Snowmass Update on UPLOAD

UPconversion Low-Noise Oscillator Axion Detection Experiment

Michael Tobar

Catriona Thomson

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

QDM Quantum Technologies and Dark Matter Research Lab

EQUS Australian Research Council Centre of Excellence for Engineered Quantum Systems

UWA PERTH · AUSTRALIA

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

QUANTUM TECHNOLOGIES AND DARK MATTER RESEARCH LAB

EQUS
Australian Research Council Centre of Excellence for Engineered Quantum Systems

THE UNIVERSITY OF WESTERN AUSTRALIA

QDM
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Maxim Goryachev

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Ben McAllister
Cindy Zhao
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Steven Osborne

ADJUNCT
Alexey Veryaskin (Trinity Labs)

A New Technique

THE AC HALOSCOPE

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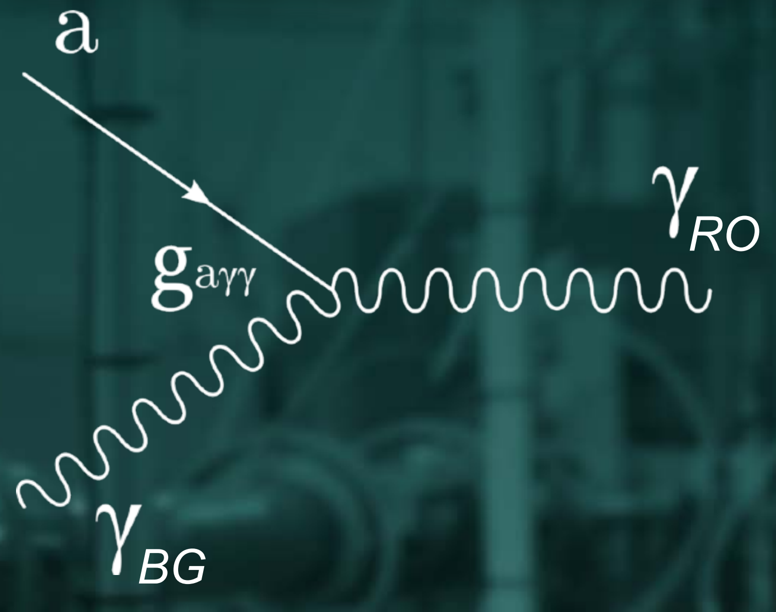

- **Two** electromagnetic modes

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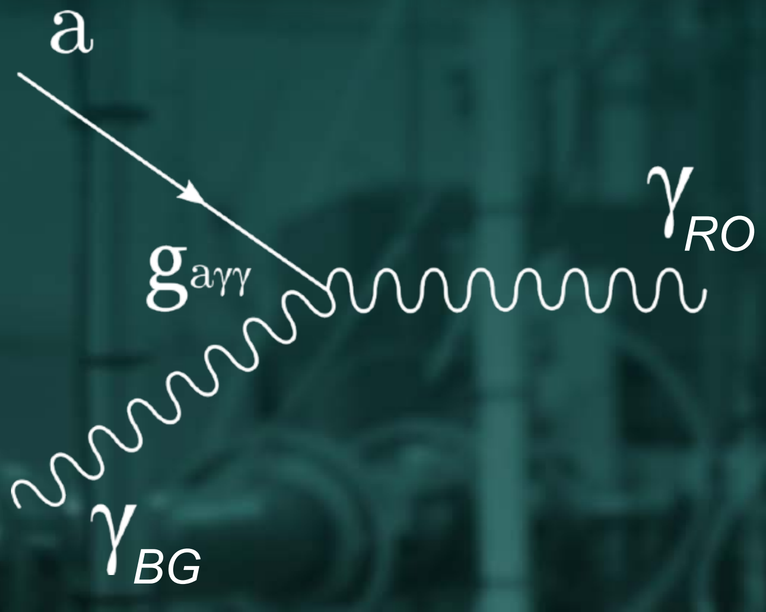

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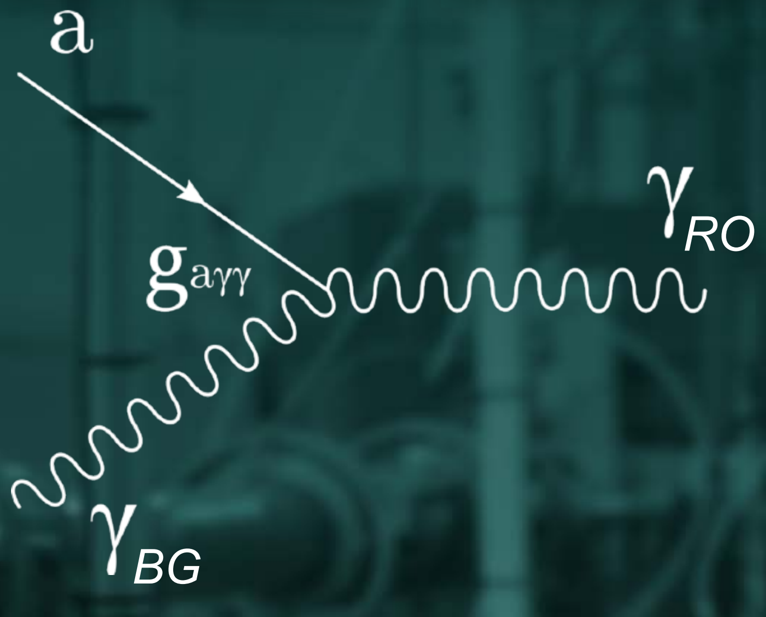

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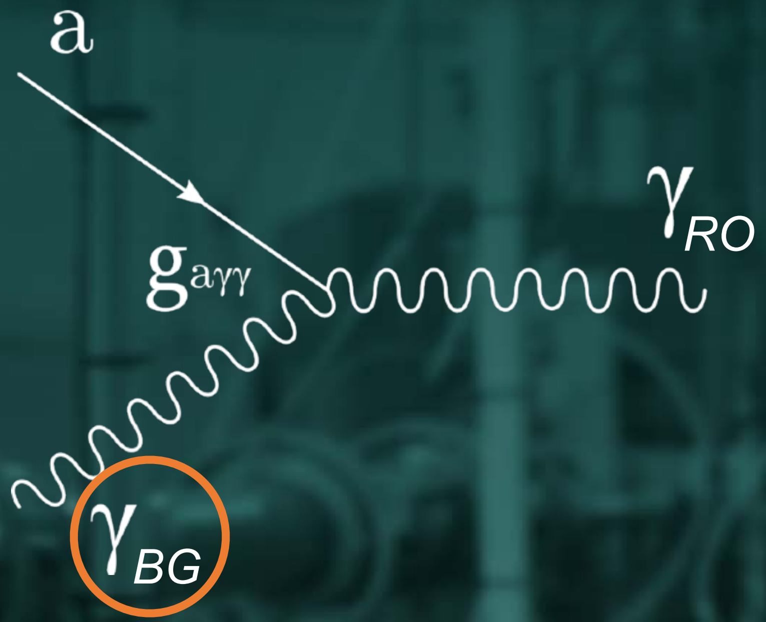

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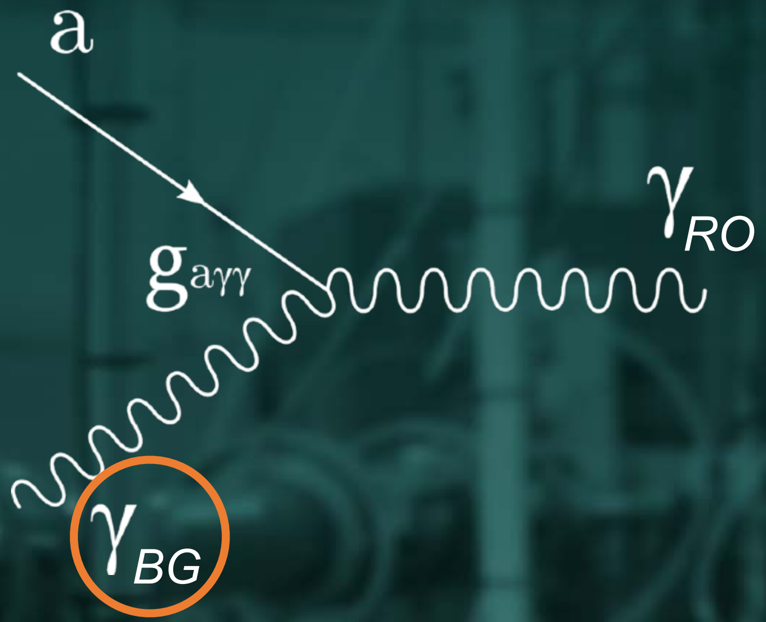

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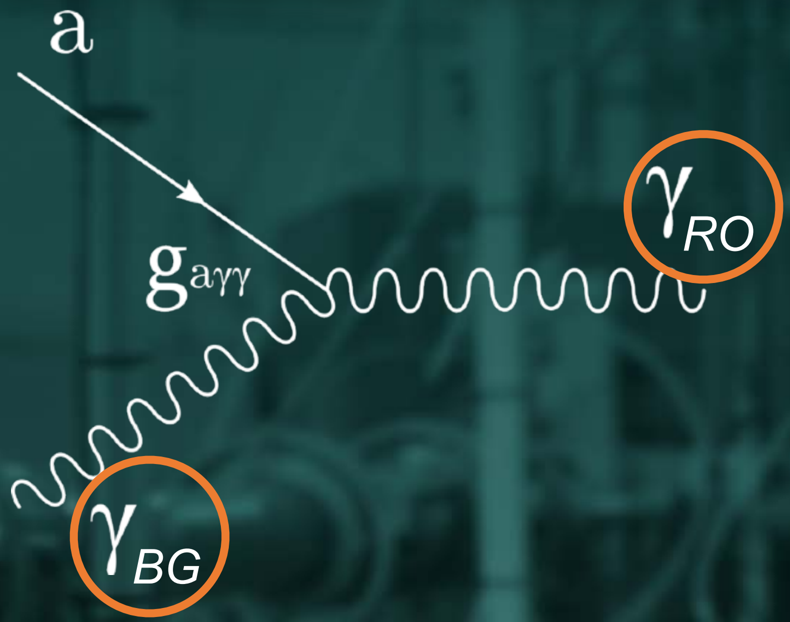

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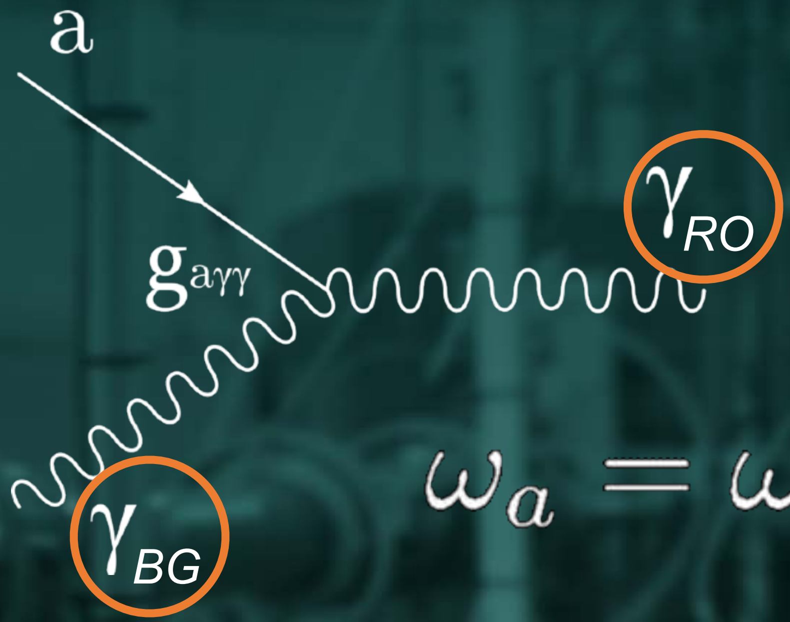

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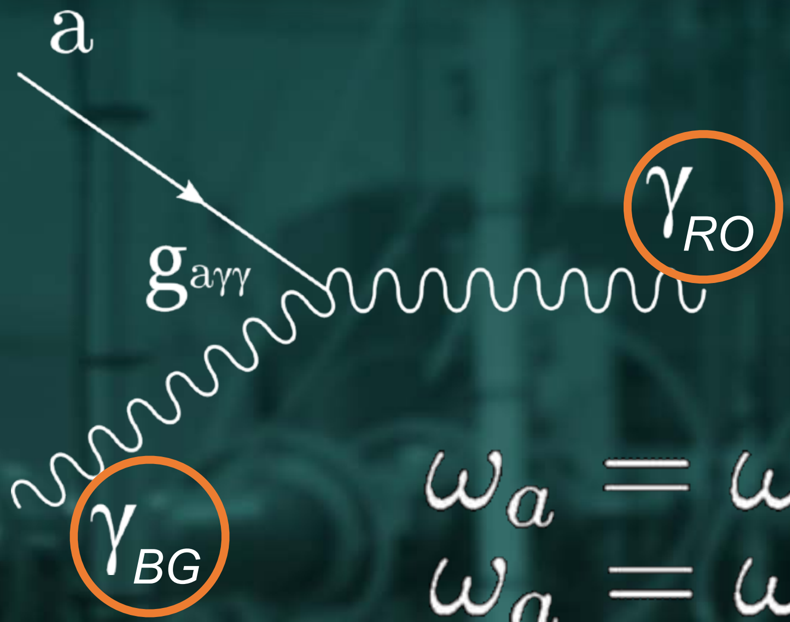

