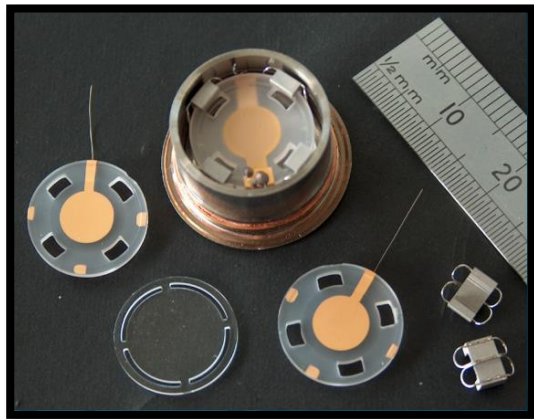


The Multimode Acoustic Gravitational Wave Experiment: MAGE

QDM



Will Campbell

William.Campbell@uwa.edu.au



THE UNIVERSITY OF
**WESTERN
AUSTRALIA**



EQUS

ARC CENTRE OF EXCELLENCE FOR
**DARK
MATTER**
PARTICLE PHYSICS



Outline

1. Motivation
2. Precision metrology
3. Quartz bulk acoustic wave resonators
4. The Multimode Acoustic Gravitational wave Experiment (MAGE)
5. Future / current work.

Motivation: High Frequency GWs

High Frequency Gravitational Waves

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High Frequency Gravitational Waves

No known astrophysical
sources exist at these
frequencies

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No known astrophysical sources exist at these frequencies



Any potential detection points to physics *beyond that of the standard model*

Motivation: High Frequency GWs

High Frequency Gravitational Waves

<https://arxiv.org/abs/2011.12414>

Theorised sources:



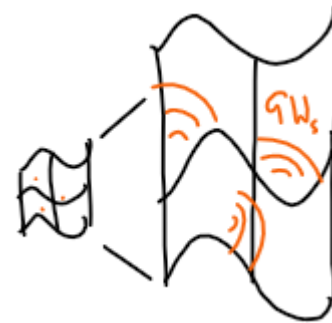
Primordial
black hole
merger



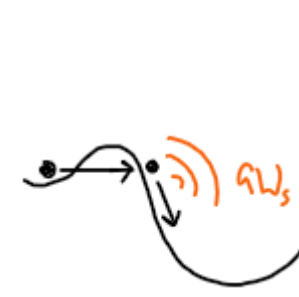
Black hole
super-
radiance



Neutron star
merger



Inflation



Phase
Transitions



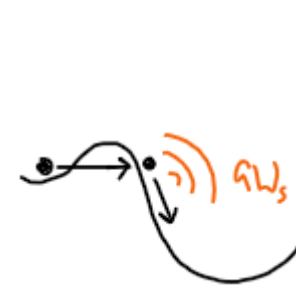
Topological
Defects

Motivation: High Frequency GWs

High Frequency Gravitational Waves

<https://arxiv.org/abs/2011.12414>

Theorised sources:



Coherent sources

Stochastic sources

Motivation: High Frequency GWs

HFGWs



Precision Metrology

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

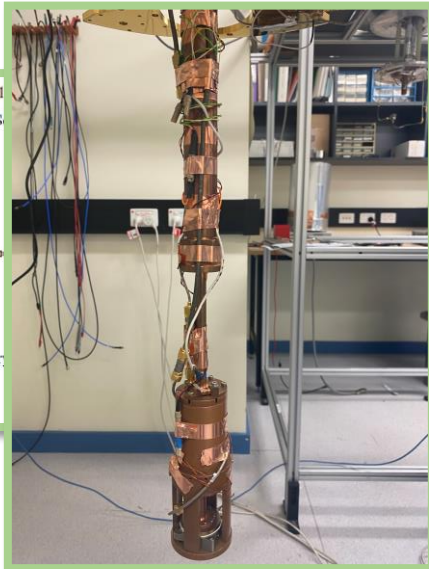
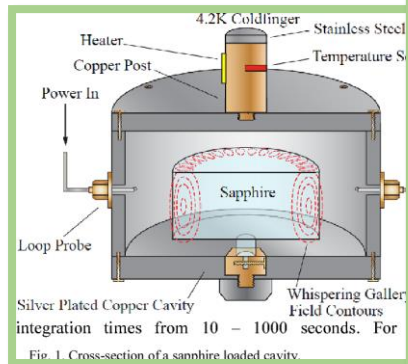


Physics at low energies

Metrological Systems:

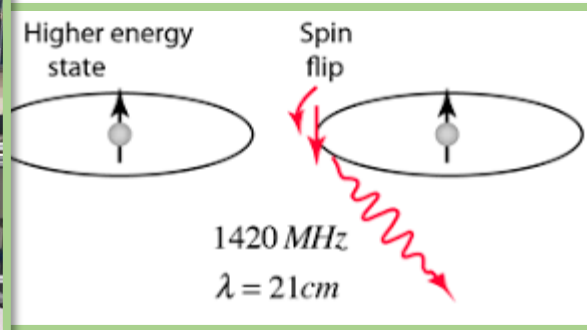
Photonic

- WGM Resonators
- Microwave Cavities



Atomic

- H - Maser
- Atomic Clocks



Acoustic

- Superfluid
- BAW Resonator



Precision Metrology

Science of precise measurement

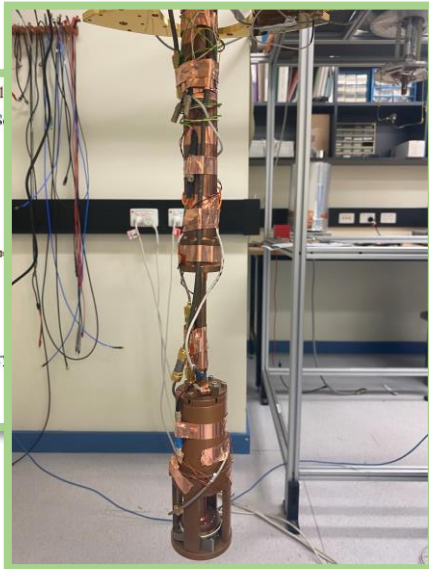
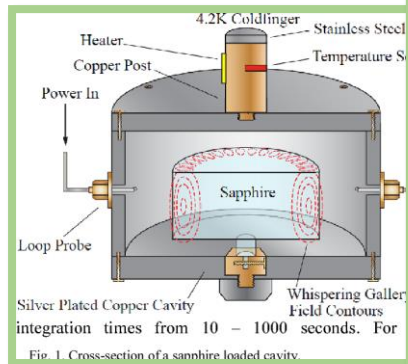


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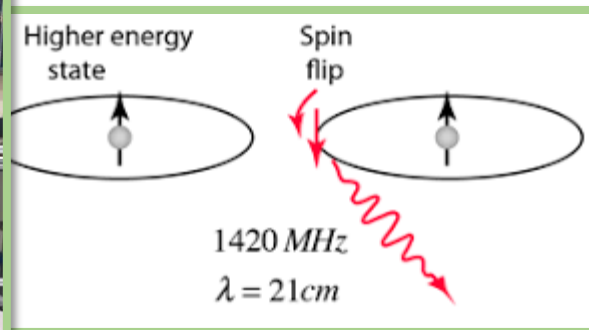
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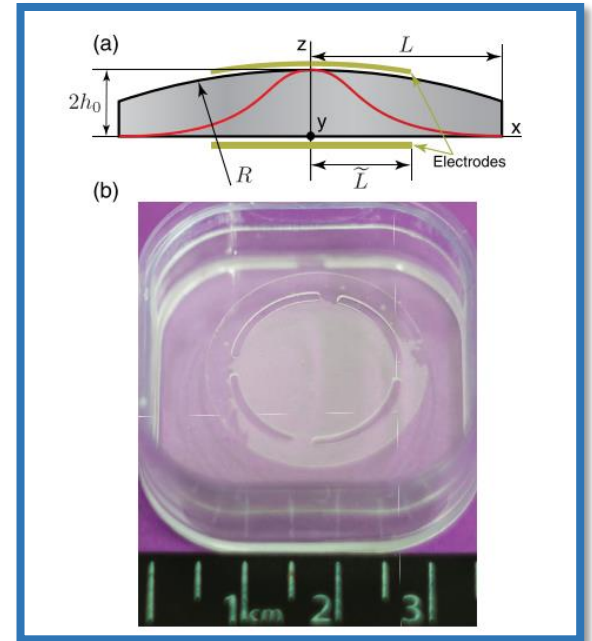
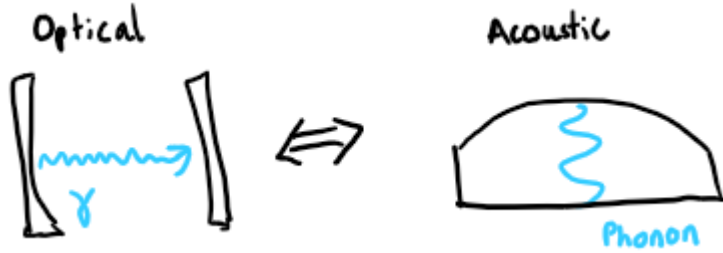
Acoustic

