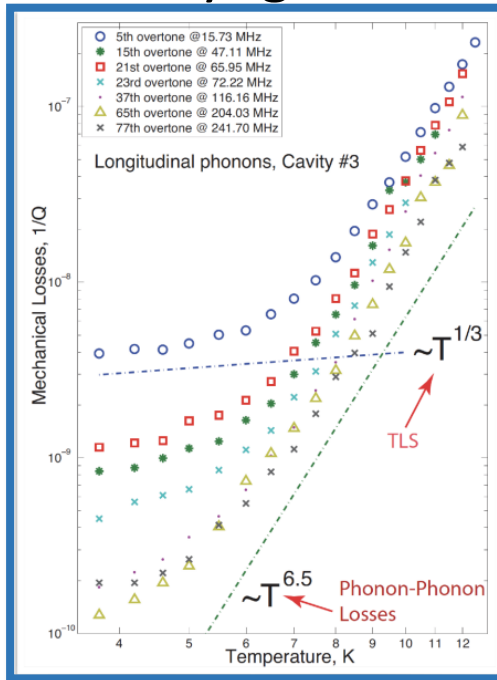
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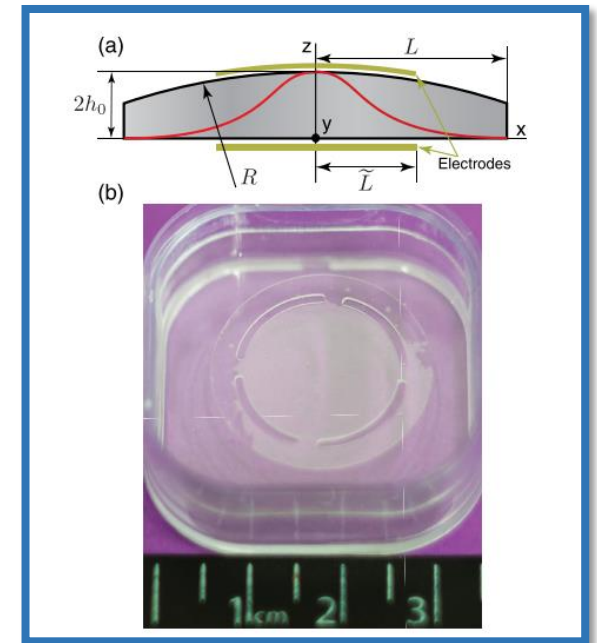
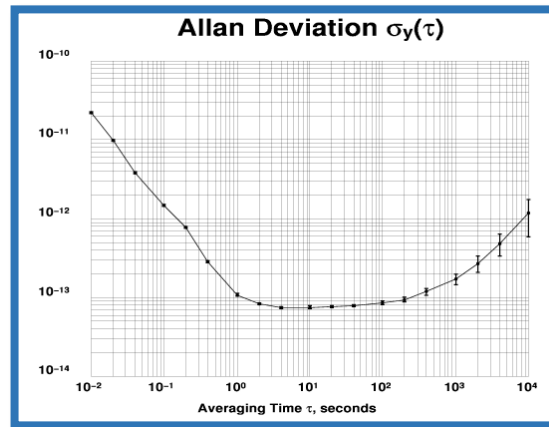
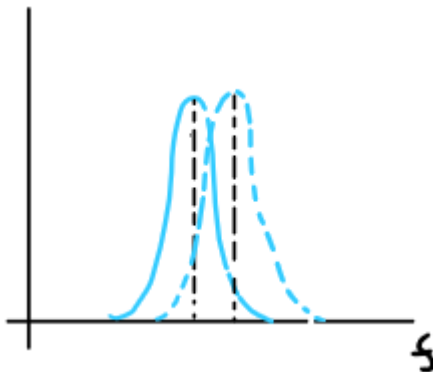
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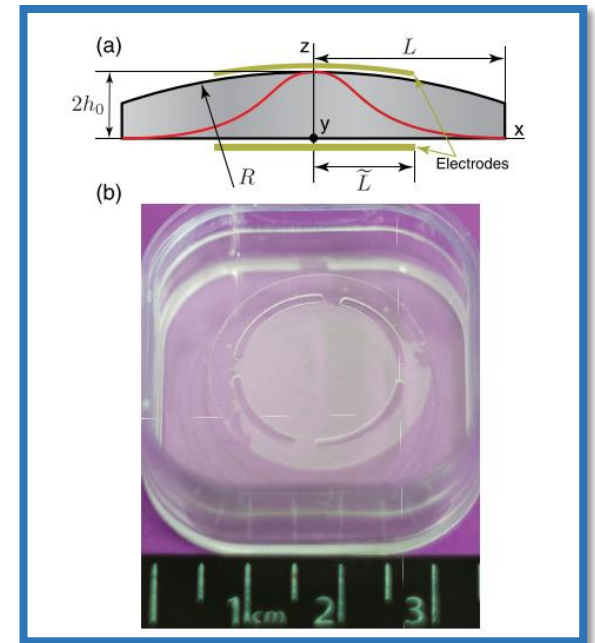
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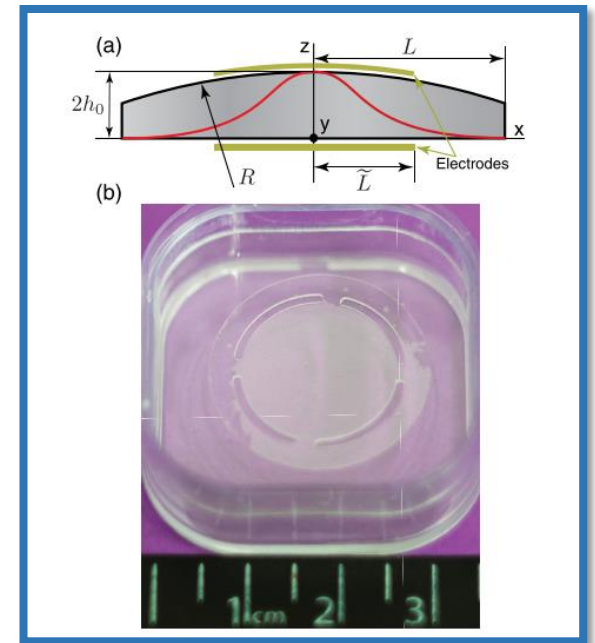
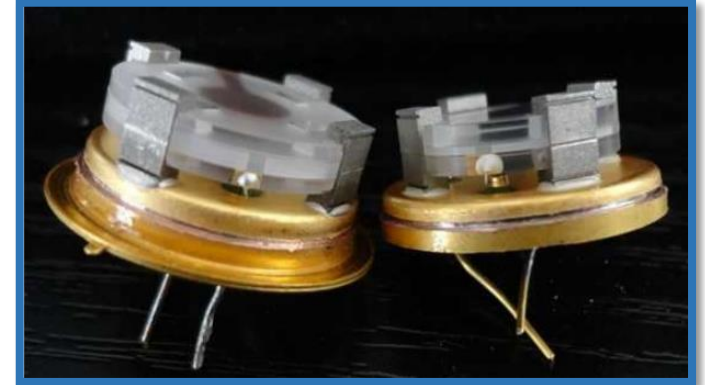
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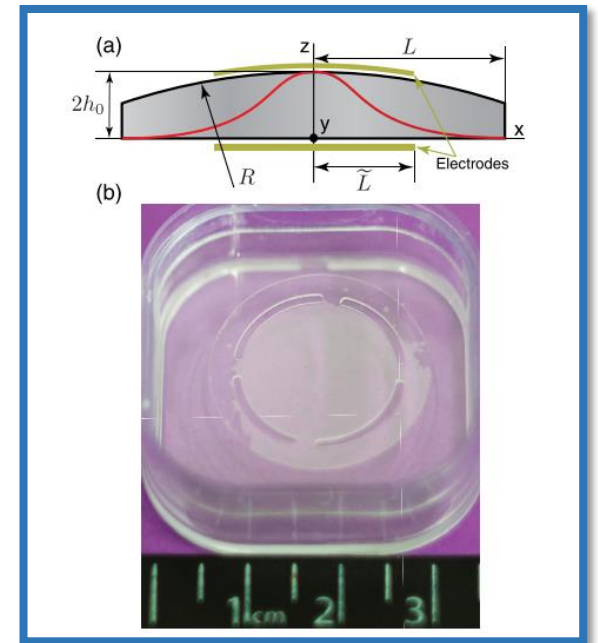
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- High density of modes from 1-1000 MHz
- Ongoing studies of behaviour at cryogenic temperatures