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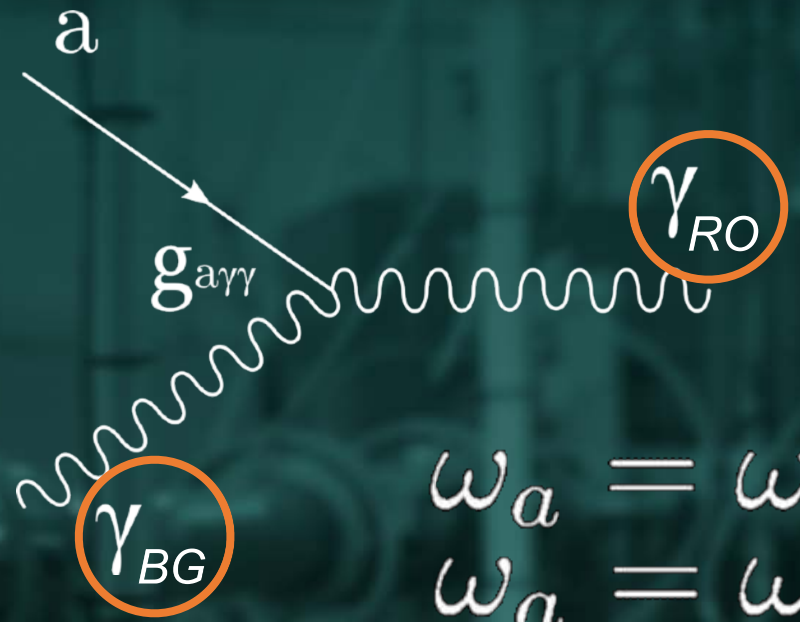

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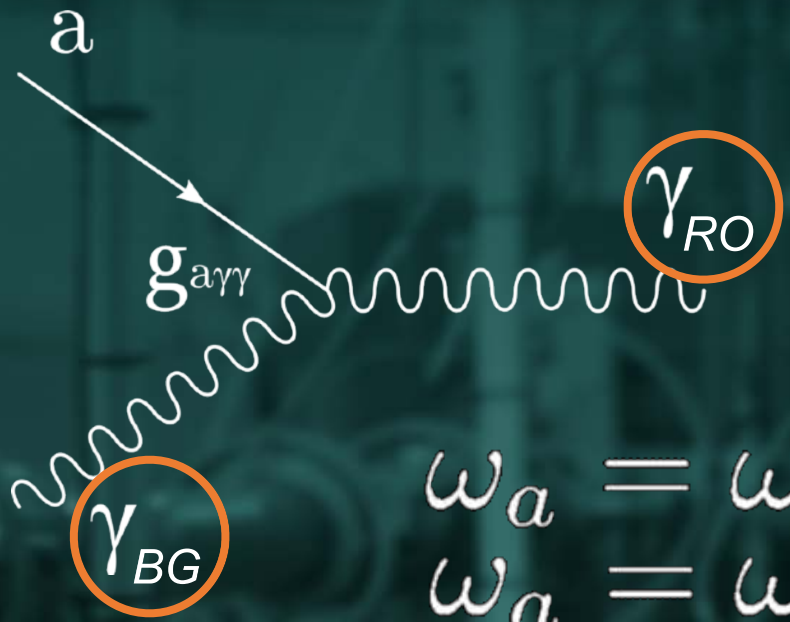

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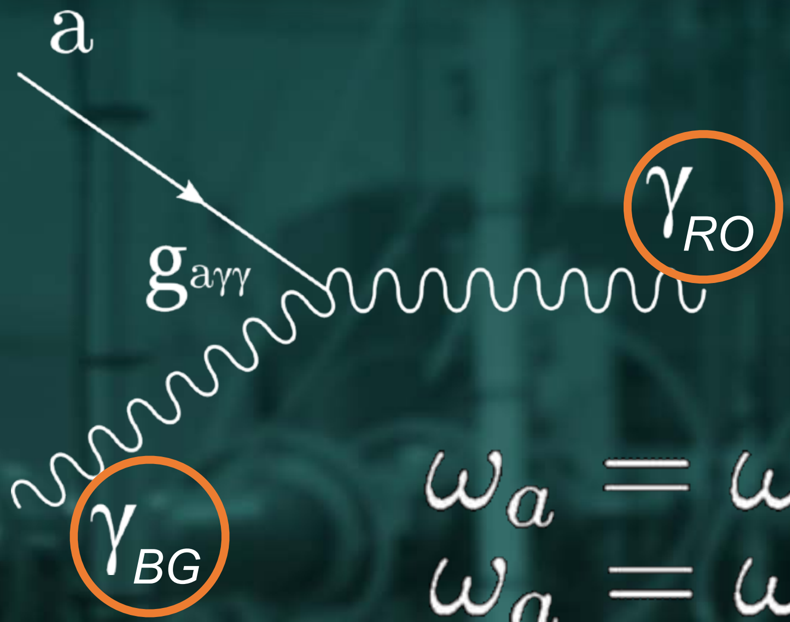

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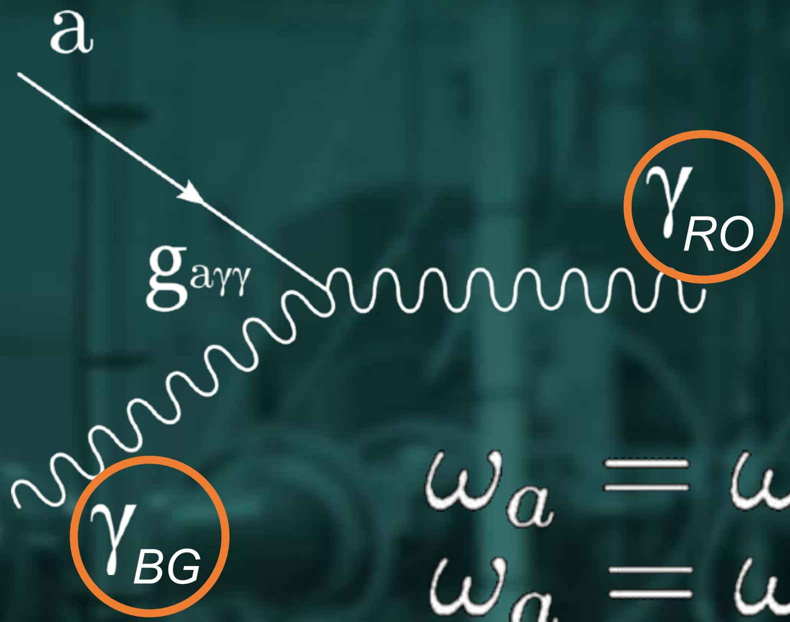

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UPLOAD: Previous Work->First Experiment and Theory

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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

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Physics of the Dark Universe 26 (2019) 100345

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Corrected versions consistent with
1) **Optical phase experiments,**
2) **AC Microwave Power Techniques and**
3) **Total Derivative = 0**

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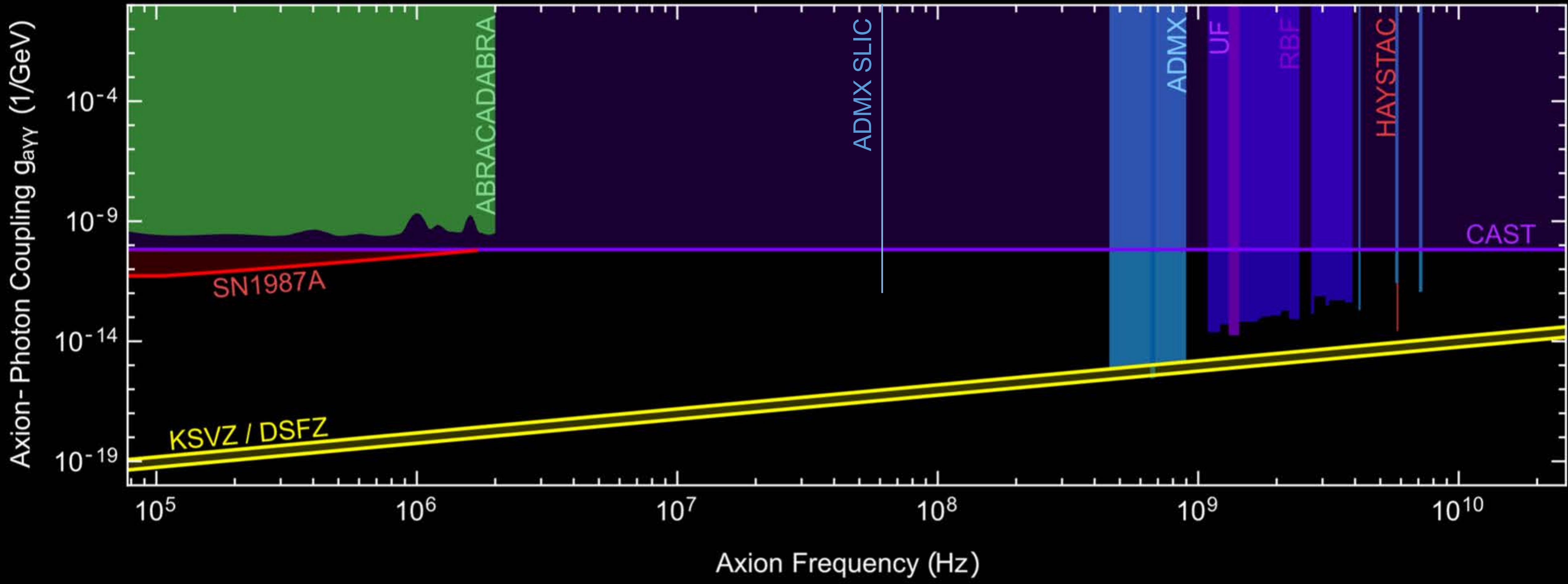