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- **BAW Resonator**



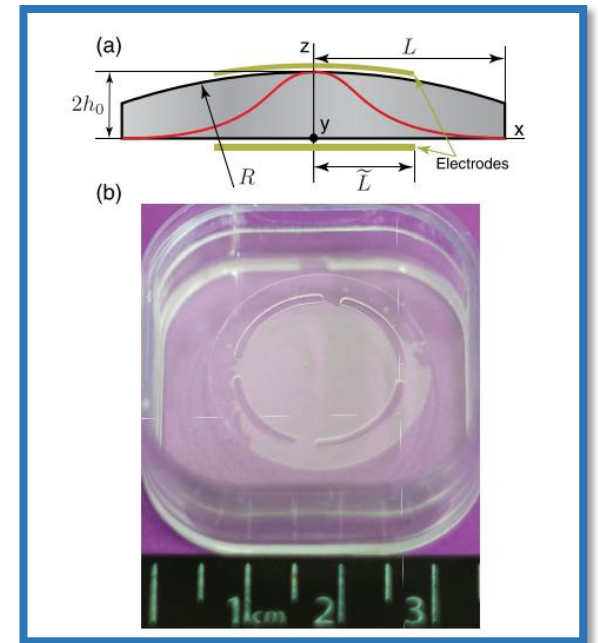
Quartz Bulk Acoustic Wave Resonators

- Acoustic analogue to a Optical Fabry-Perot cavity.



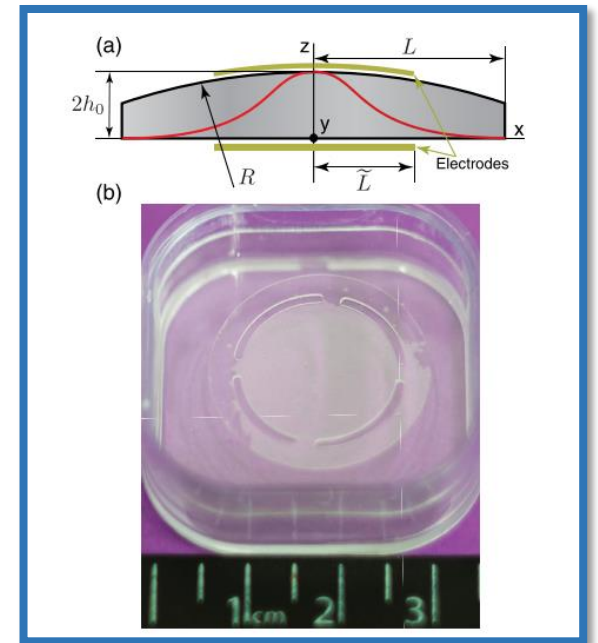
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- Already a well established technology



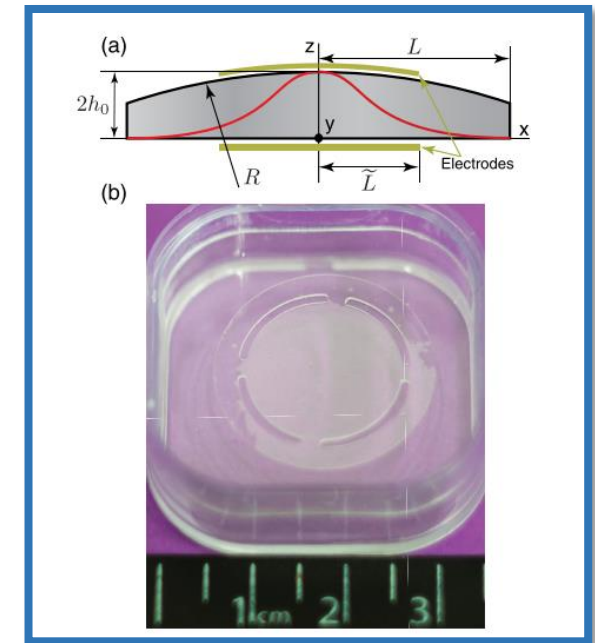
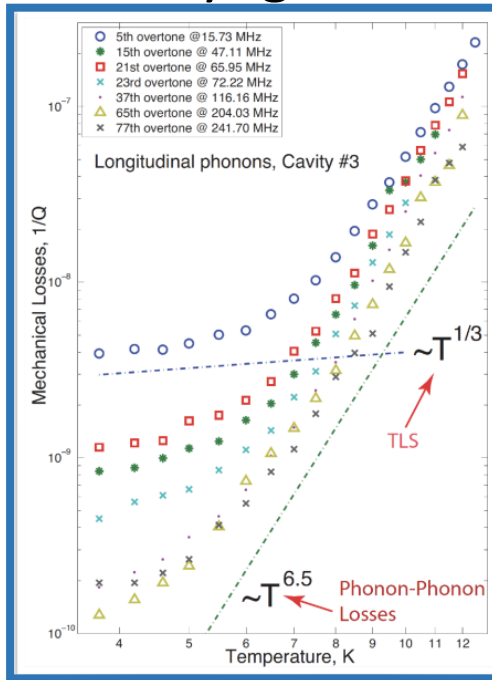
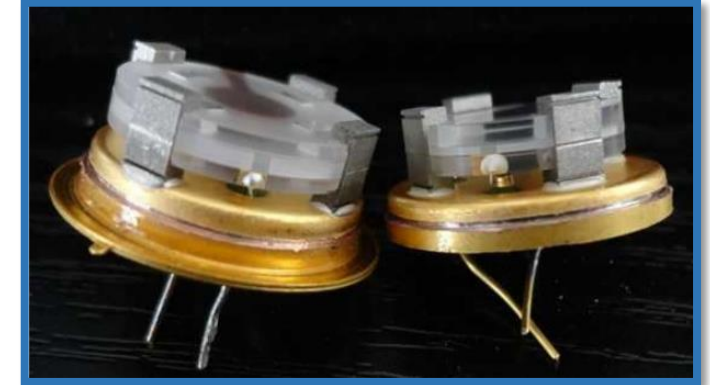
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- Gram scale mode mass, macroscopic resonator