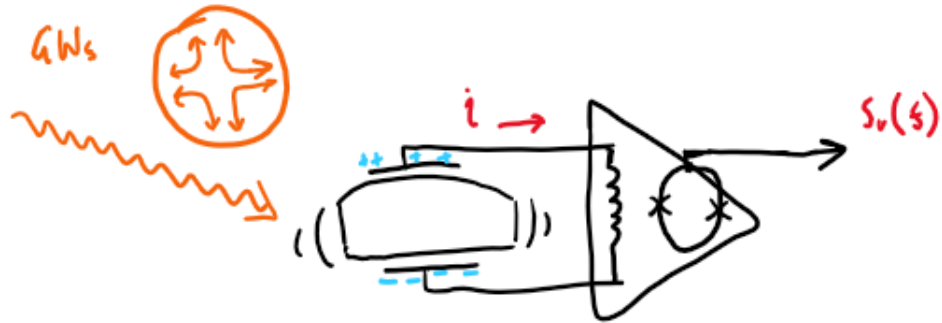


MAGE – Searching for new physics

Quartz BAW coupled to a DC SQUID amplifier → Highly sensitive resonant mass antenna

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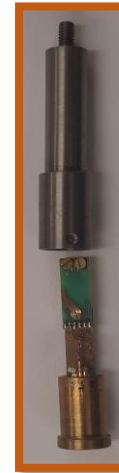


$$\ddot{B}_\lambda + \tau_\lambda^{-1} \dot{B}_\lambda + \omega_\lambda^2 B = -c^2 R_{i0j0} \int_V dv \frac{\rho}{m_\lambda} U_\lambda^i(\mathbf{x}) x^j.$$

Primary target:

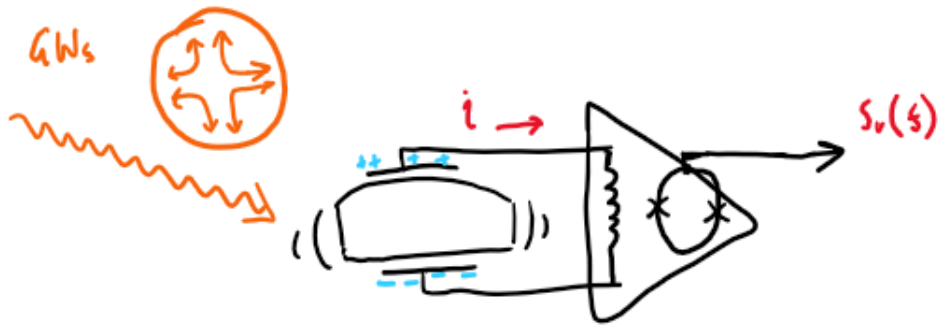
High frequency gravitational waves (MHz)

PRD 90, 102005 (2014)



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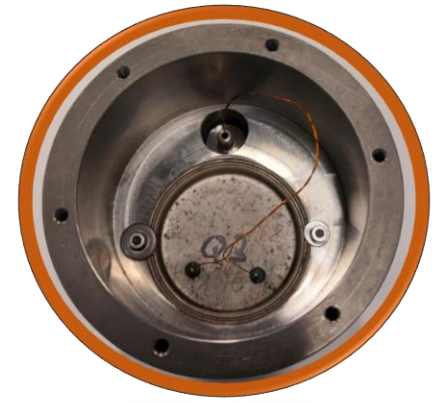
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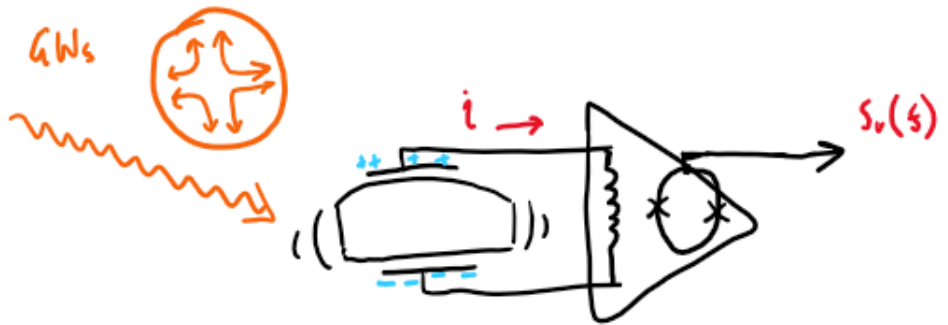
No known astrophysical sources exist at these frequencies

PRD 90, 102005 (2014)



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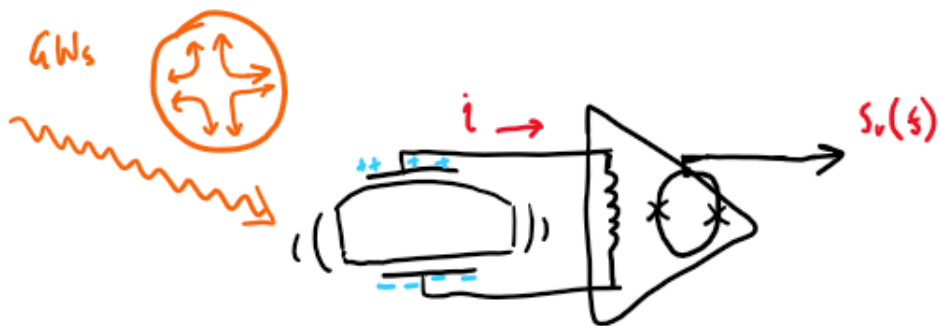
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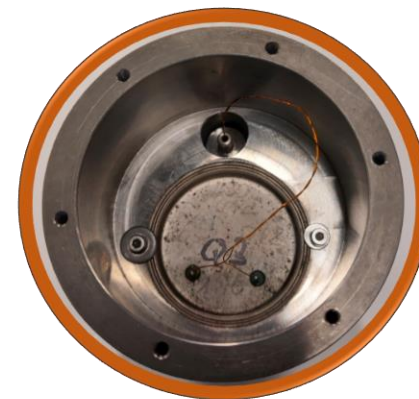
Any potential detection points to new physics outside the standard model !