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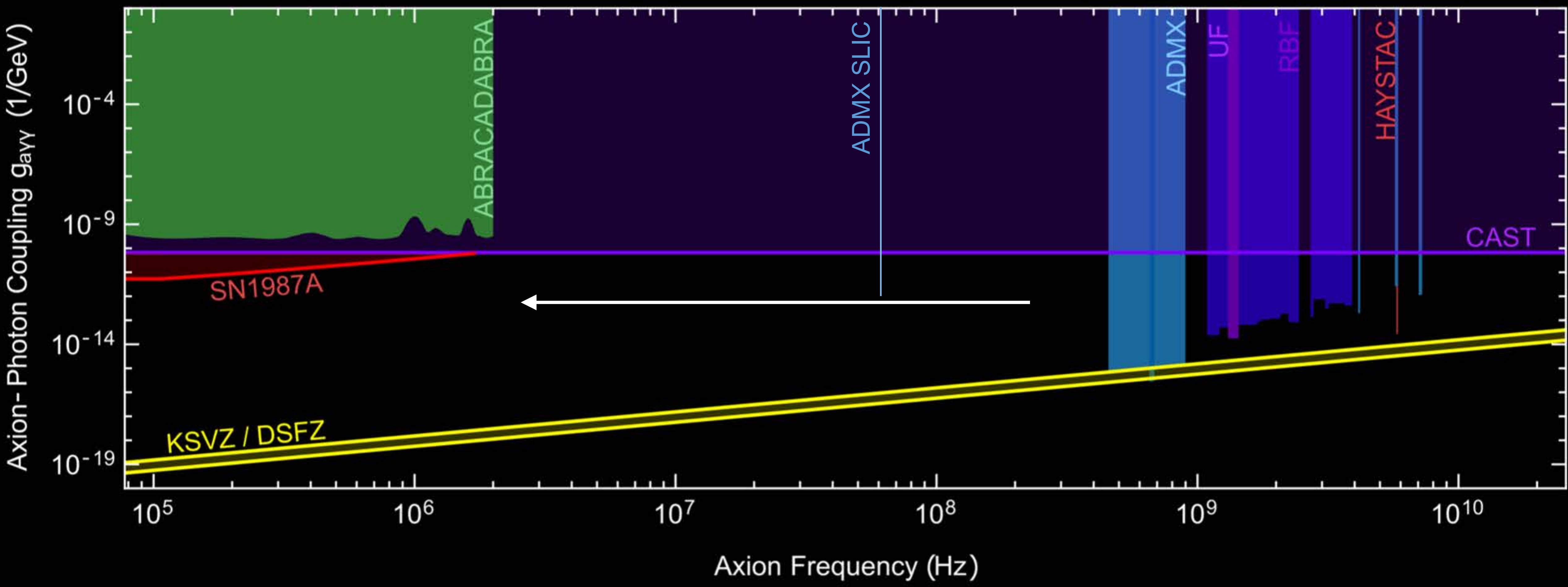
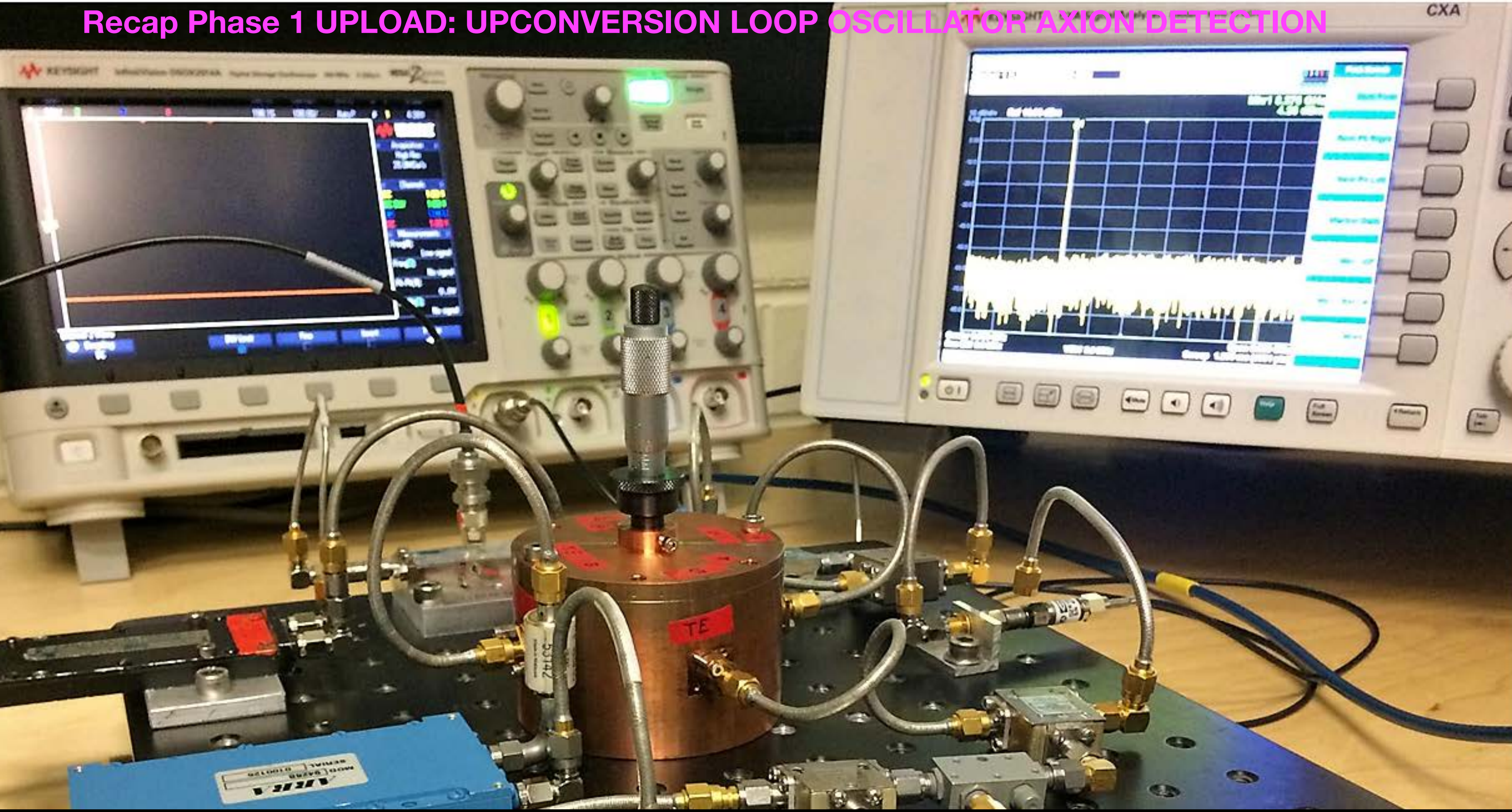
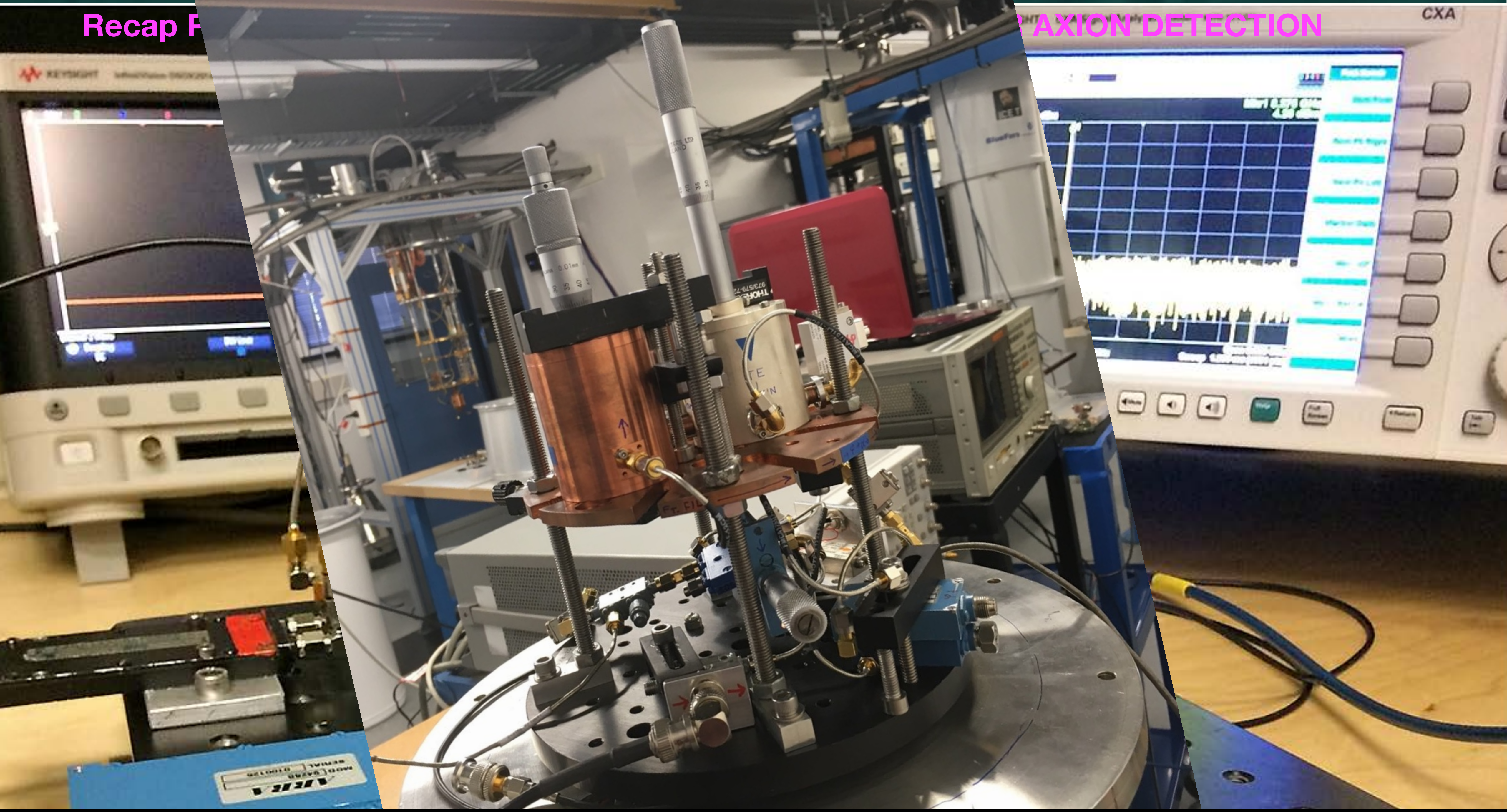