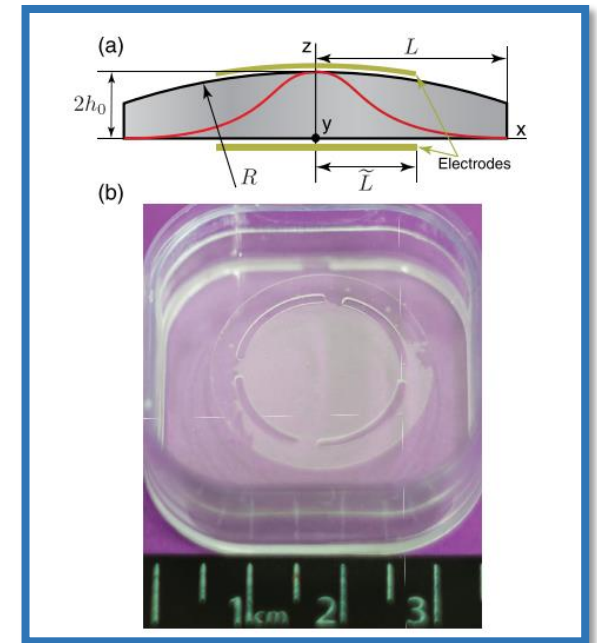
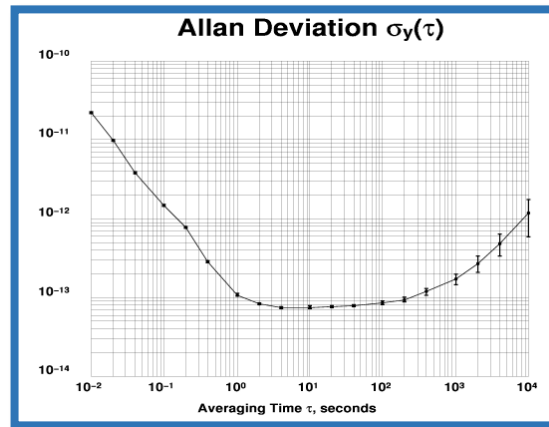
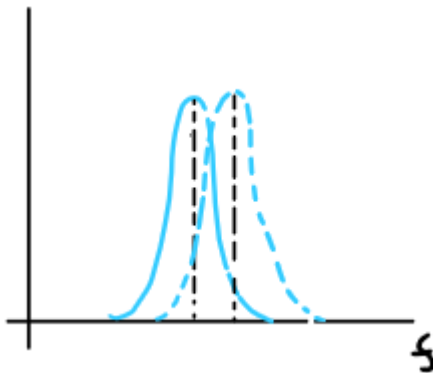
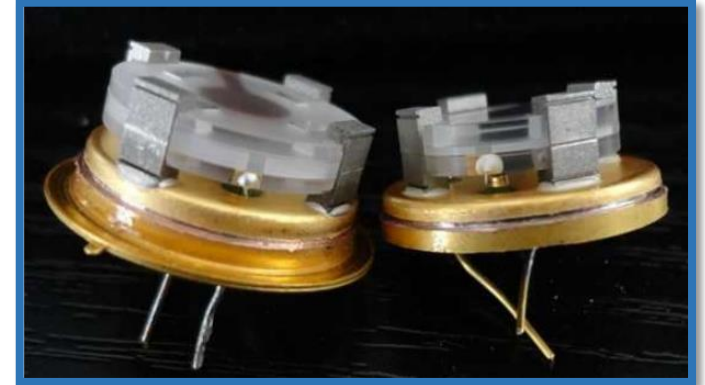
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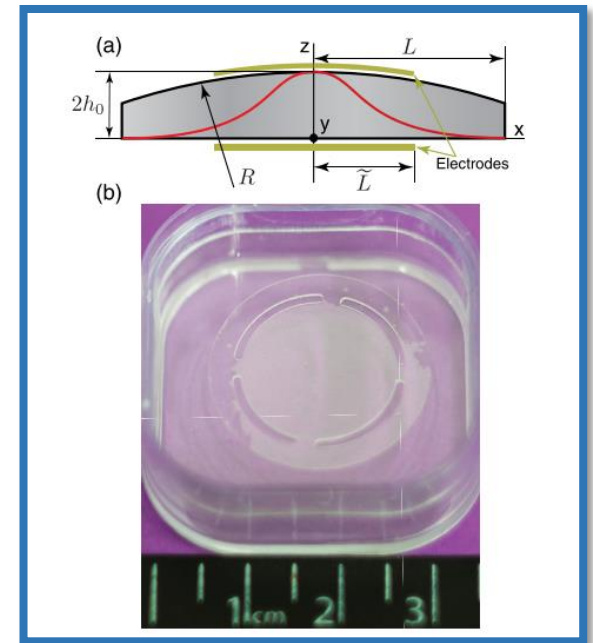
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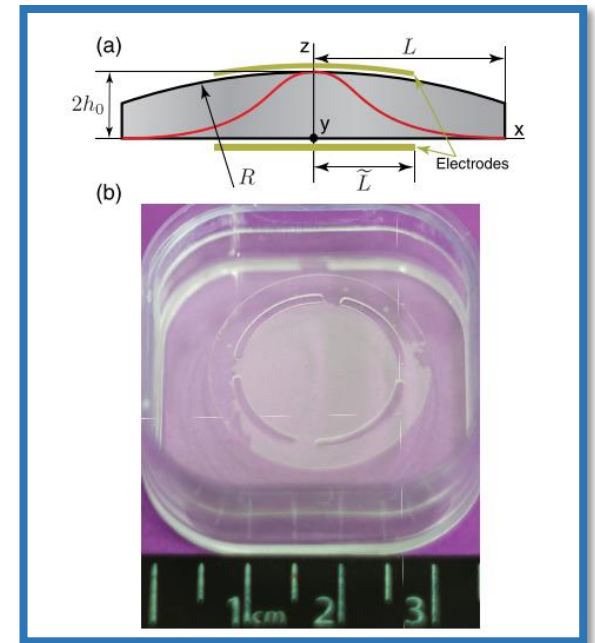
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- Piezoelectric coupling provides excitation & readout



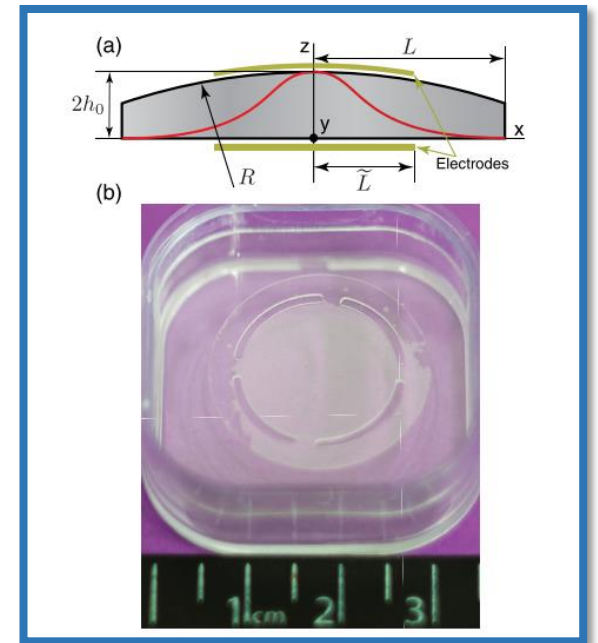
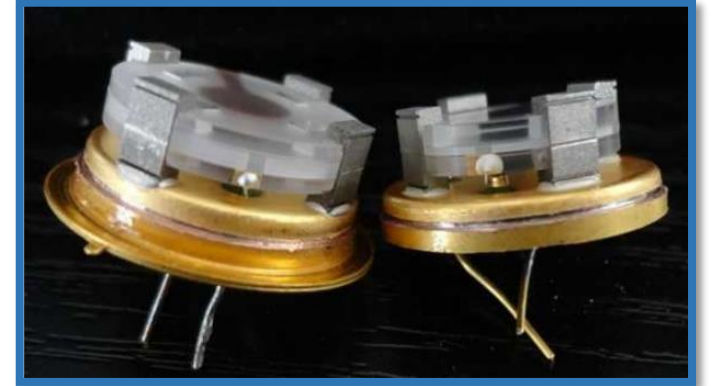
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- Impressive short - mid term frequency stability
- Piezoelectric coupling provides excitation & readout
- High density of modes from 1-1000 MHz
- Ongoing studies of behaviour at cryogenic temperatures

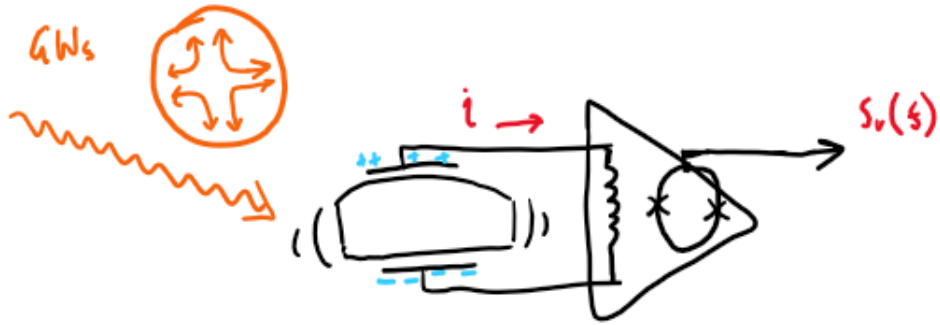


MAGE – Searching for new physics

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

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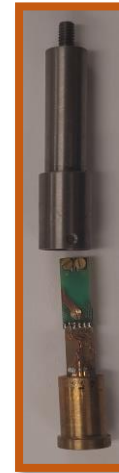


$$\ddot{B}_\lambda + \tau_\lambda^{-1} \dot{B}_\lambda + \omega_\lambda^2 B = -c^2 R_{i0j0} \int_V dv \frac{\rho}{m_\lambda} U_\lambda^i(\mathbf{x}) x^j.$$

Primary target:

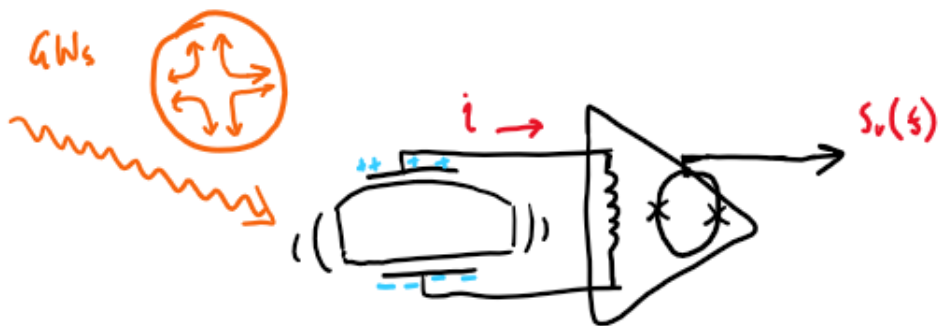
High frequency gravitational waves (MHz)

<https://arxiv.org/abs/1410.2334>

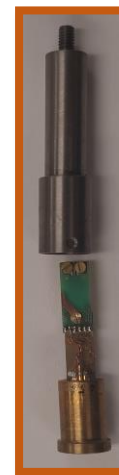


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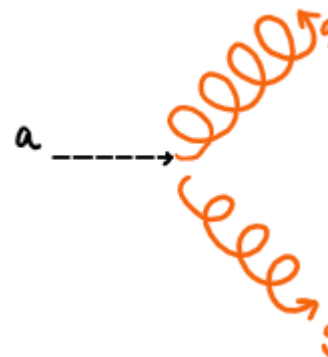