MAGE – Searching for new physics

Quartz BAW coupled to a DC SQUID amplifier \longrightarrow Highly sensitive resonant mass antenna

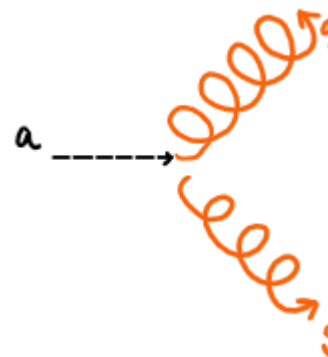


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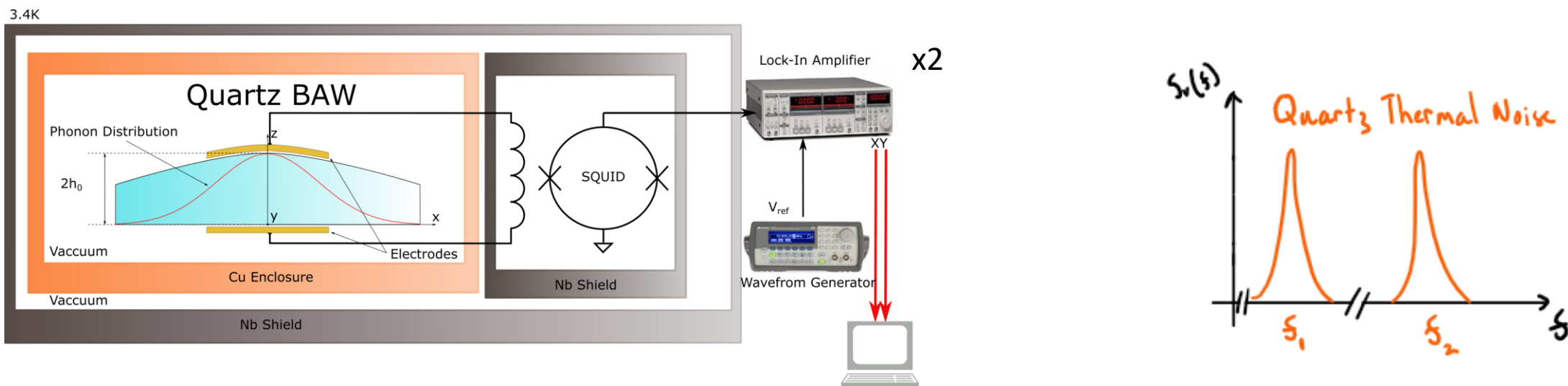
HFGWs due to DM:

Sub – solar black hole mergers, black hole super radiance, axion decay into gravitons



MAGE – Searching for new physics

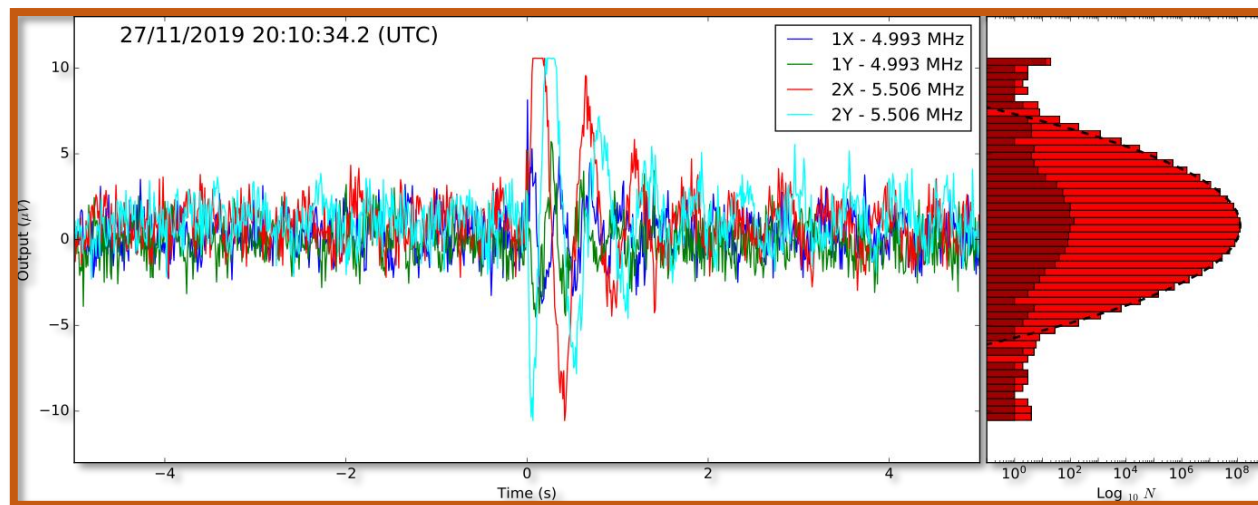
First Observational Period → GEN 1 & GEN 2, 153 days of data, two modes



Data Analysis:

Two significantly strong, rare events

Phys. Rev. Lett. **127**, 071102



MAGE – Searching for new physics

What's next ?

MAGE – Searching for new physics

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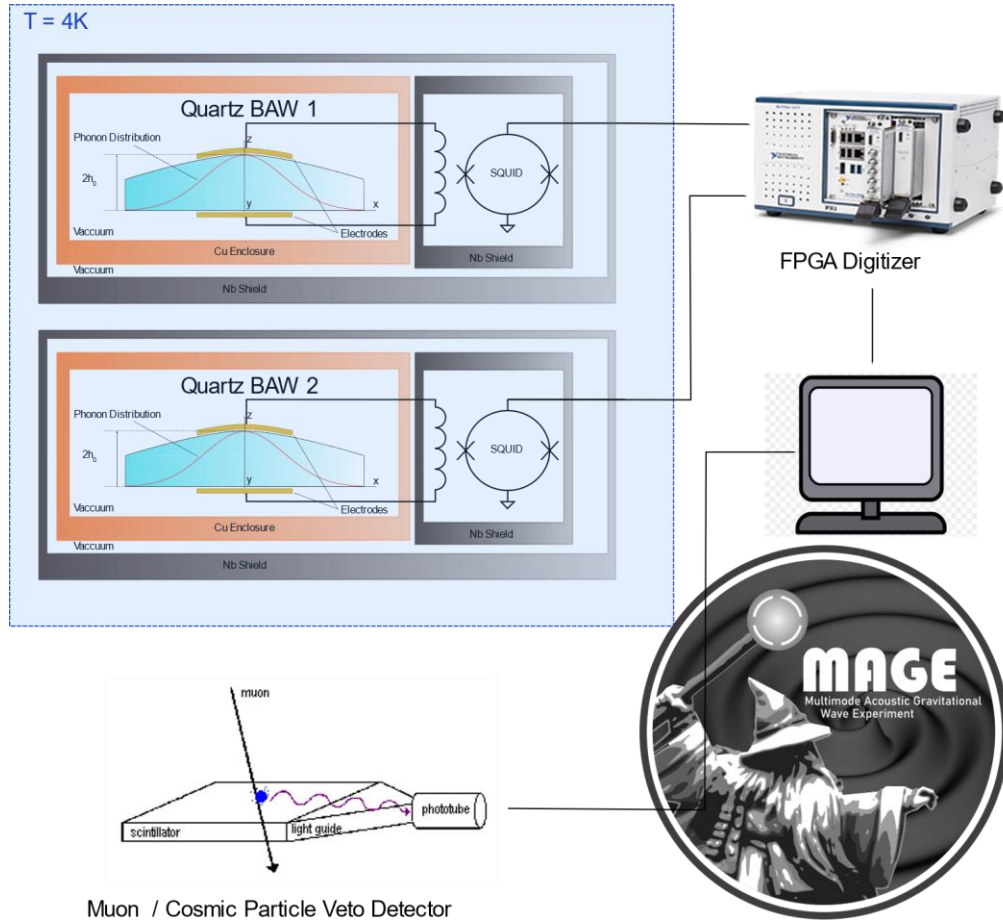


Multimode Acoustic Gravitational Wave Experiment

MAGE – Searching for new physics

What's next ?