Recap Phase 1 UPLOAD: UPCONVERSION LOOP OSCILLATOR AXION DETECTION



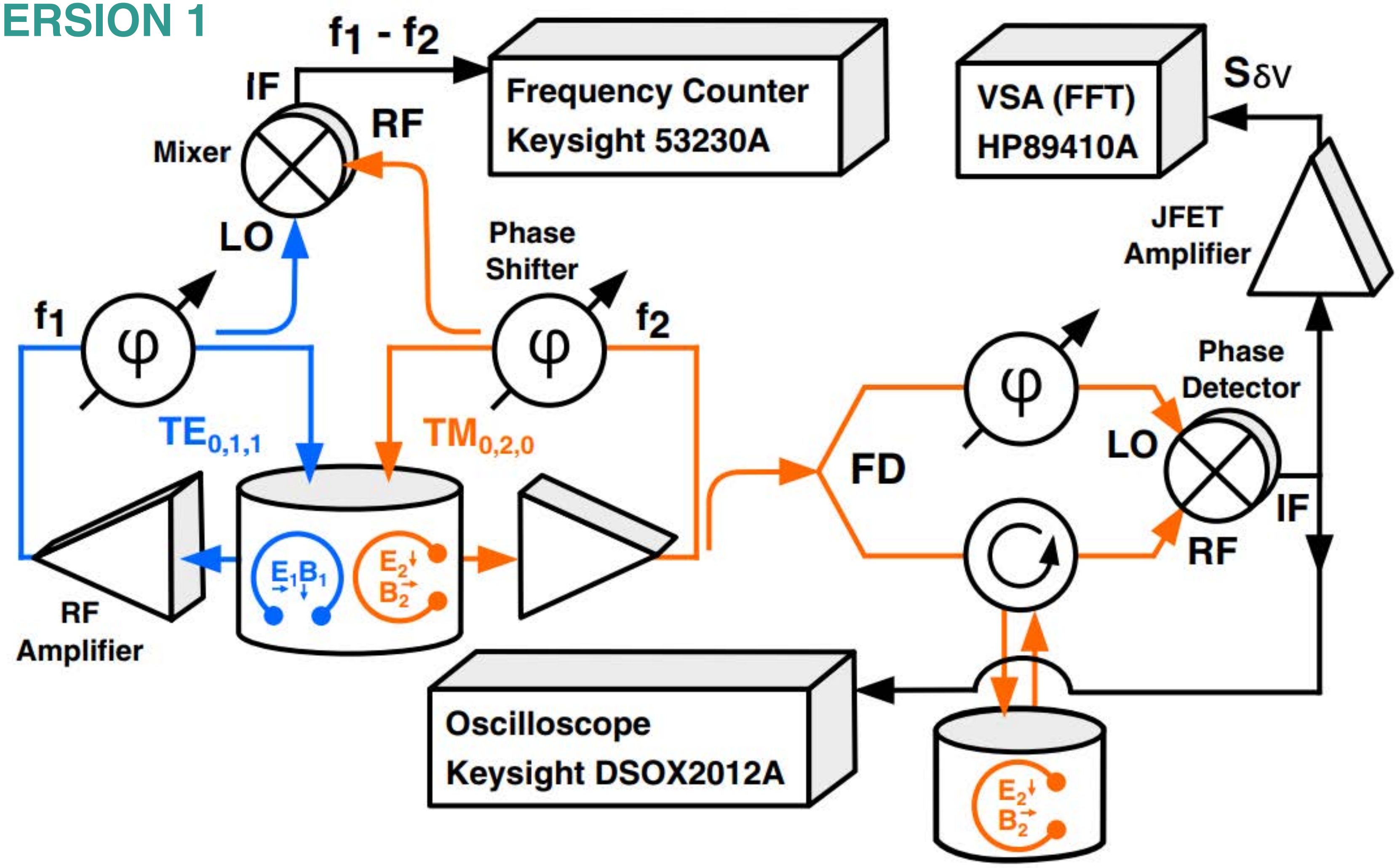
Recap F

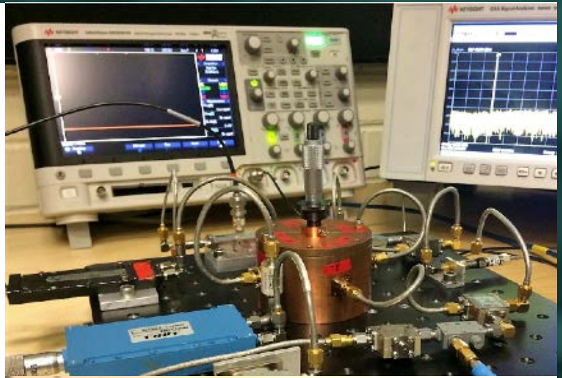
AXION DETECTION

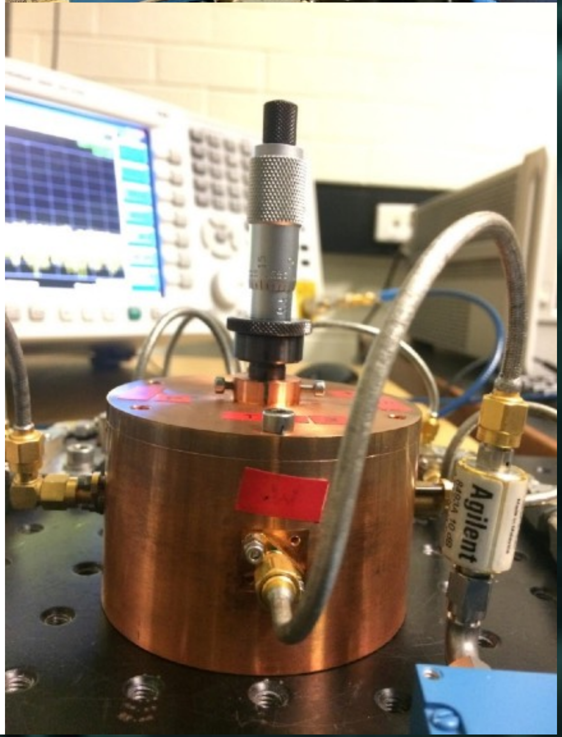


Experimental Design

VERSION 1

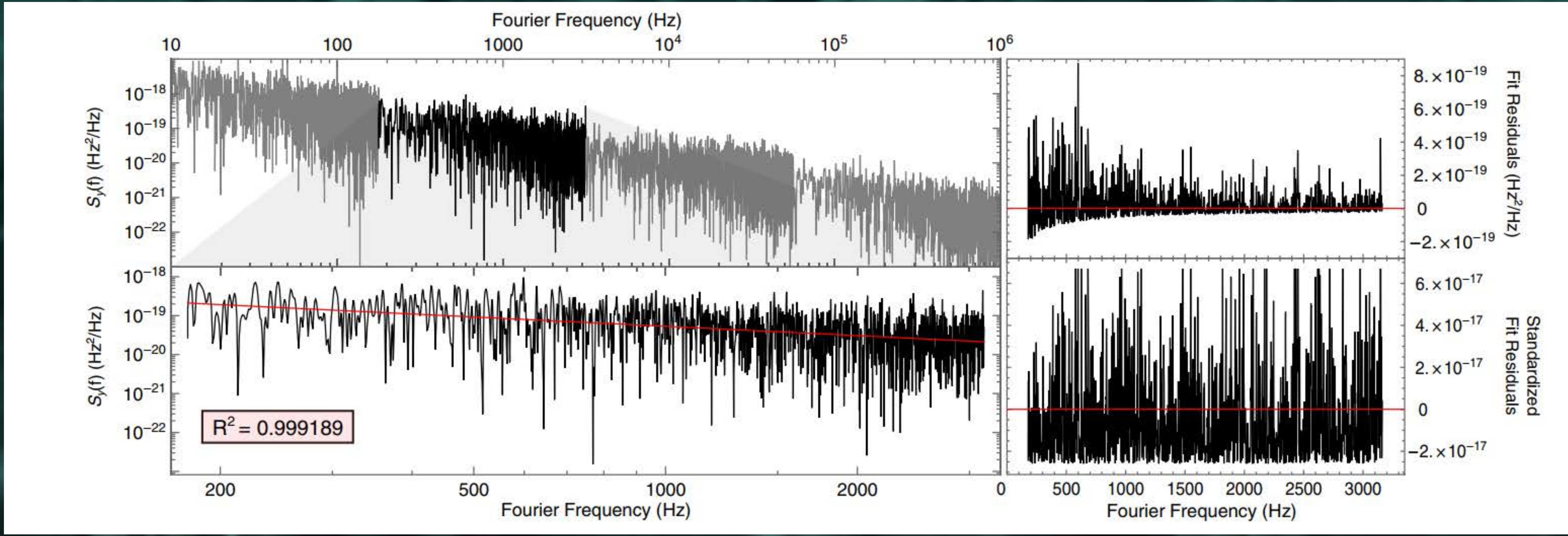






Results IDENTIFYING AN AXION SIGNAL

$$\left\langle \frac{\delta f_{a_2}}{f_2} \right\rangle_{\pm} = |k_{a\pm}| g_{a\gamma\gamma} \langle a_0 \rangle$$



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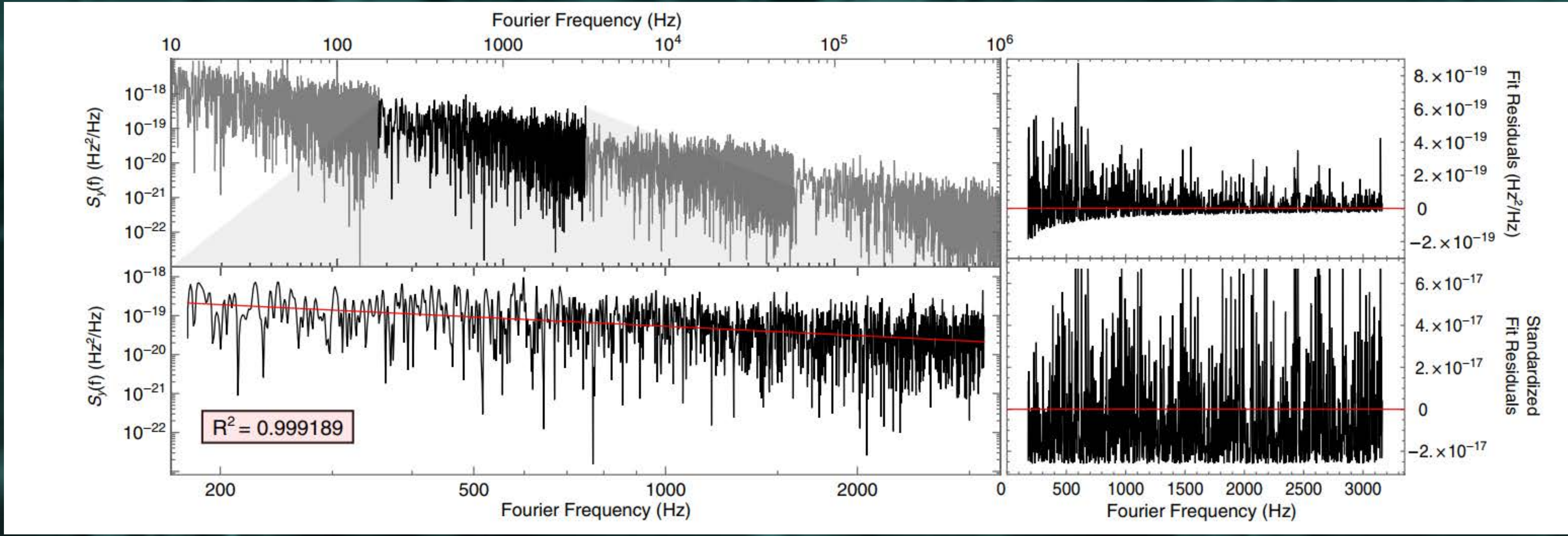

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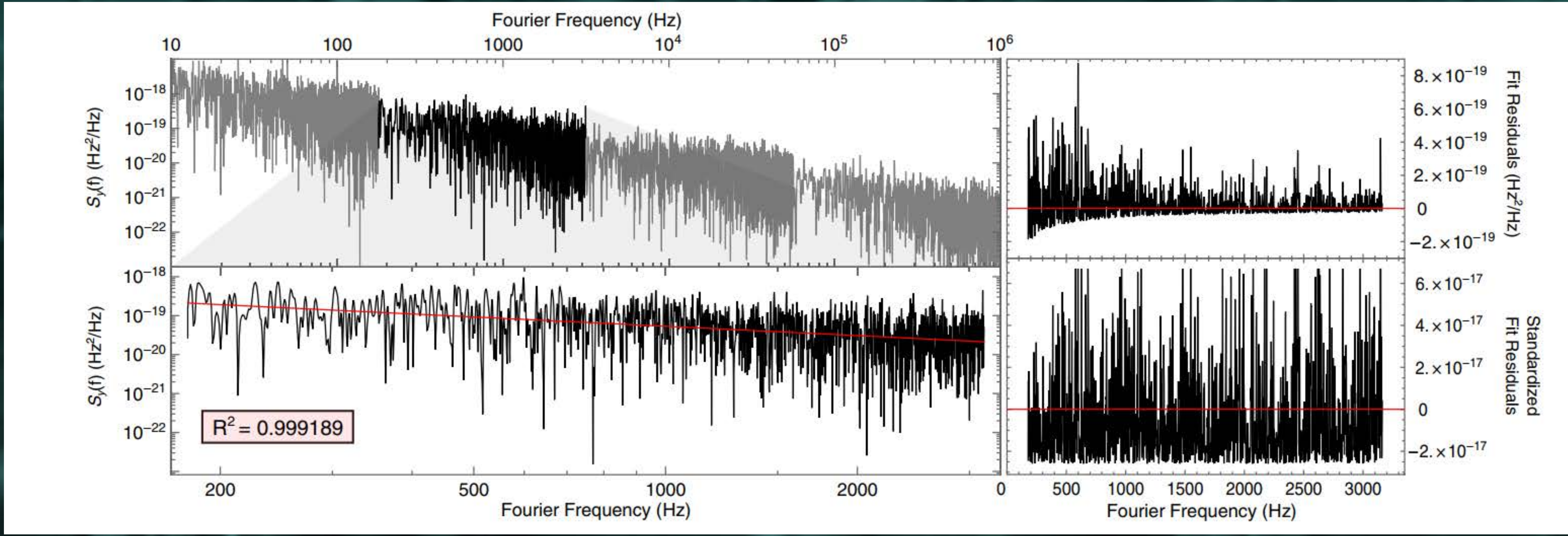

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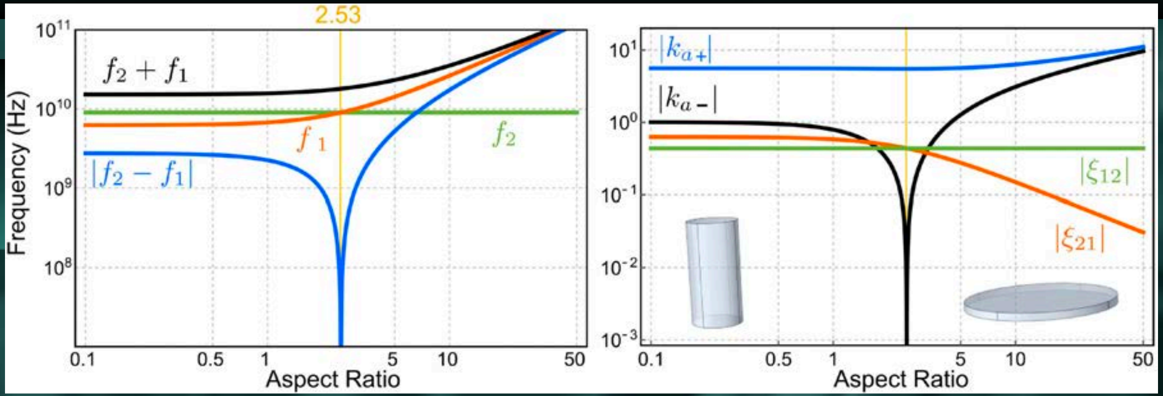