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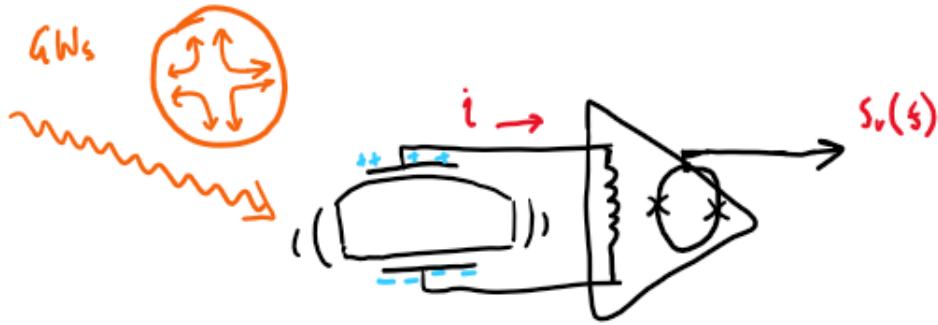
HFGWs due to DM:

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



MAGE – Searching for new physics

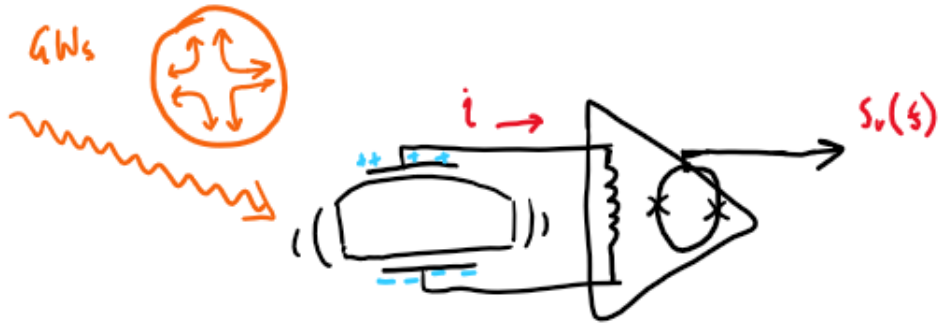
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$$S_h^+(\omega) \Big|_{\omega=\omega_\lambda} = \sqrt{\frac{4k_b T_\lambda \omega_\lambda}{Q_\lambda M_\lambda}} \left(\frac{1}{\omega_\lambda^2 h_0 \xi} \right)$$

MAGE – Searching for new physics

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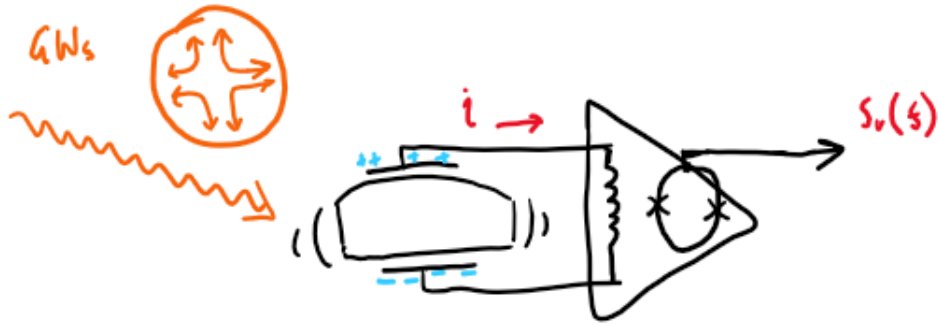


Mode Temperature

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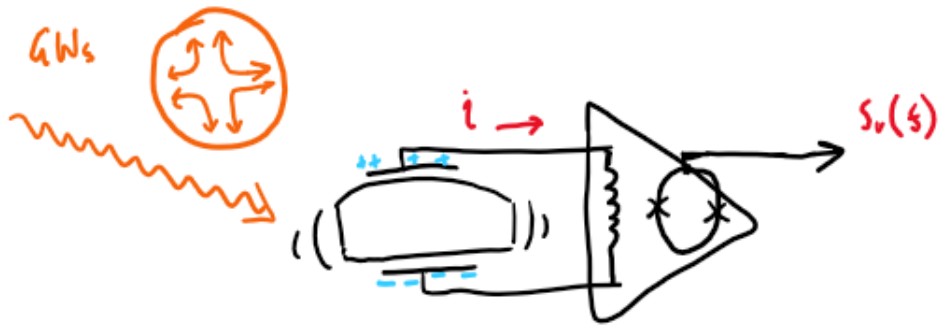
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Quality Factor

MAGE – Searching for new physics

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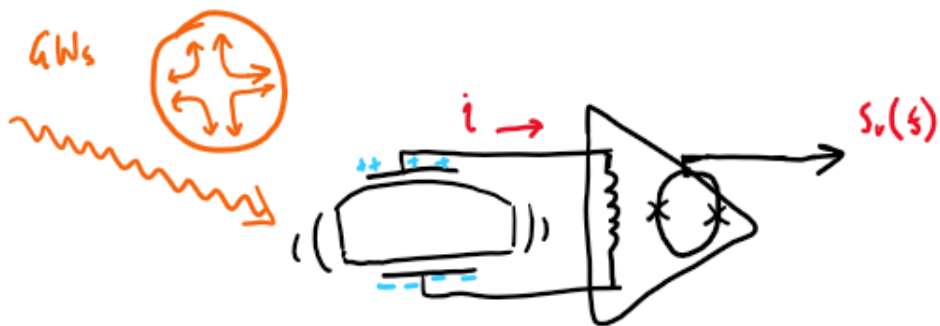


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Mode Temperature \longleftarrow T_λ
 Quality Factor \longleftarrow Q_λ
 Gravitational Coupling \longleftarrow ξ

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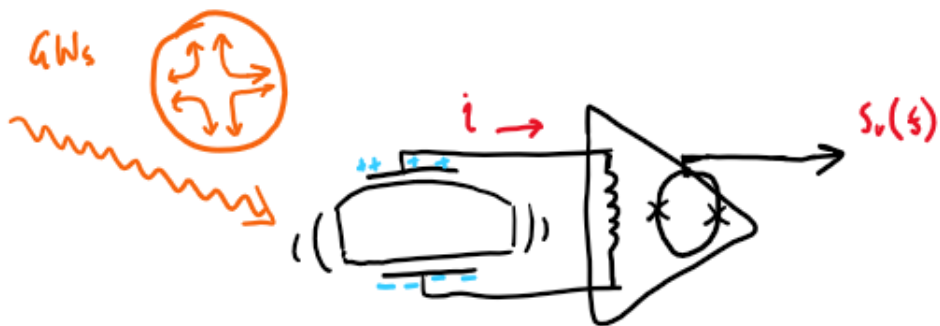


$$S_h^+(\omega) \Big|_{\omega=\omega_\lambda} = \sqrt{\frac{4k_b T_\lambda \omega_\lambda}{Q_\lambda M_\lambda}} \left(\frac{1}{\omega_\lambda^2 h_0 \xi} \right) \quad \xi_\lambda = h_0 \tilde{\xi}_\lambda = \int_V dv \frac{\rho}{m_\lambda} U_\lambda^i(\mathbf{x}) x^j$$

Gravitational Coupling

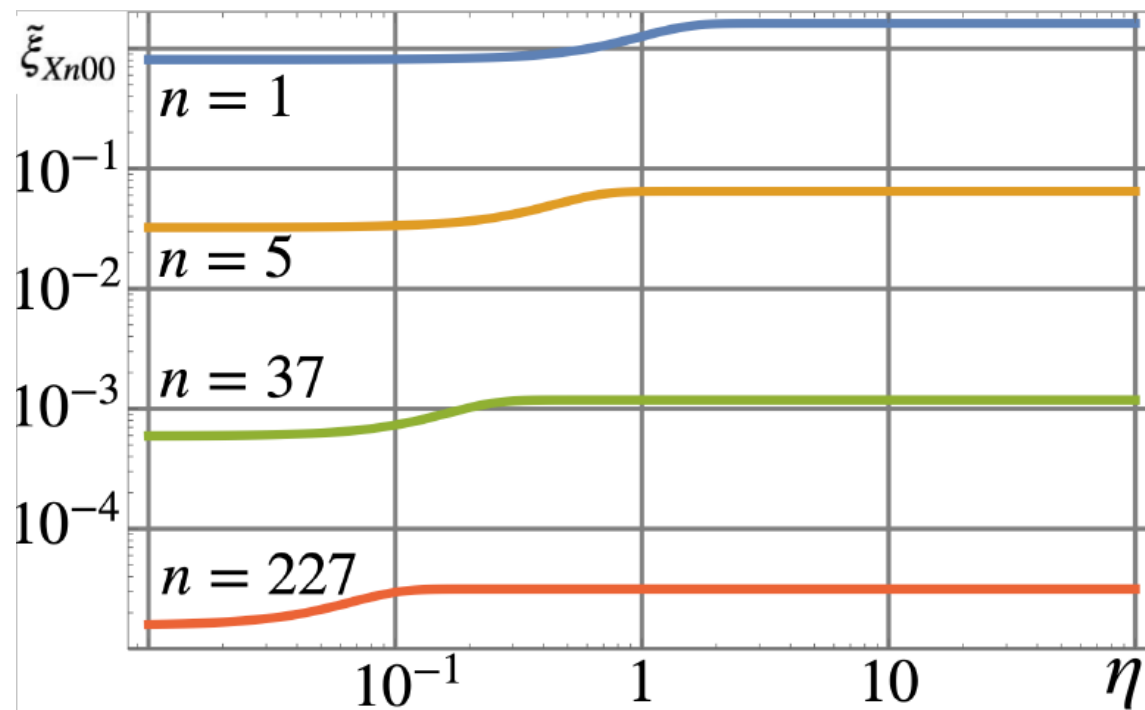
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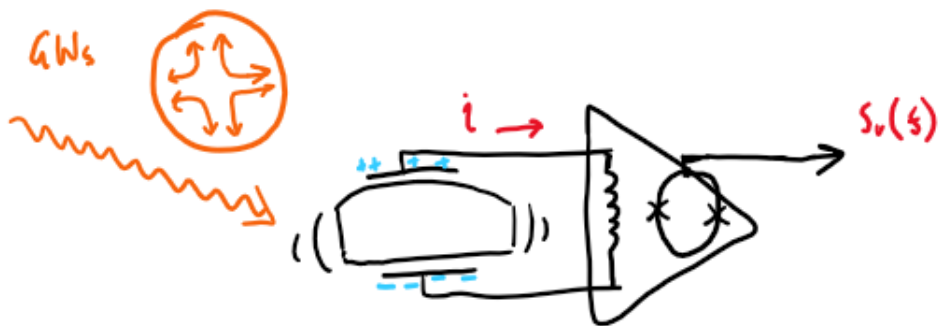
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Gravitational Coupling