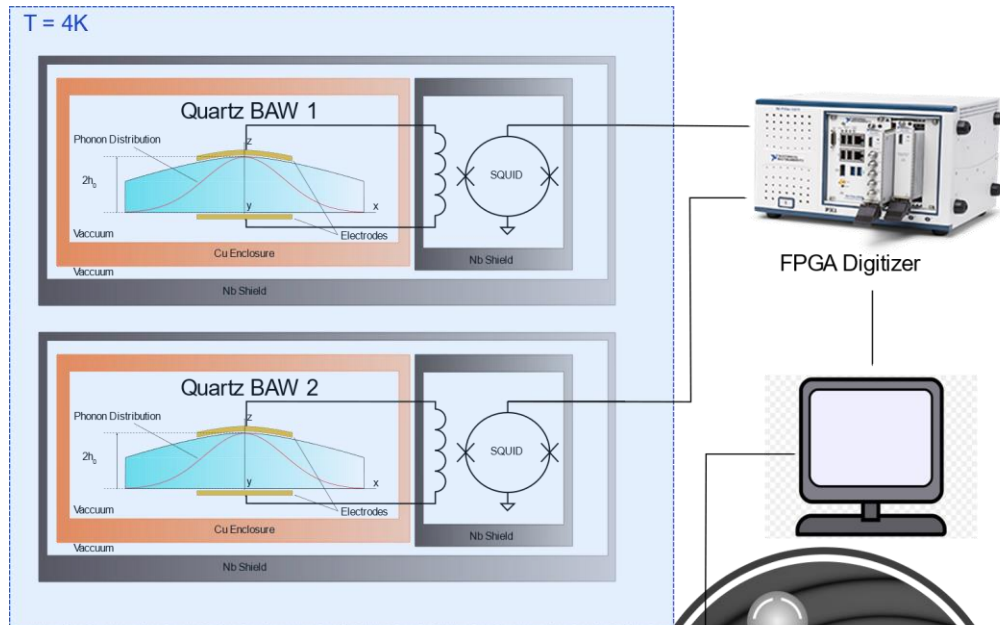
→ Multimode Acoustic Gravitational Wave Experiment



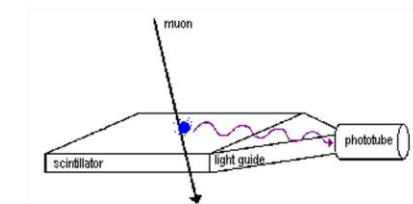
MAGE – Searching for new physics

What's next ?

→ **M**ultimode **A**coustic **G**ravitational Wave **E**xperiment



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



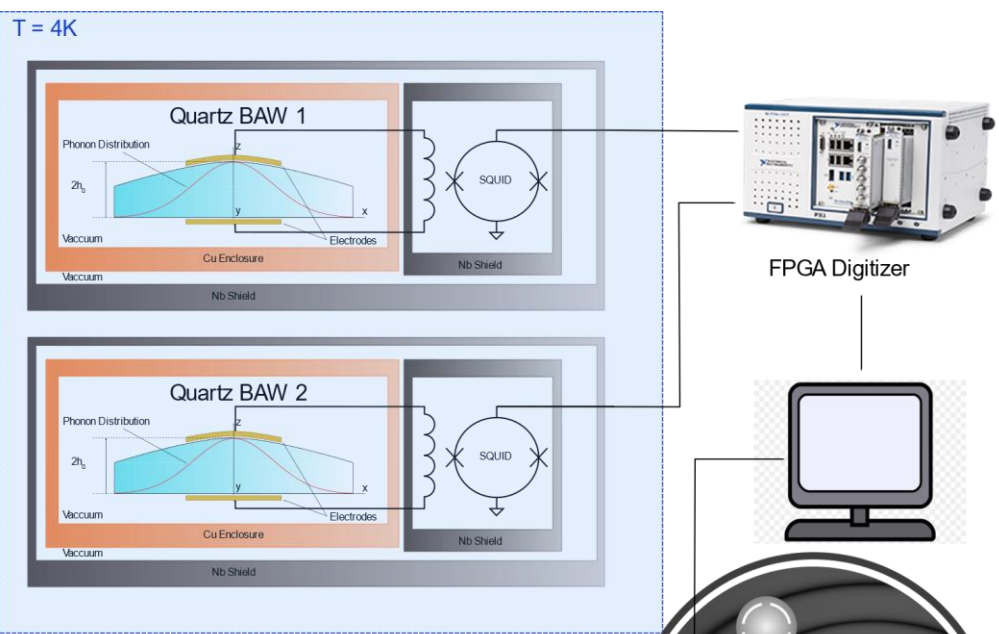
Muon / Cosmic Particle Veto Detector



MAGE – Searching for new physics

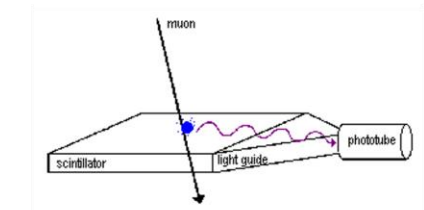
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Exclude potential sources of events:



Muon / Cosmic Particle Veto Detector





MAGE – Searching for new physics

Currently taking data!



MAGE – Searching for new physics

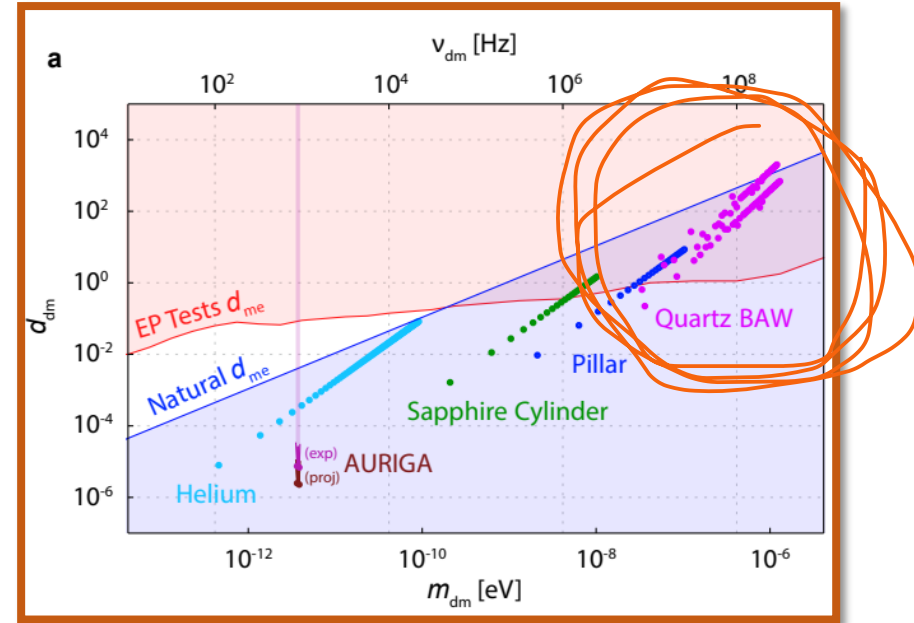
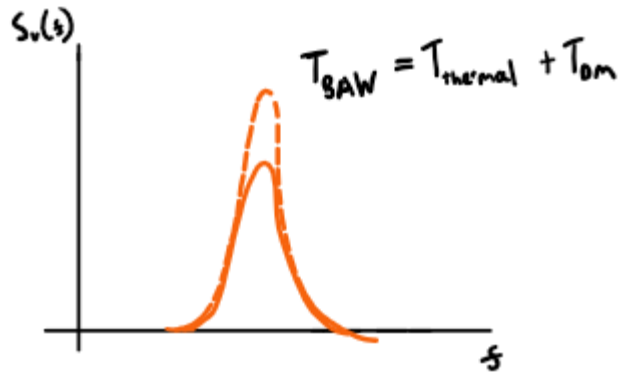
Other possibilities for MAGE:



MAGE – Searching for new physics

Other possibilities for MAGE:

Scalar DM \rightarrow Isotropic strain signal



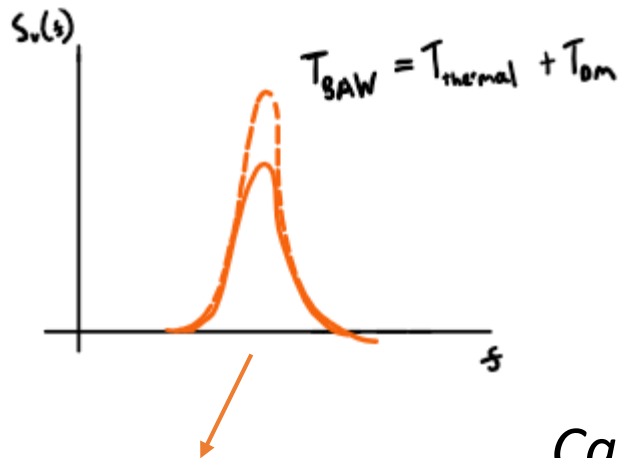
Phys. Rev. Lett. **124**, 151301



MAGE – Searching for new physics

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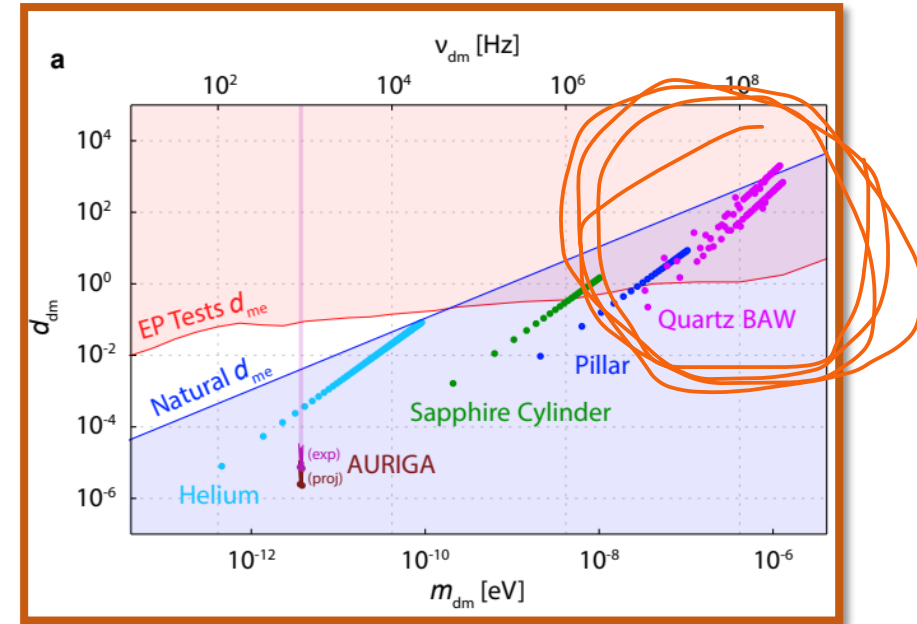
Scalar DM \rightarrow Isotropic strain signal



Nontrivial DM signal

Can exclude:
 Transient flows
 Daily modulation

Ongoing work:
 Resonance tuning



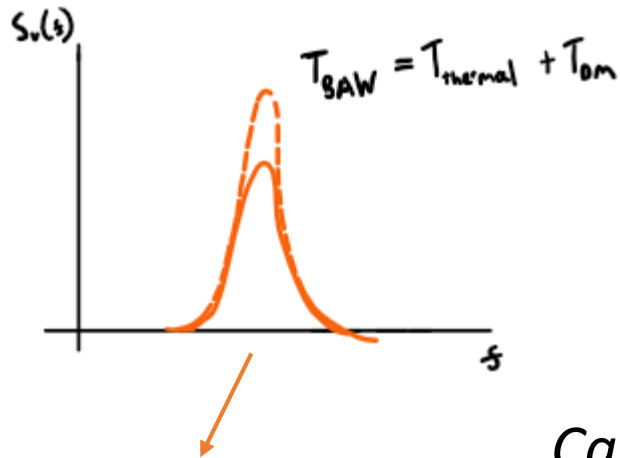
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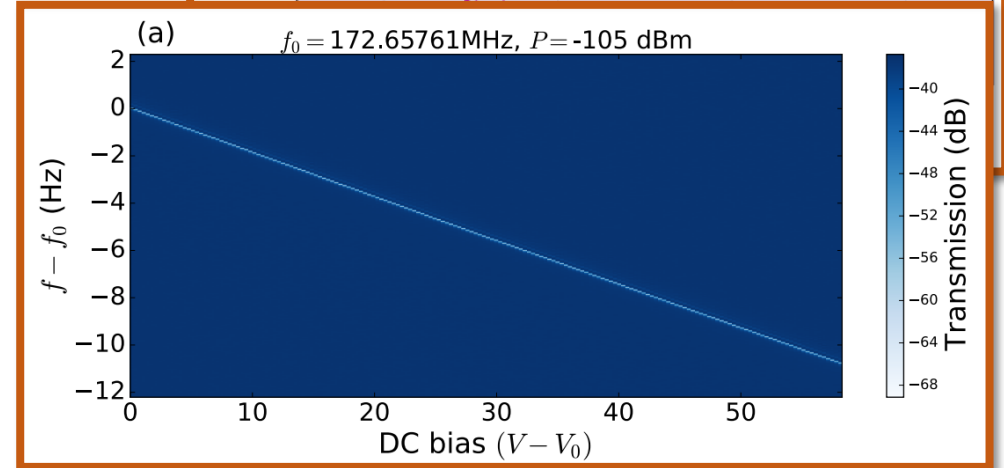
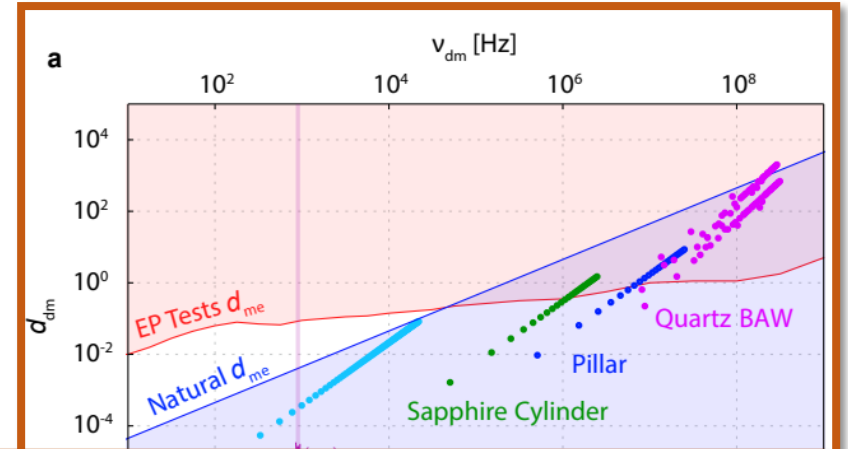