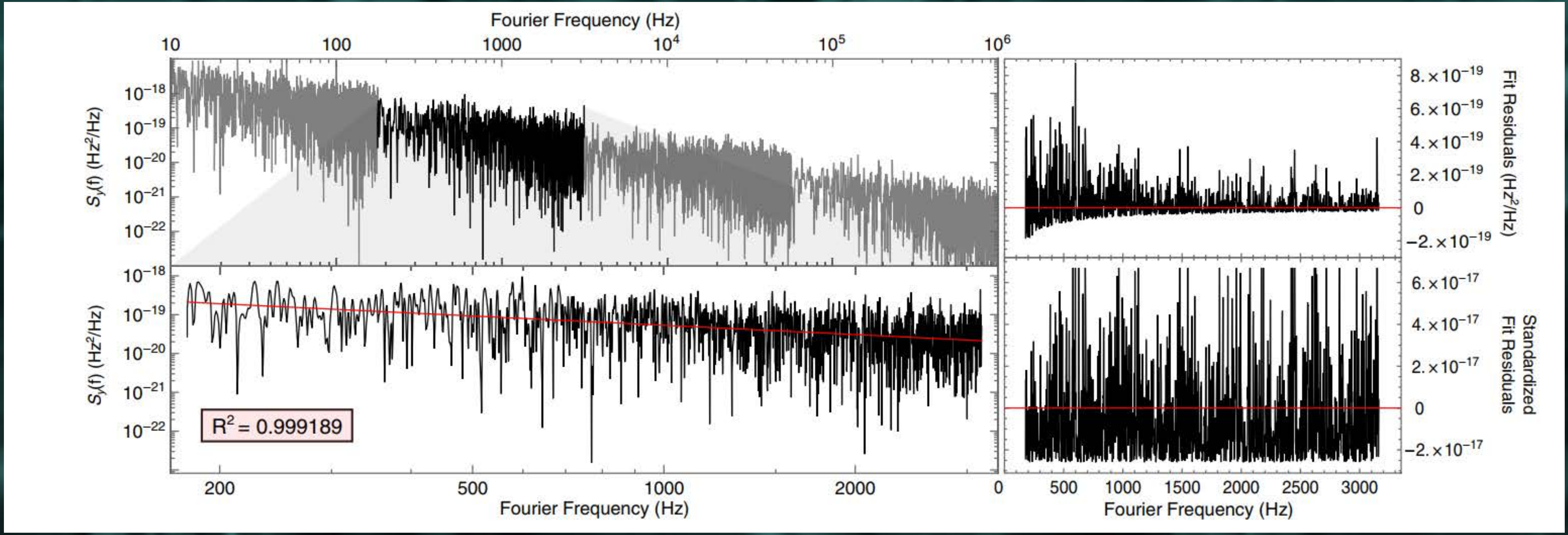

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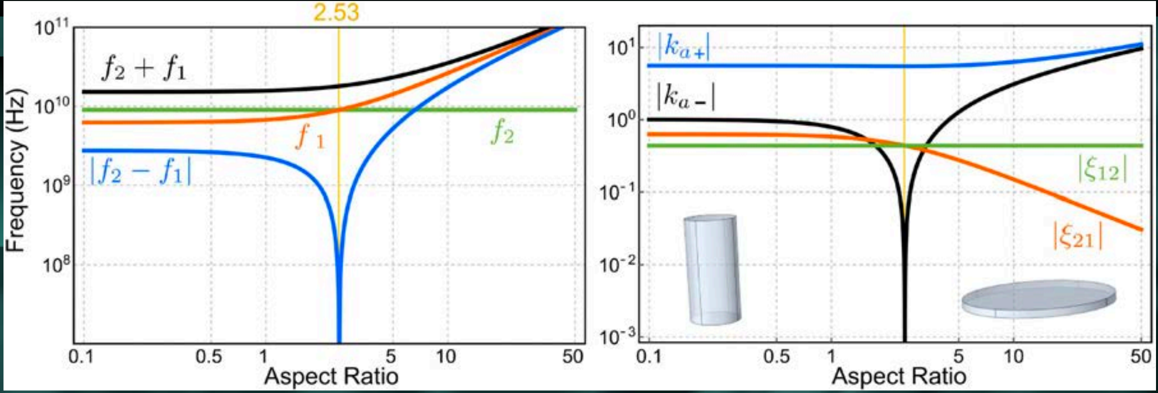
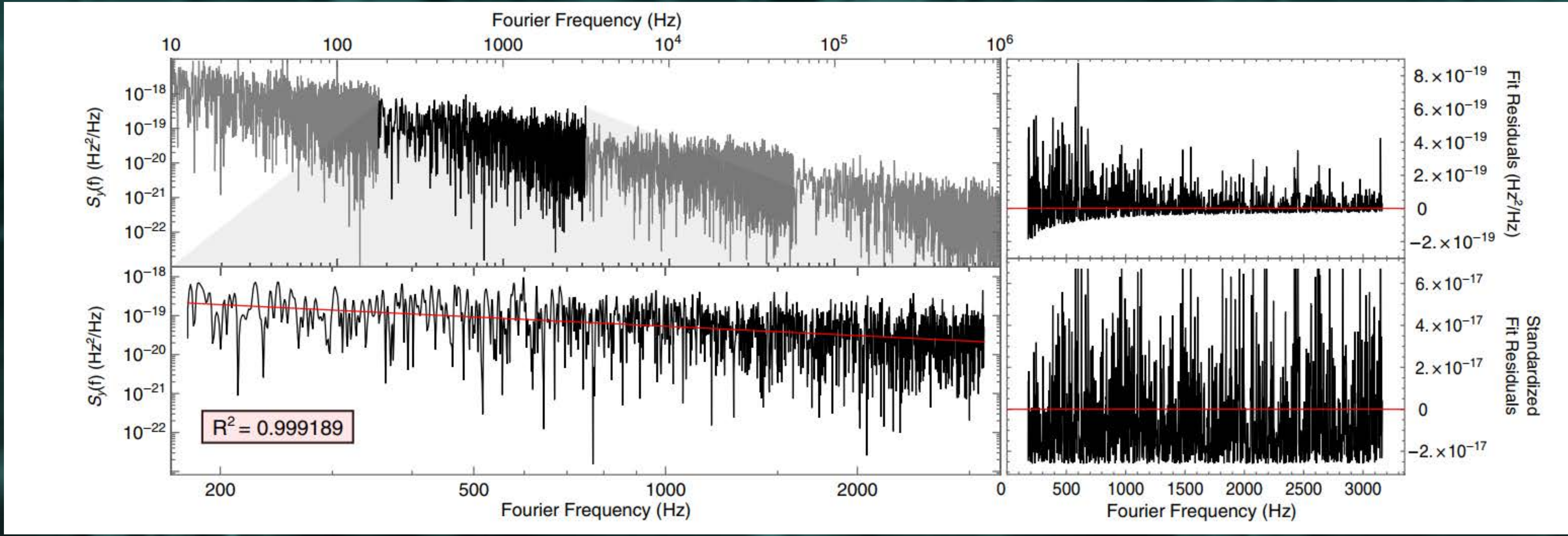


TABLE I: Experimental Microwave Oscillator Parameters

	$TE_{0,1,1}$ (Mode 1 Fig. 1)	$TM_{0,2,0}$ (Mode 2 Fig. 1)
Q_L	6000	4200
β_{in}	0.9	0.95
P_{inc}	10 dBm	6 dBm
P_c	48 dBm	42 dBm
f_0	9.00168 - 9.00256 GHz	8.9988765 GHz
k_{a-}	$8.4 \times 10^{-4} - 1.1 \times 10^{-3}$	$8.4 \times 10^{-4} - 1.1 \times 10^{-3}$
k_{a+}	5.5	5.5



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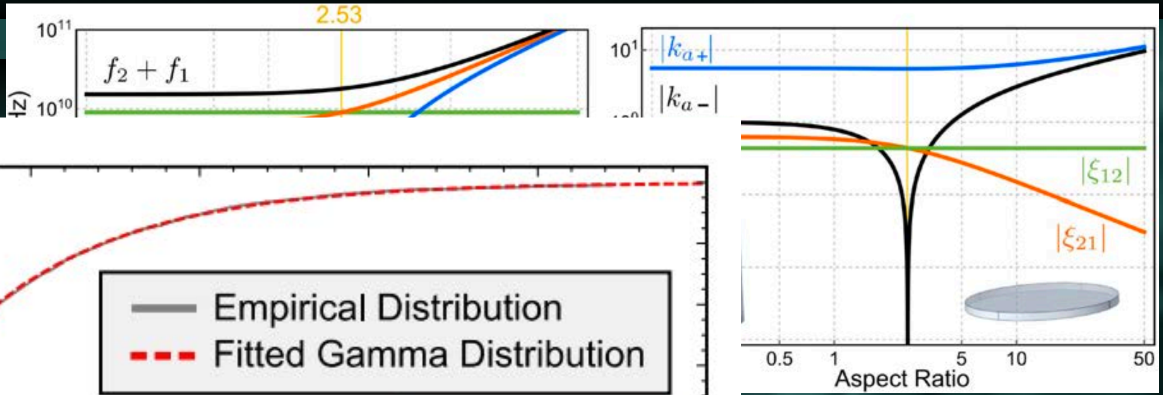

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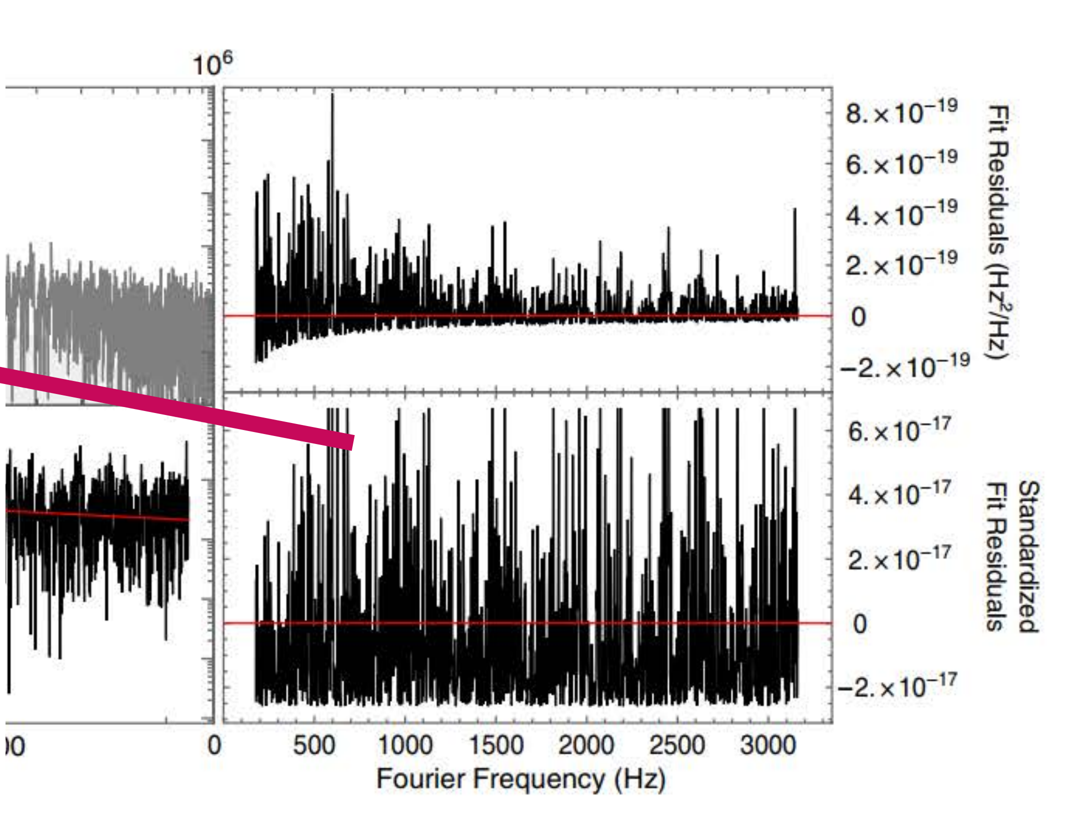