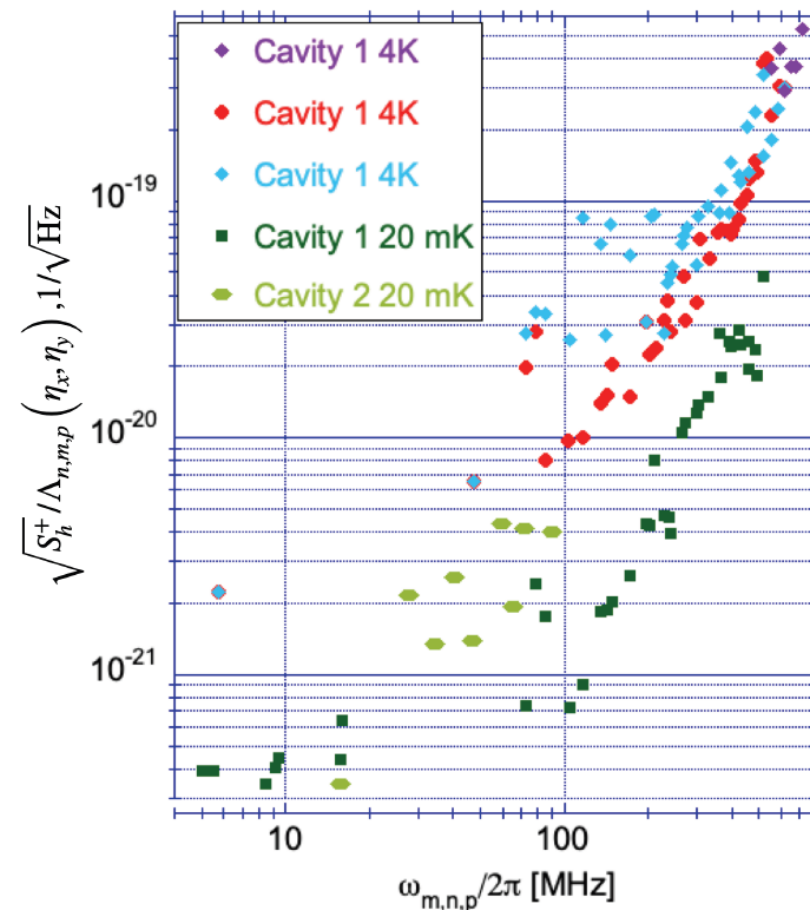


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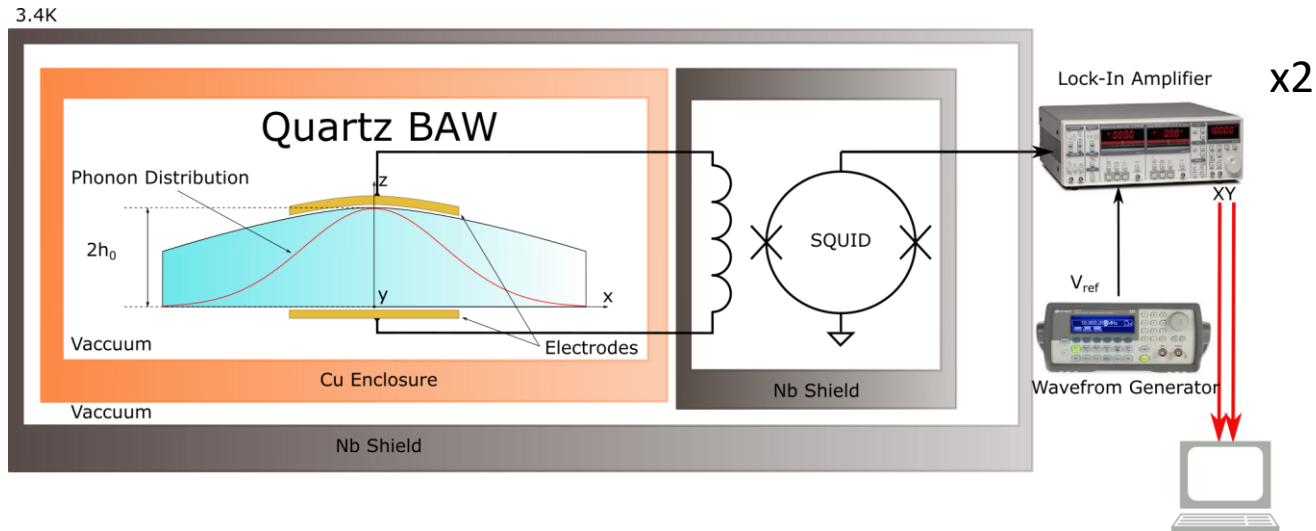


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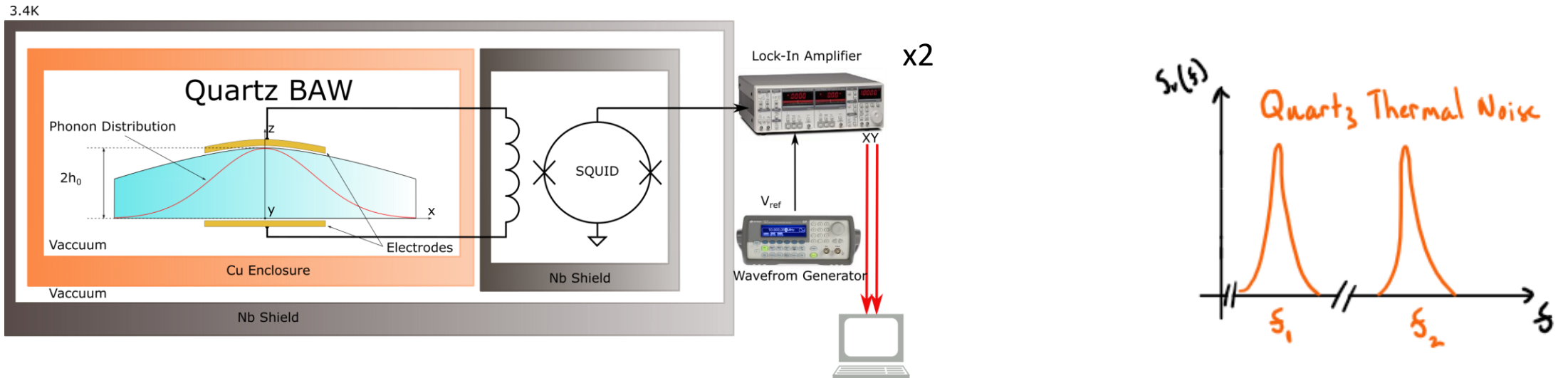
MAGE – Searching for new physics