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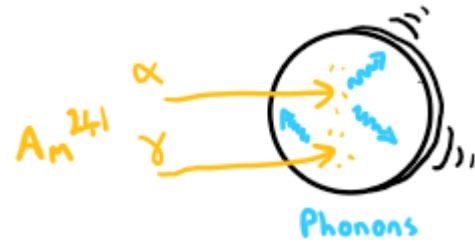
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→ 2207.01176



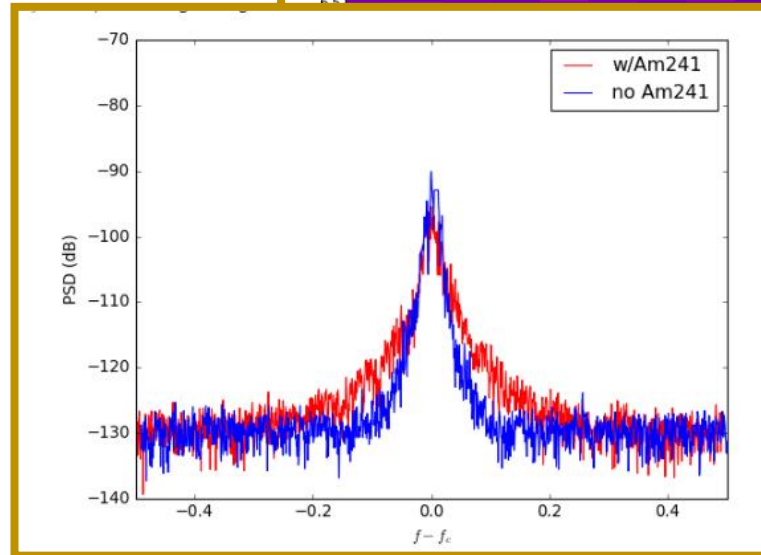
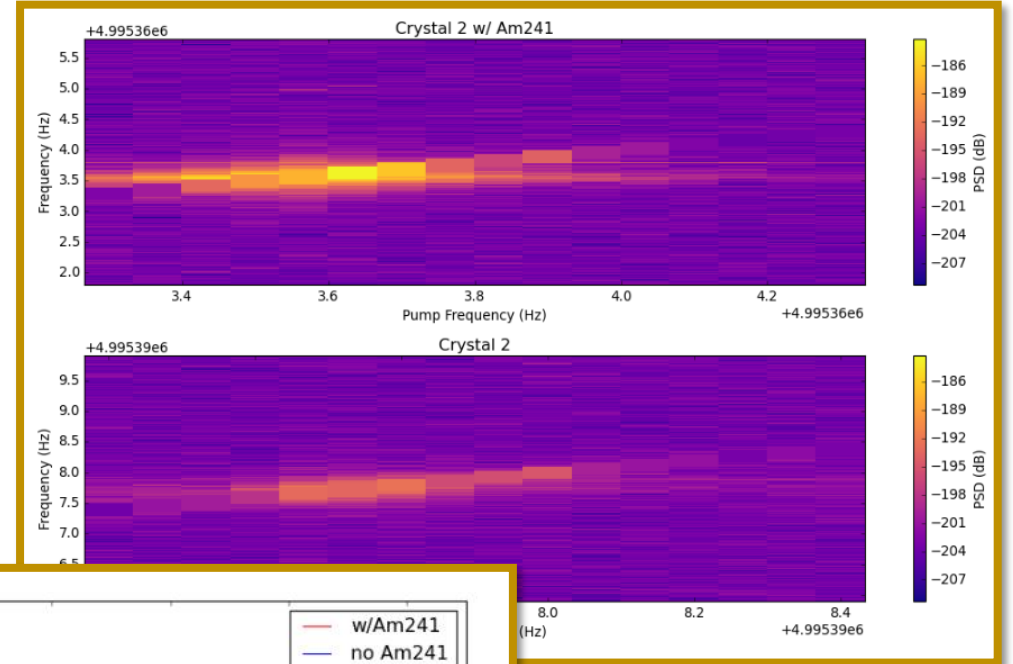
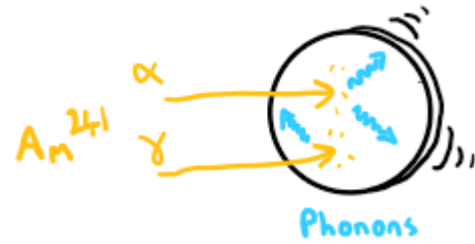
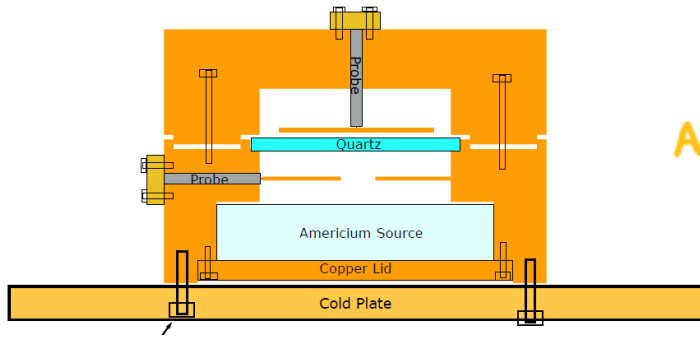
Quartz Bolometer

Can we detect radiation with a quartz BAW ?