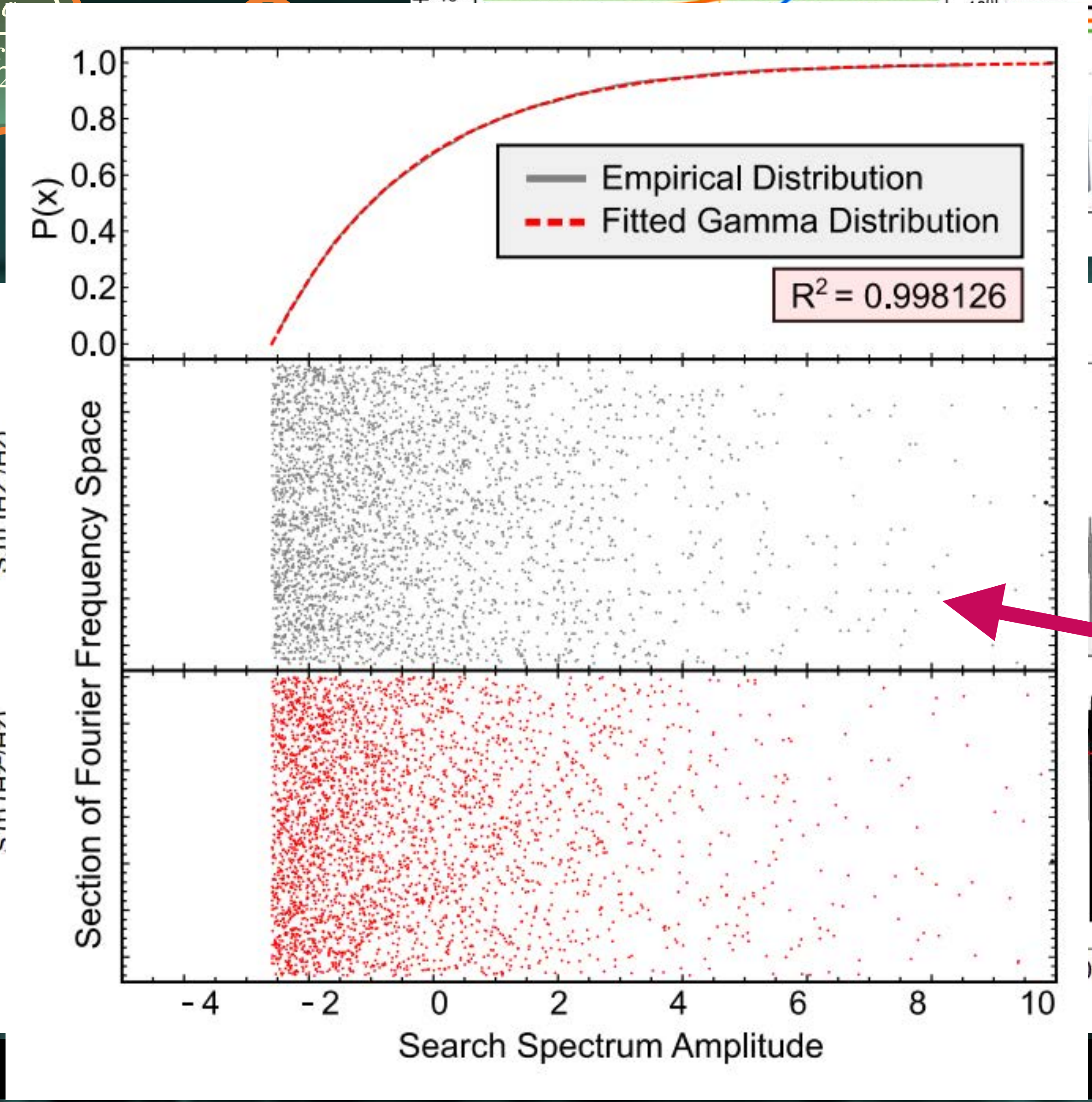

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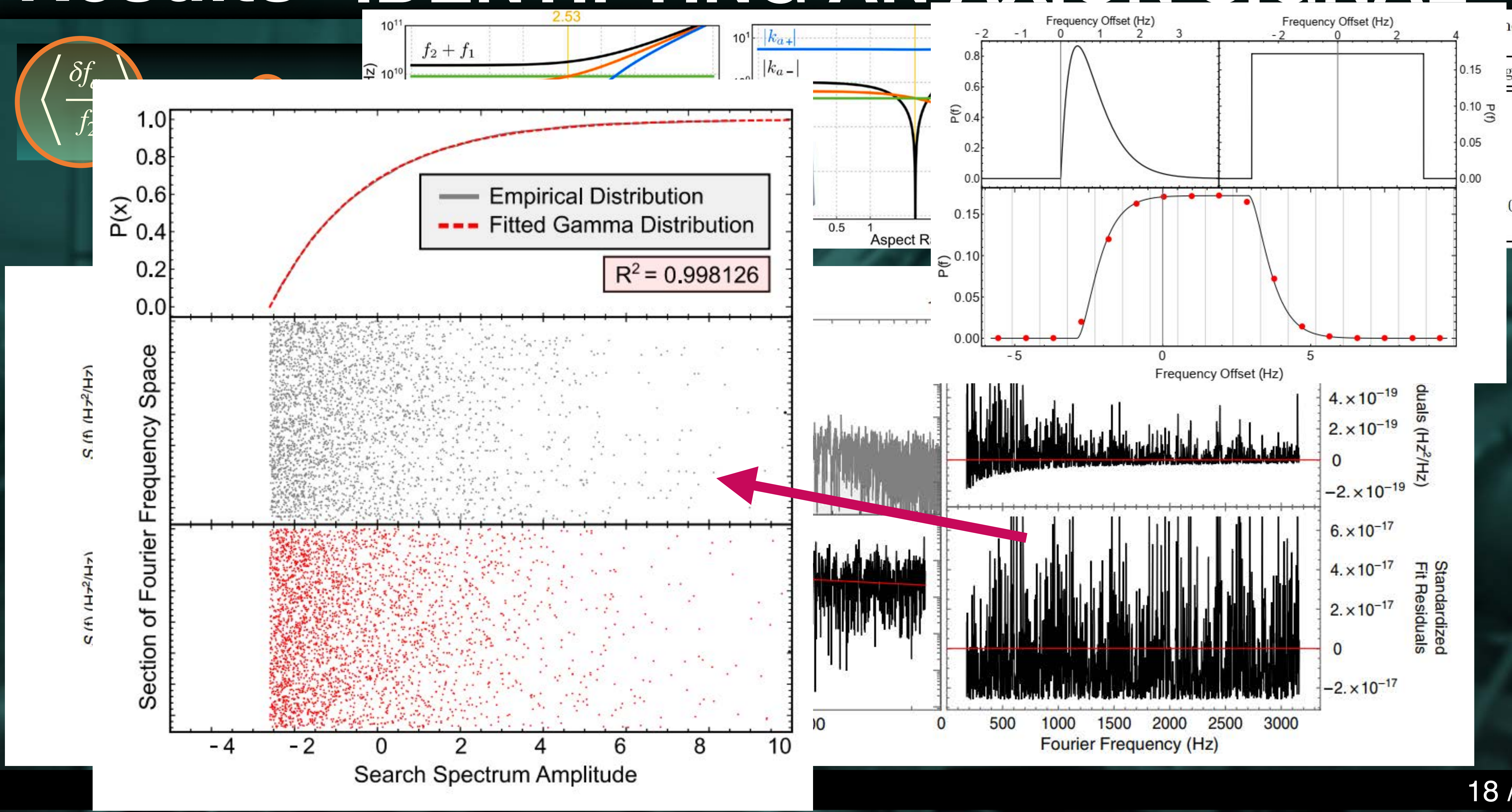

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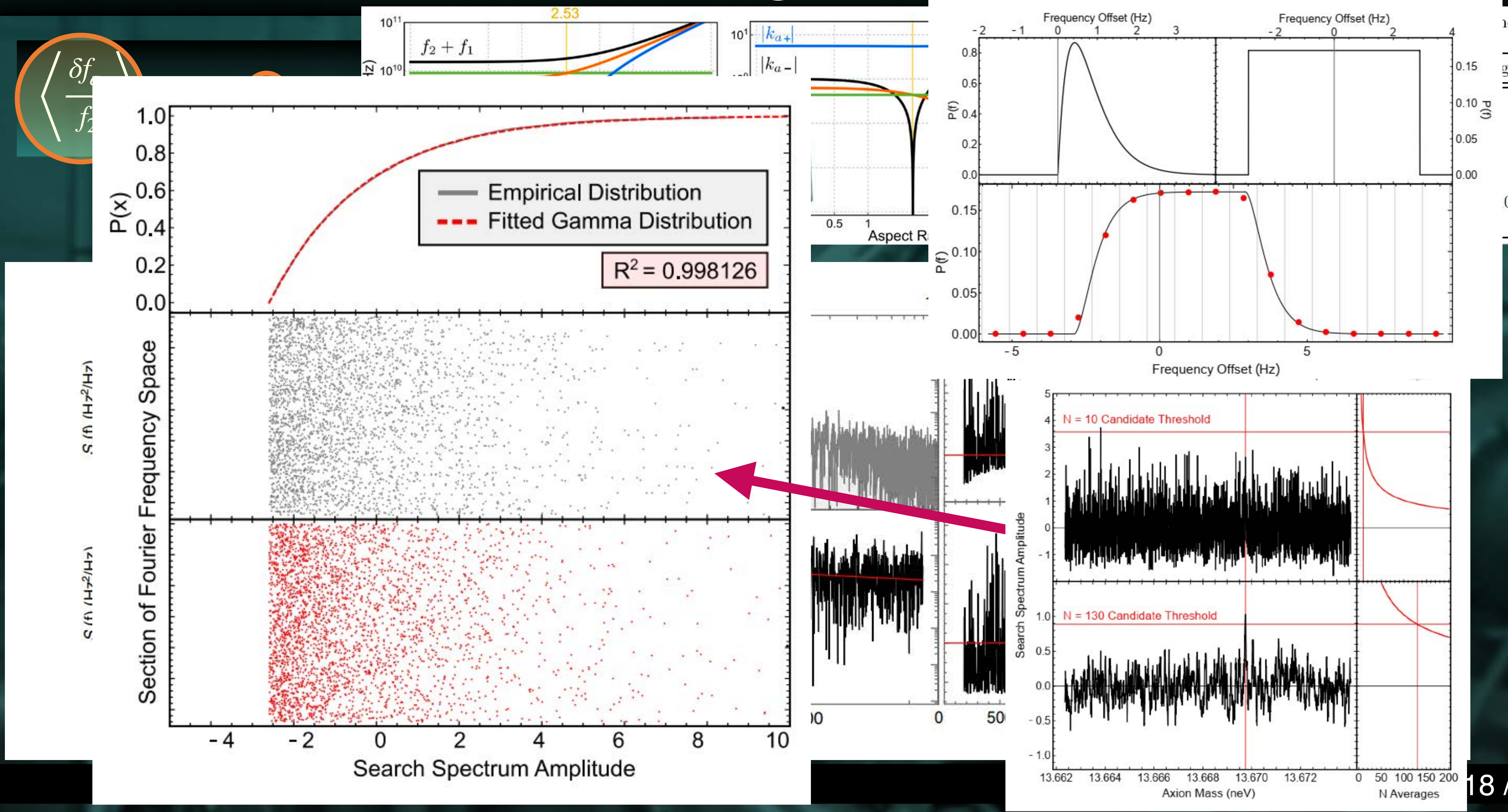
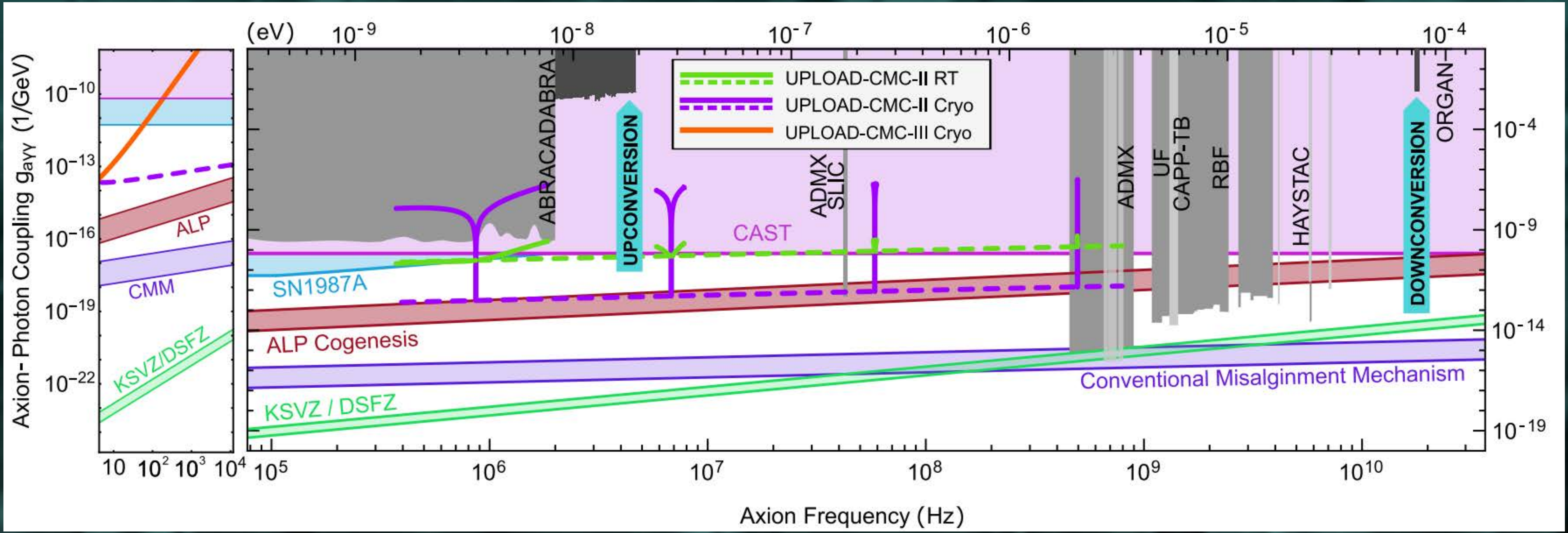
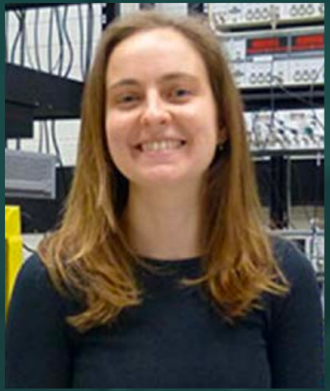
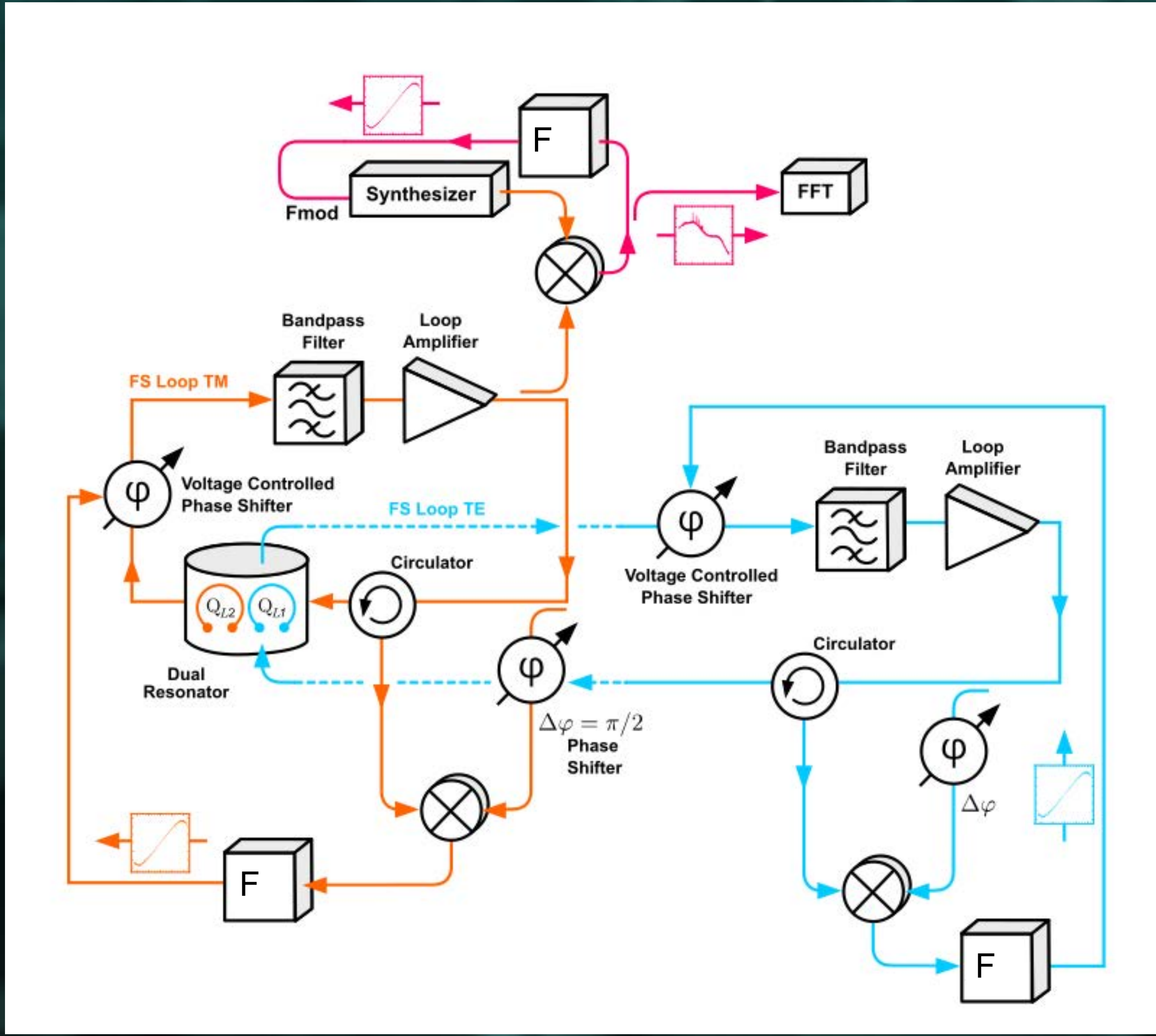