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



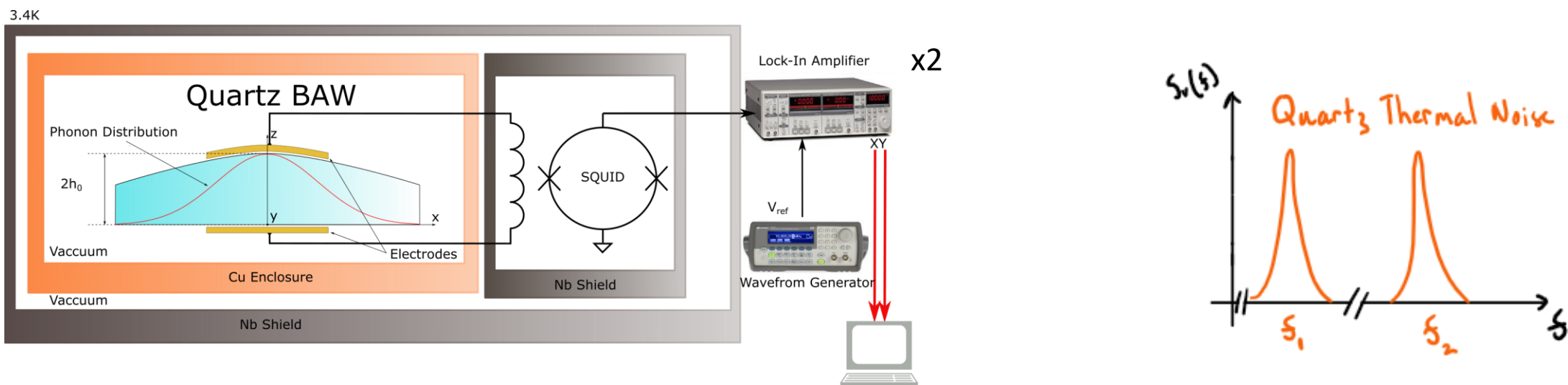
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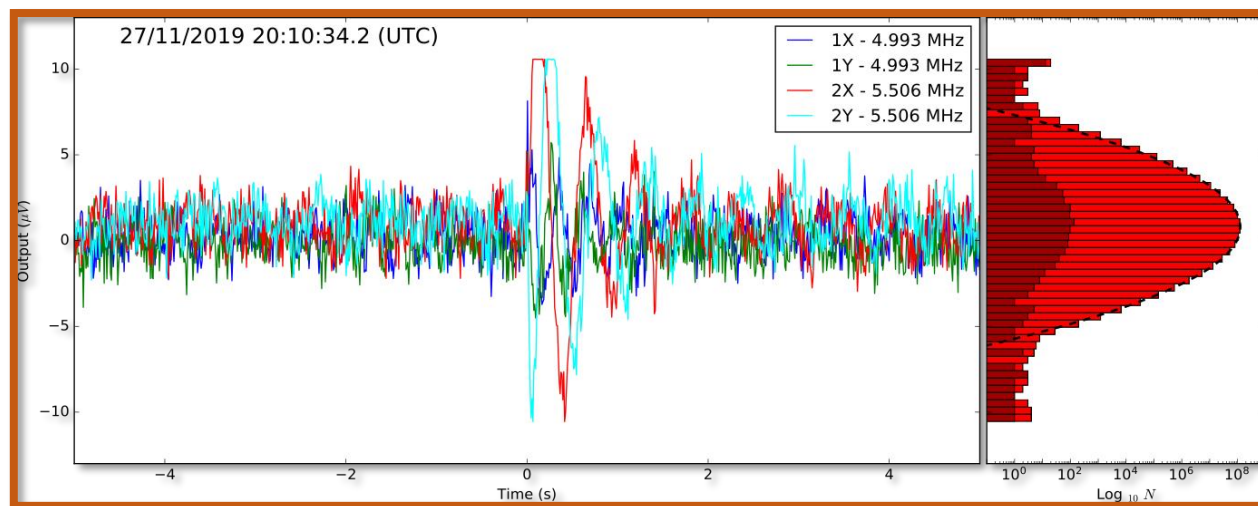


Data Analysis:

Two significantly strong, rare events

<https://arxiv.org/abs/2102.05859>

Discussed potential sources



MAGE – Searching for new physics

What's next ?

MAGE – Searching for new physics

What's next ?

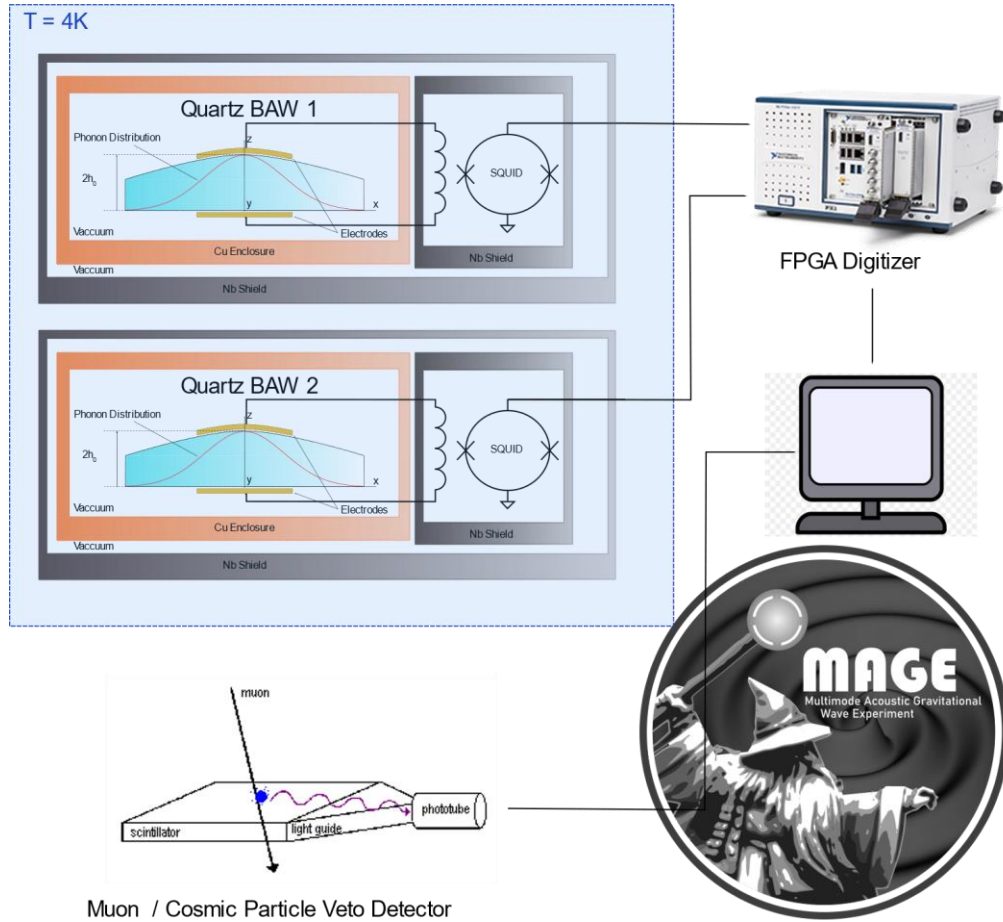


Multimode Acoustic Gravitational Wave Experiment

MAGE – Searching for new physics

What's next ?

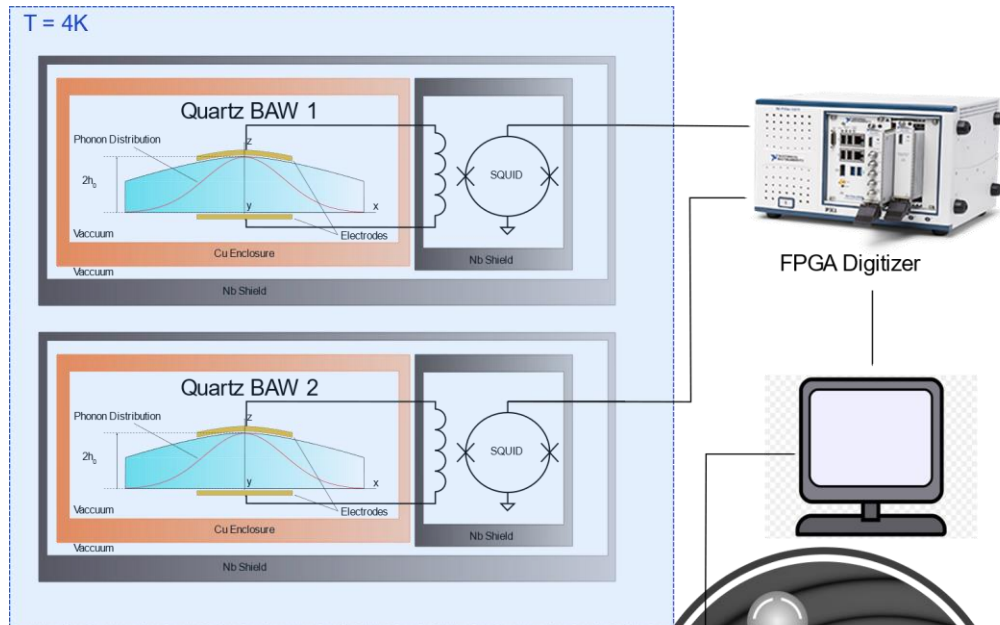
—————→ Multimode Acoustic Gravitational Wave Experiment



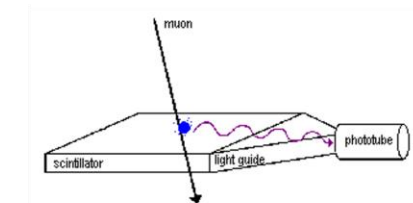
MAGE – Searching for new physics

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)