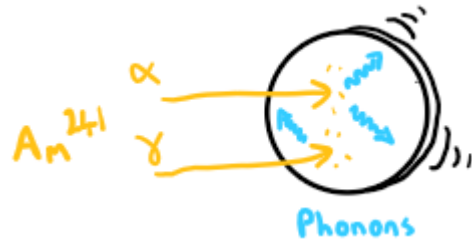
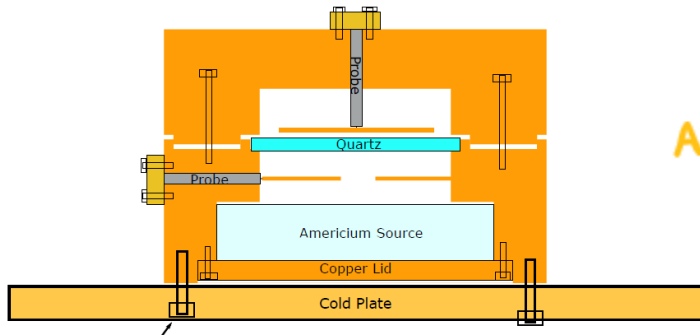
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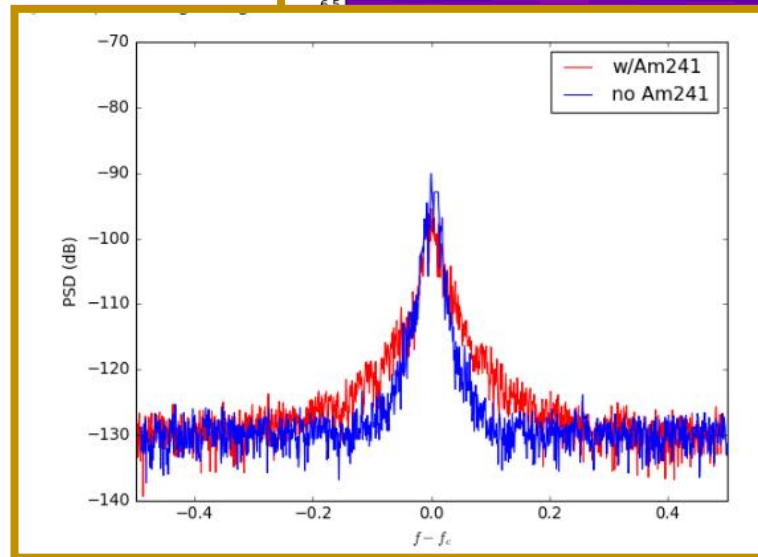
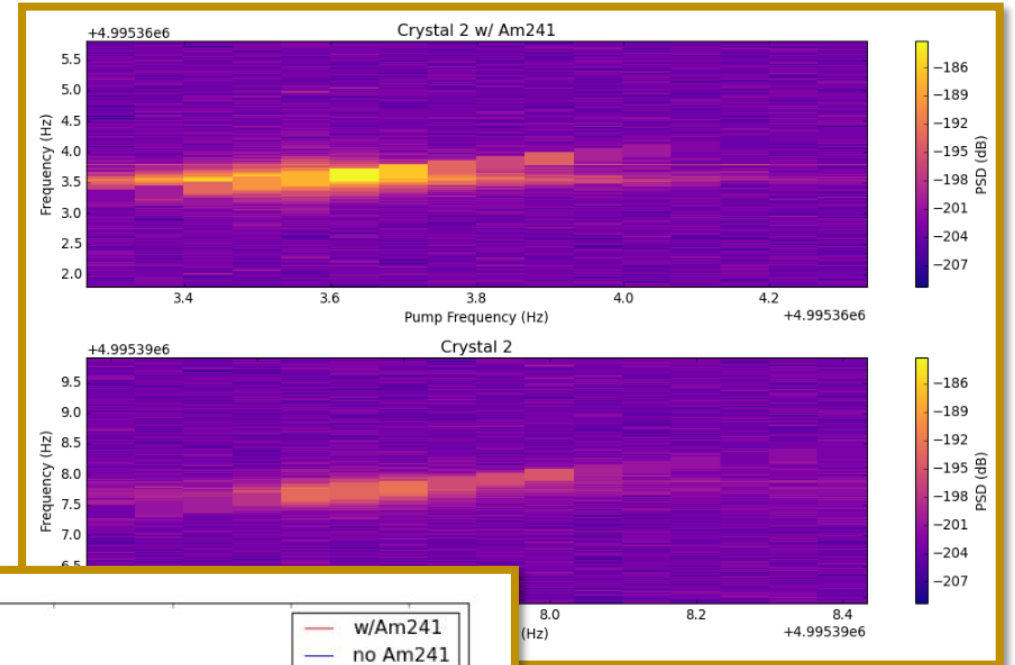
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Am²⁴¹ source increases BAW mode temperature

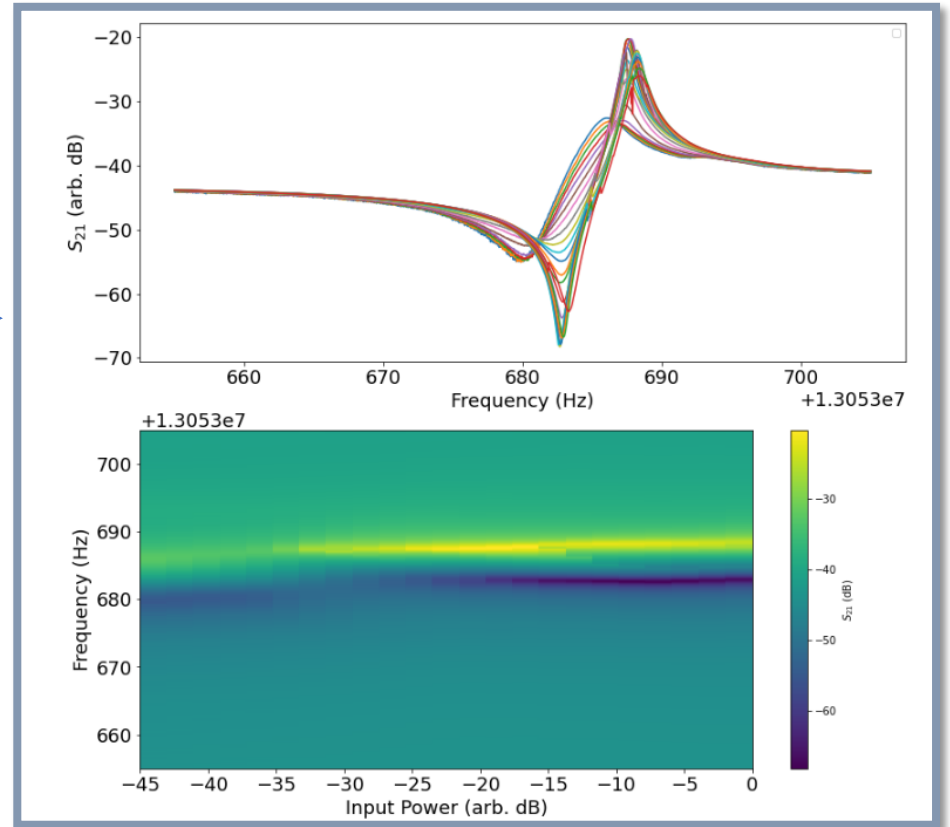
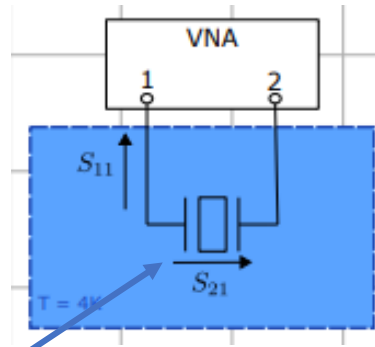
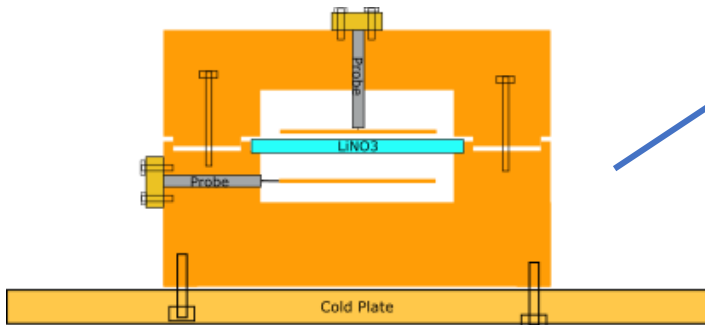
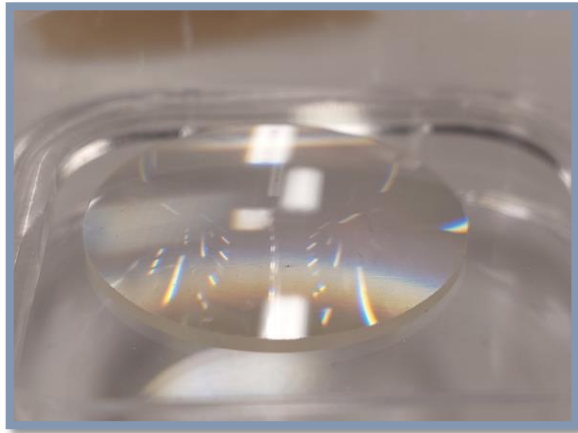
Possibly some residual long term effects