Phase 1 FIRST LIMITS



Add noise suppression and vacuum





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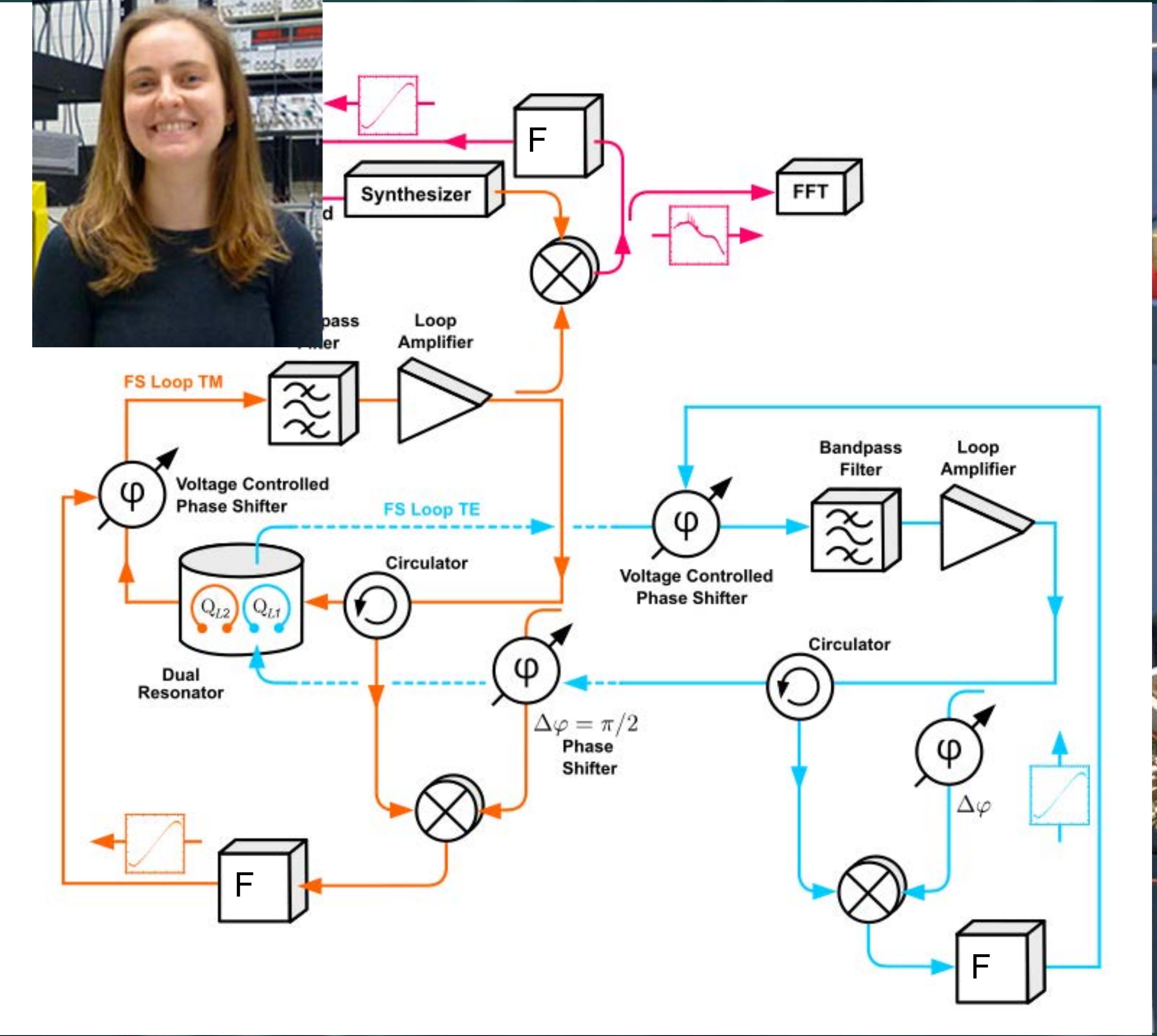
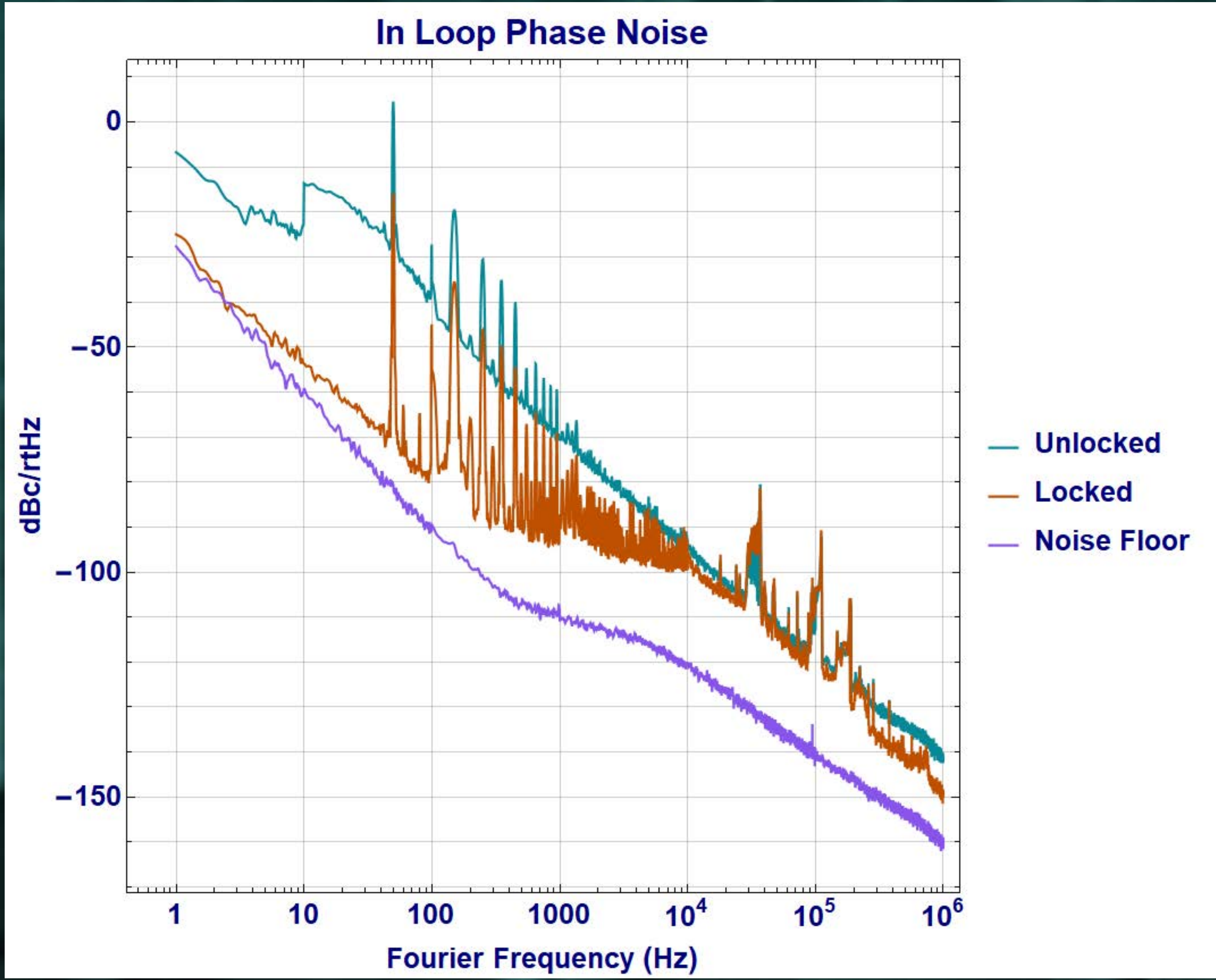