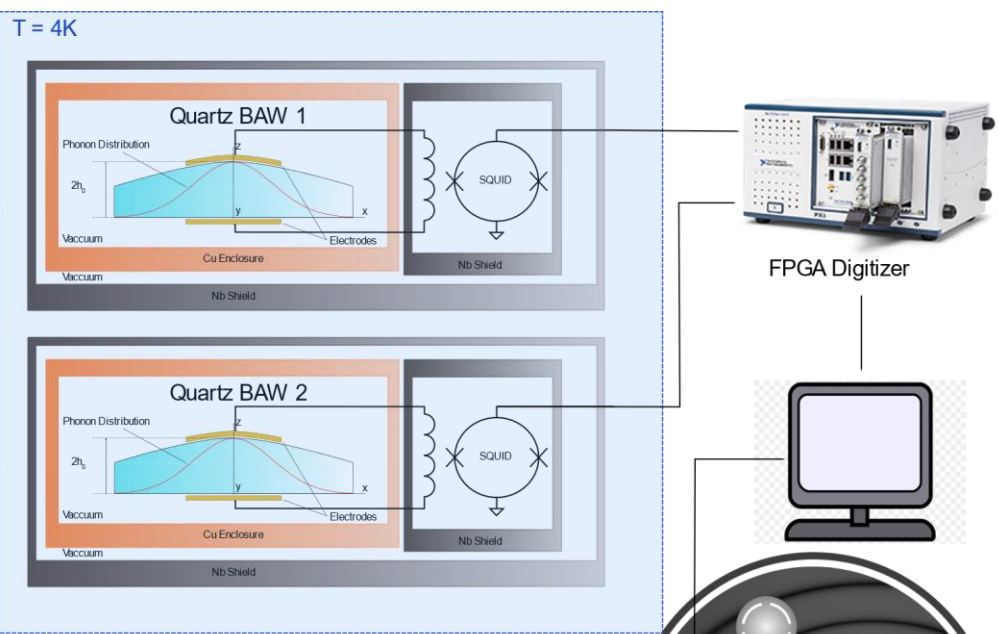
Muon / Cosmic Particle Veto Detector



MAGE – Searching for new physics

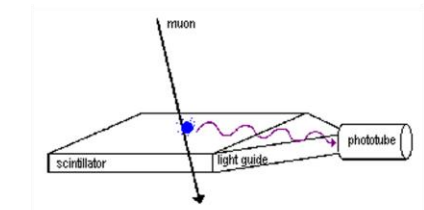
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Exclude potential sources of events:



Muon / Cosmic Particle Veto Detector



MAGE – Searching for new physics

What's next ?



New Hardware



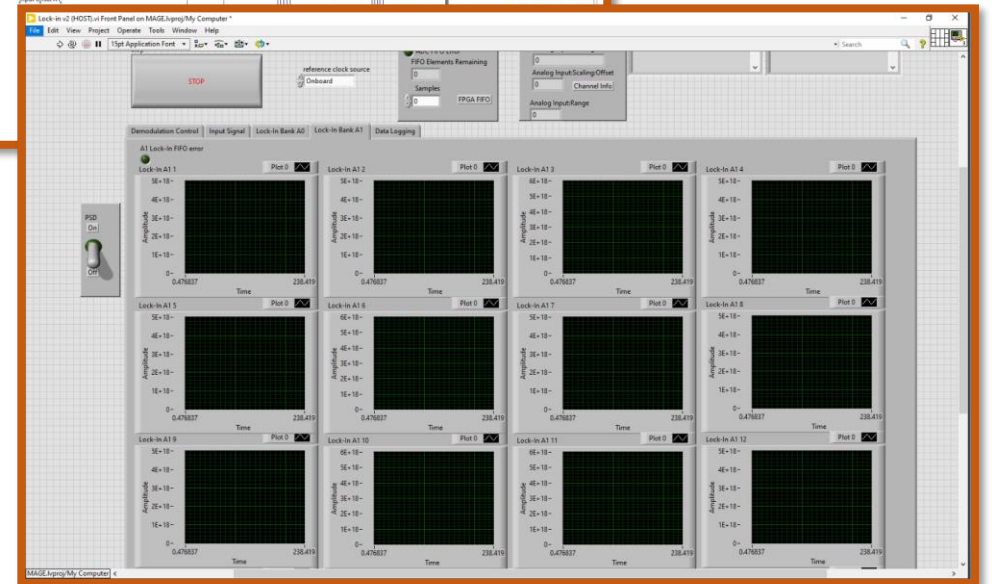
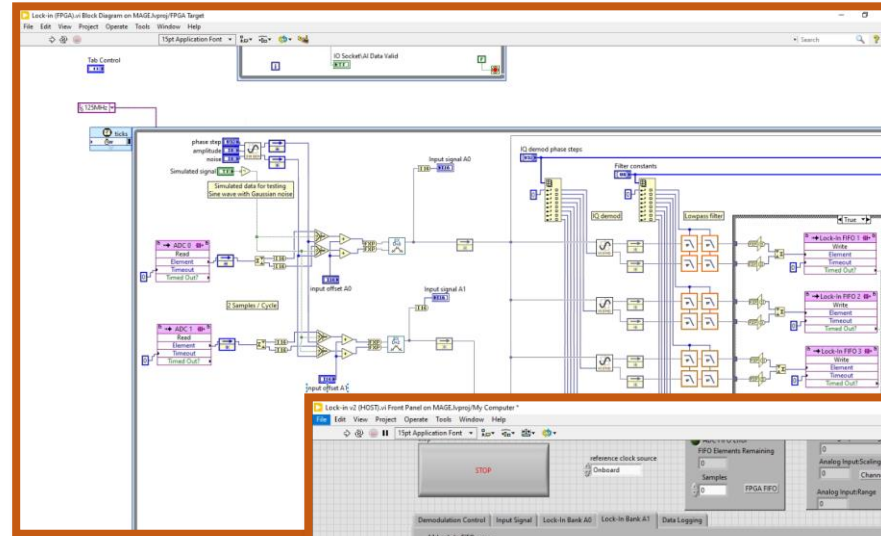


MAGE – Searching for new physics

New Hardware

Upgrade to FPGA data acquisition

National Instruments Digitizer
LabVIEW



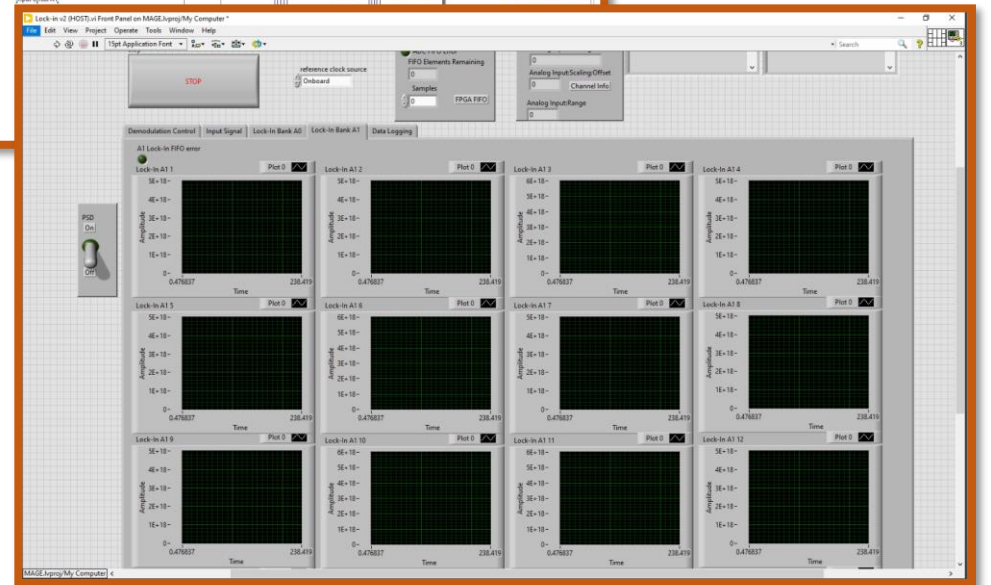
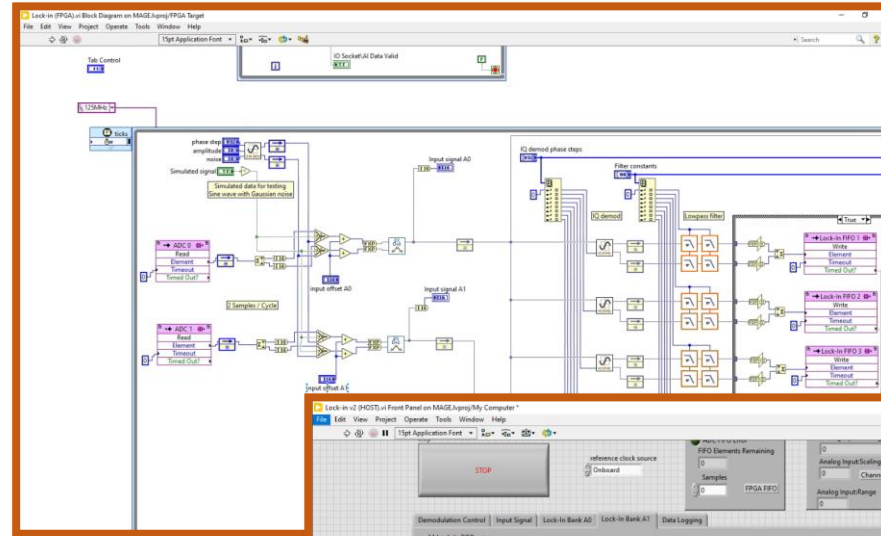