Ongoing work



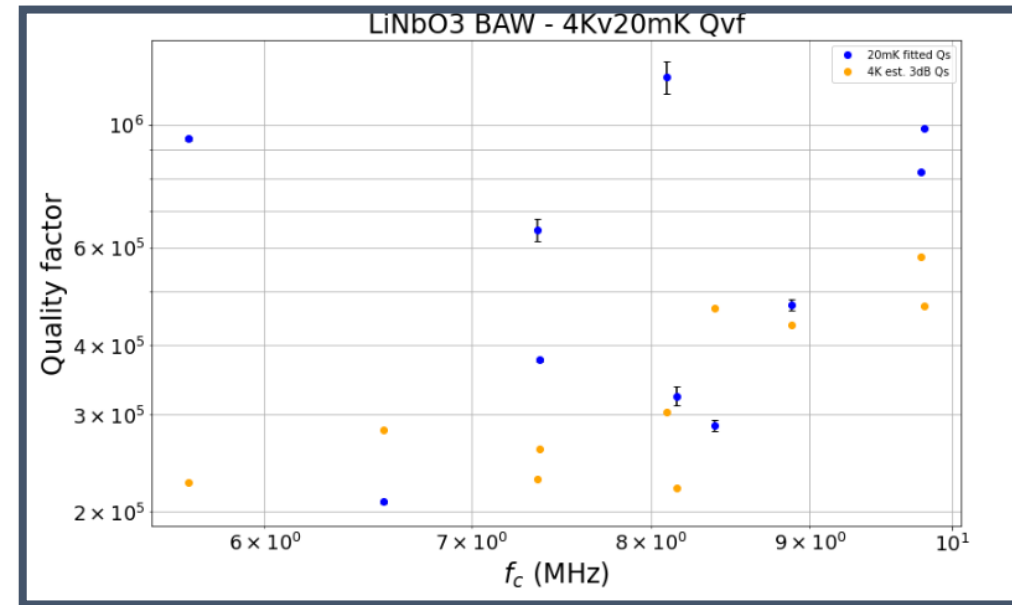
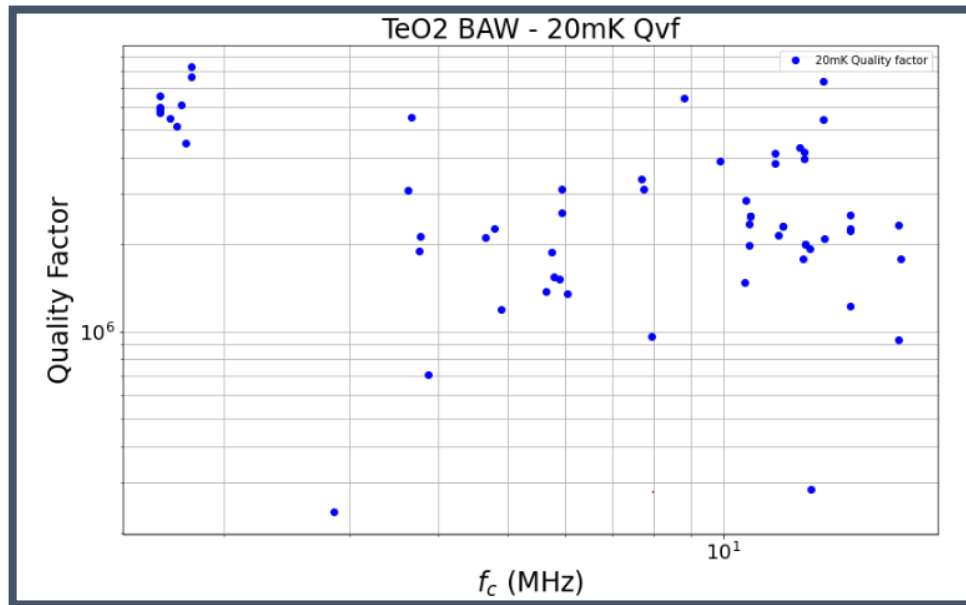
LiNbO₃ and TeO₂ Bulk Acoustic Wave Resonators

Other piezoelectric crystals ?



LiNbO3 and TeO2 Bulk Acoustic Wave Resonators

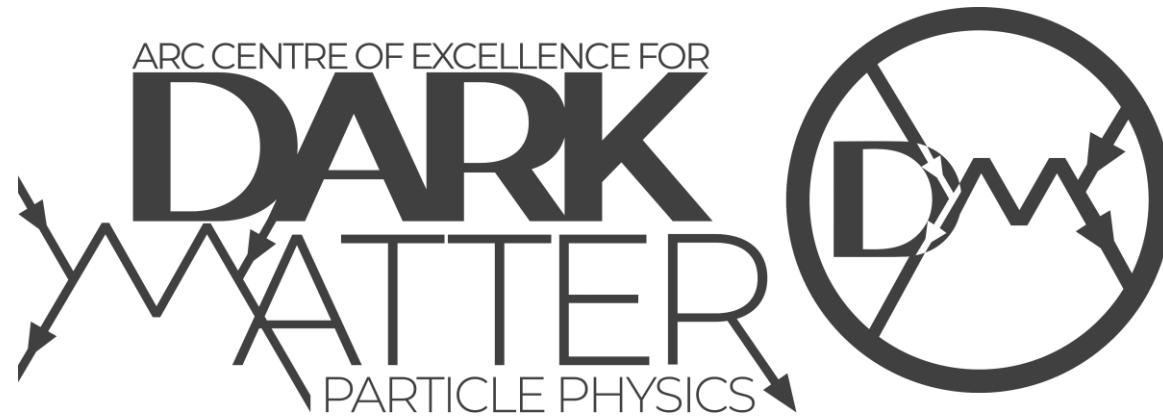
Other piezoelectric crystals ?



Plenty of modes 1-20 MHz with Quality factors $\sim 10^6$ @ 20mK

Summary

1. Many ultralight dark matter models -> Many diverse experiments required
2. Precision metrology provides us with the tools necessary to search for new physics
3. Quartz BAWs are an ideal architecture for fundamental physics
4. MAGE experiment, overview and outlook
5. Quartz bolometer?
6. Other materials, TeO₂ and LiNbO₃ BAWs -> seem like good candidates for future experiments



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