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New Hardware

Upgrade to FPGA data acquisition

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32+ Lock-in amplifiers across two inputs

Continuous data streaming & acquisition

In real time w/ strict timing & zero data loss

Yet to reach hardware limitation of device

16 modes in each crystal

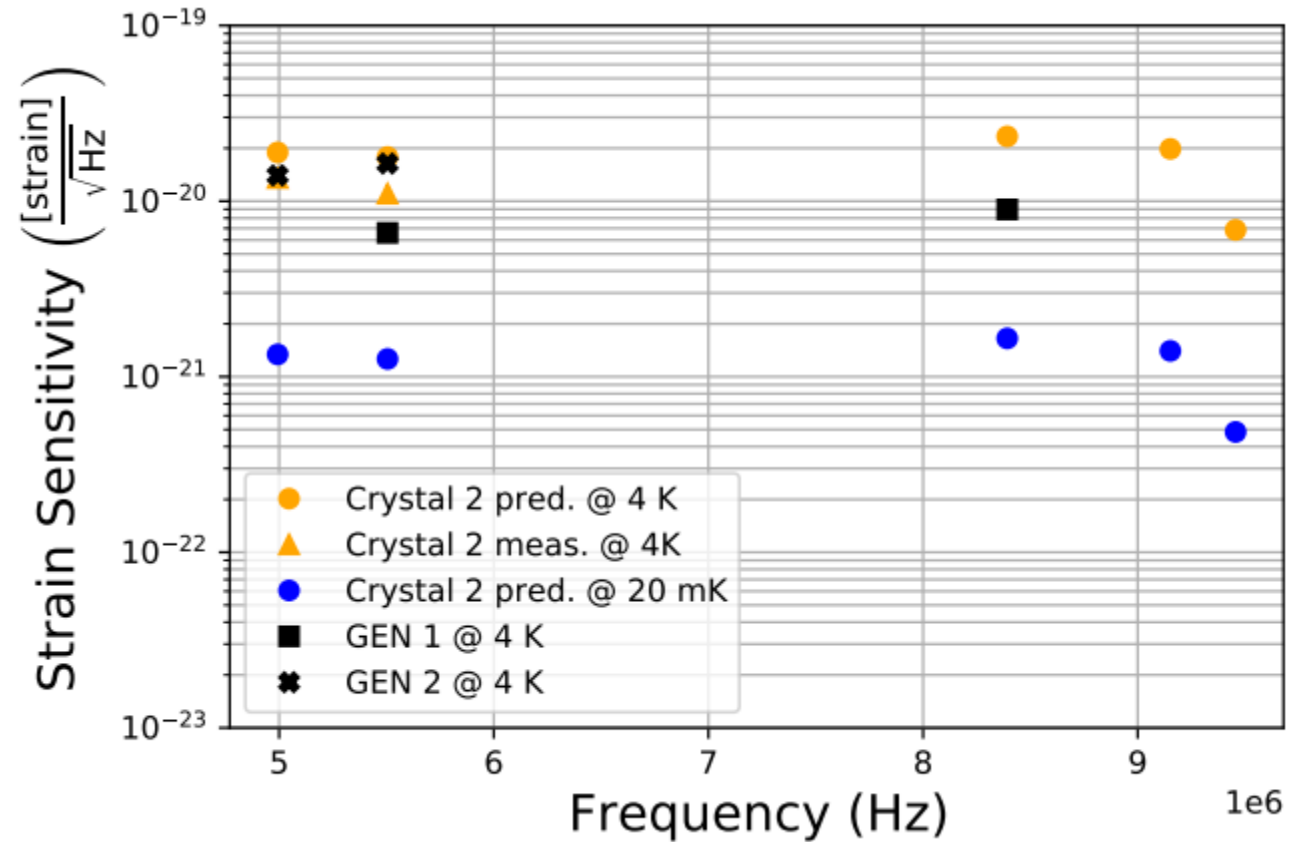


MAGE – Searching for new physics

Newest paper



<https://arxiv.org/abs/2307.00715>





MAGE – Searching for new physics

Currently have new data!



MAGE – Searching for new physics

Currently have new data!

PRELIMINARY



MAGE – Searching for new physics

Currently have new data!



8 acoustic modes in each crystal

1 month of data -> August 2023



MAGE – Searching for new physics

Currently have new data!



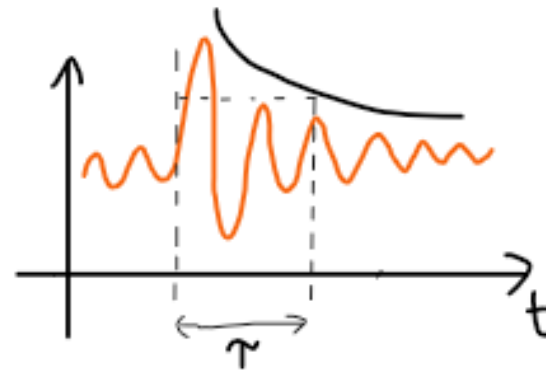
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Optimal Filtering



Search for transient events corresponding to quartz decay





MAGE – Searching for new physics

Currently have new data!



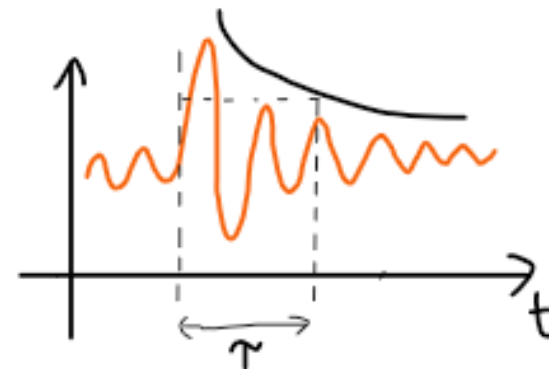
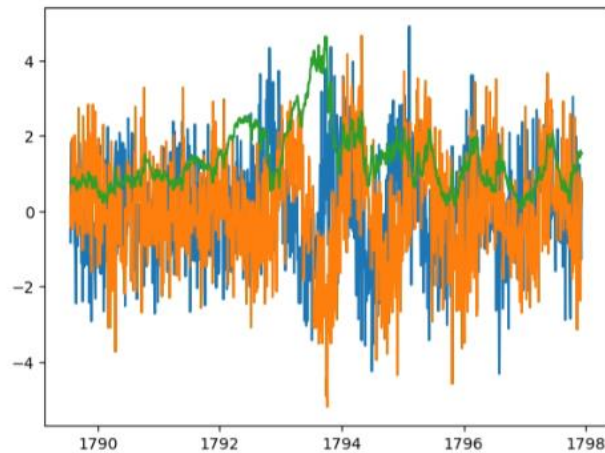
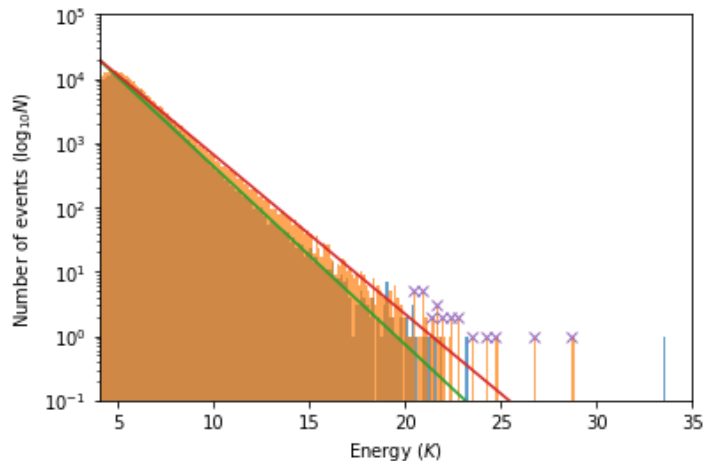
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No coincident events over 3 sigma or 12 Kelvin



MAGE – Searching for new physics

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8 acoustic modes in each crystal

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Optimal Filtering



No coincident events over 3 sigma or 12 Kelvin



Primordial
black hole
merger



Excluding PBH merger events, at 5.5 MHz for example, to a distance
Of > 0.5 pc



MAGE – Searching for new physics

Whats next ?

- Still working on cosmic particle veto
- Upcoming run, 16 modes in each crystal
- Push to higher frequencies with better SQUIDs
Explore mK operation

Thanks!

William.Campbell@uwa.edu.au

Quantum technologies and Dark Matter
Laboratories @ UWA



qdmlab.com