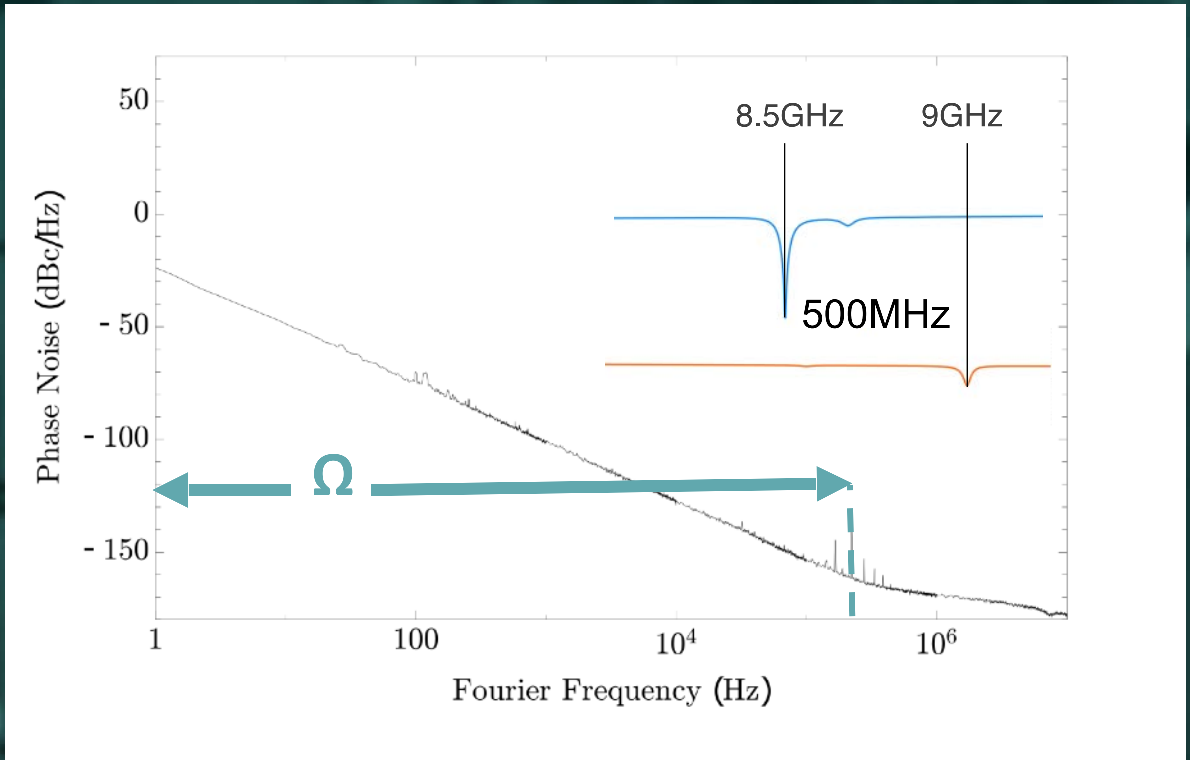
Results

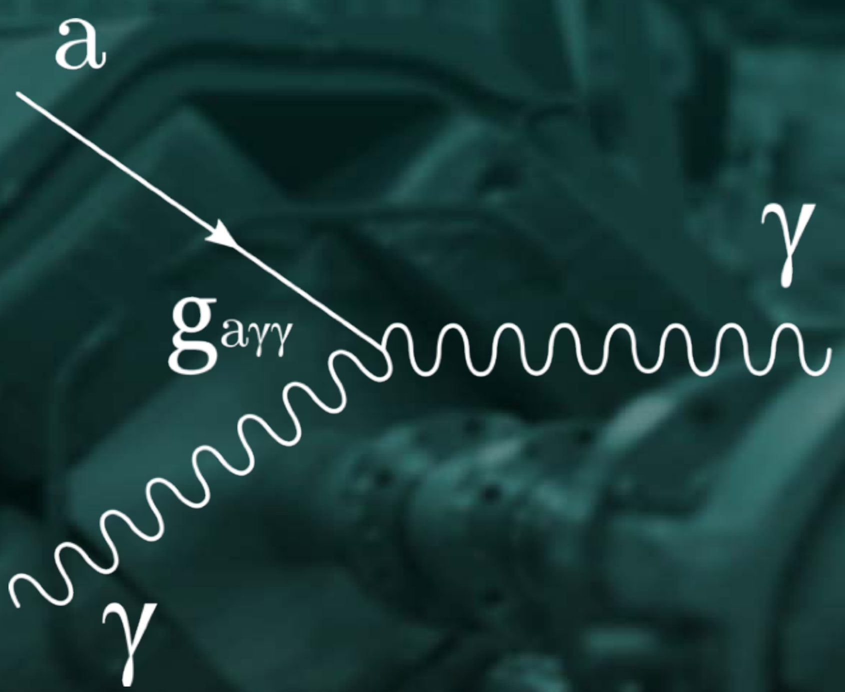
FREQUENCY NOISE PSD



Results IDENTIFYING AN AXION SIGNAL

Can Search multiple spectra, while mode tunes





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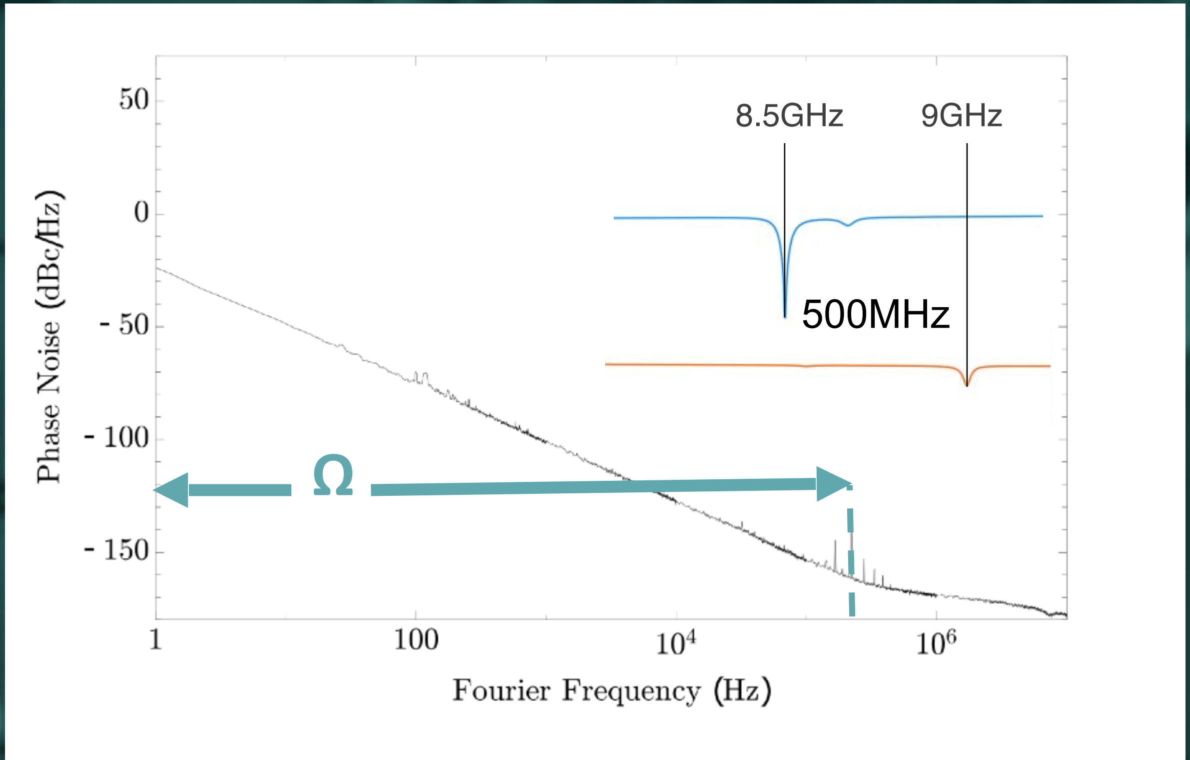
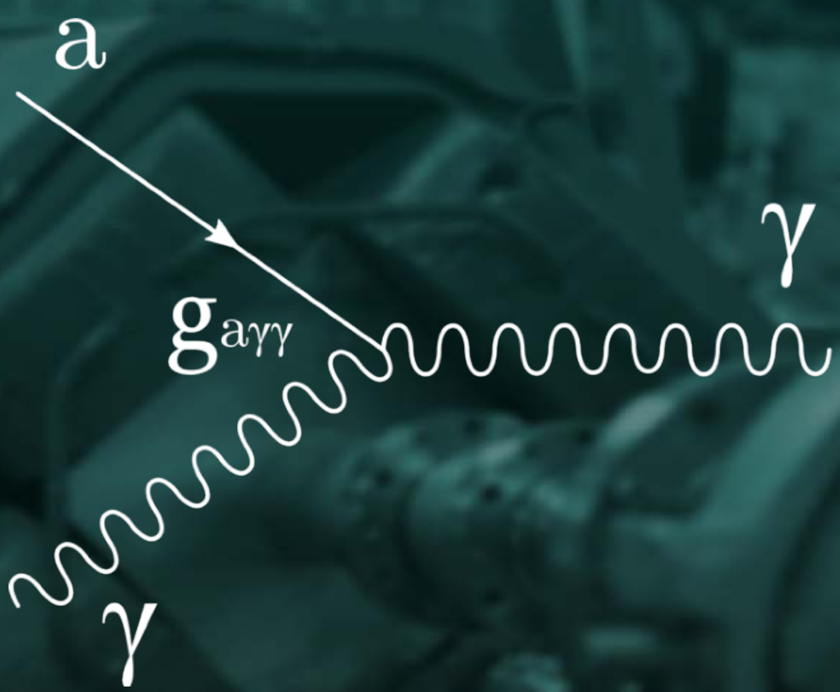
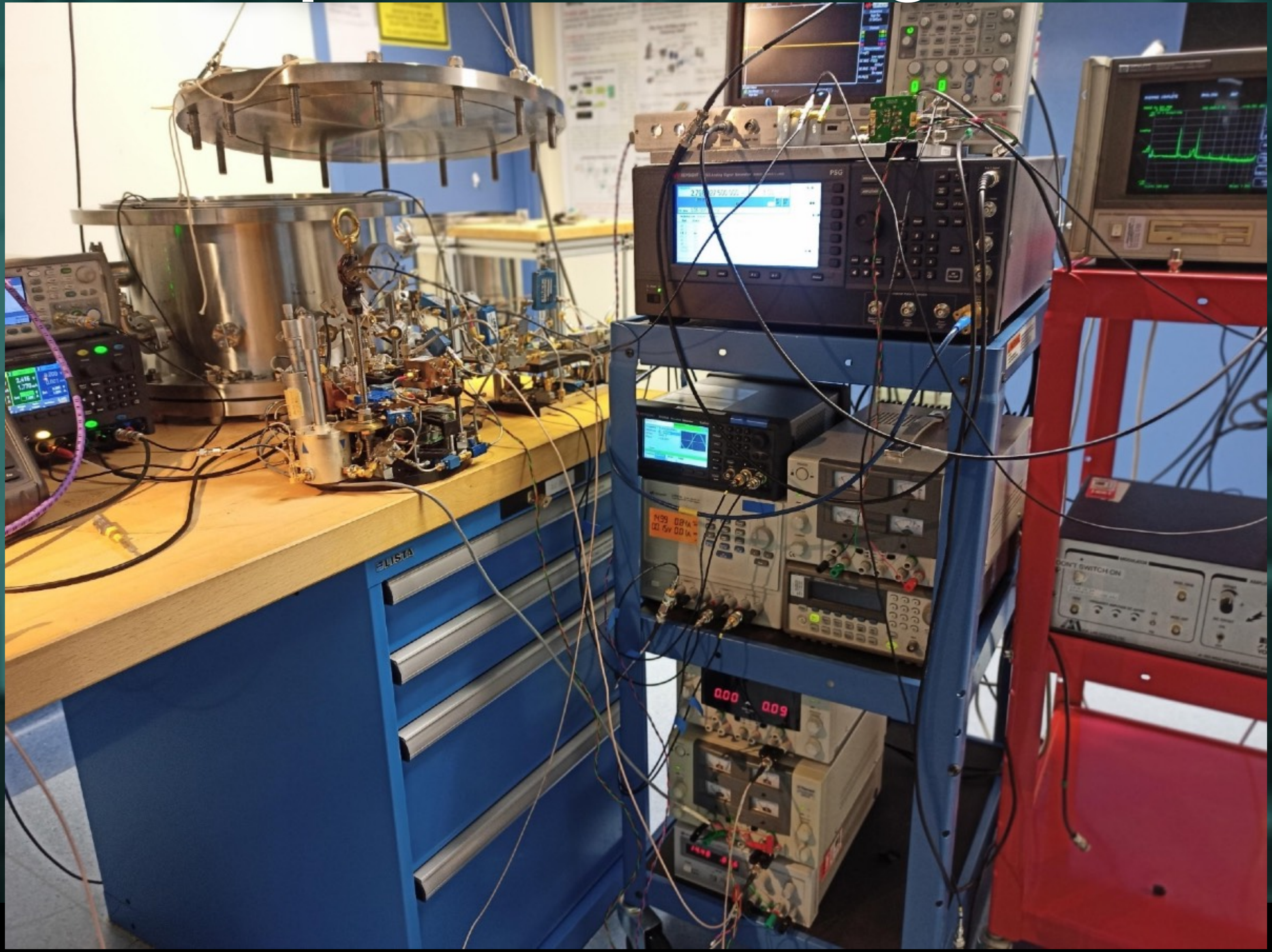




$$\omega_a = |\omega_1 - \omega_2| \pm \Omega \quad \textbf{where} \quad \Omega << \omega_1$$

THE PUMPED EXPERIMENT

Experimental Design



THE PUMPED EXPERIMENT

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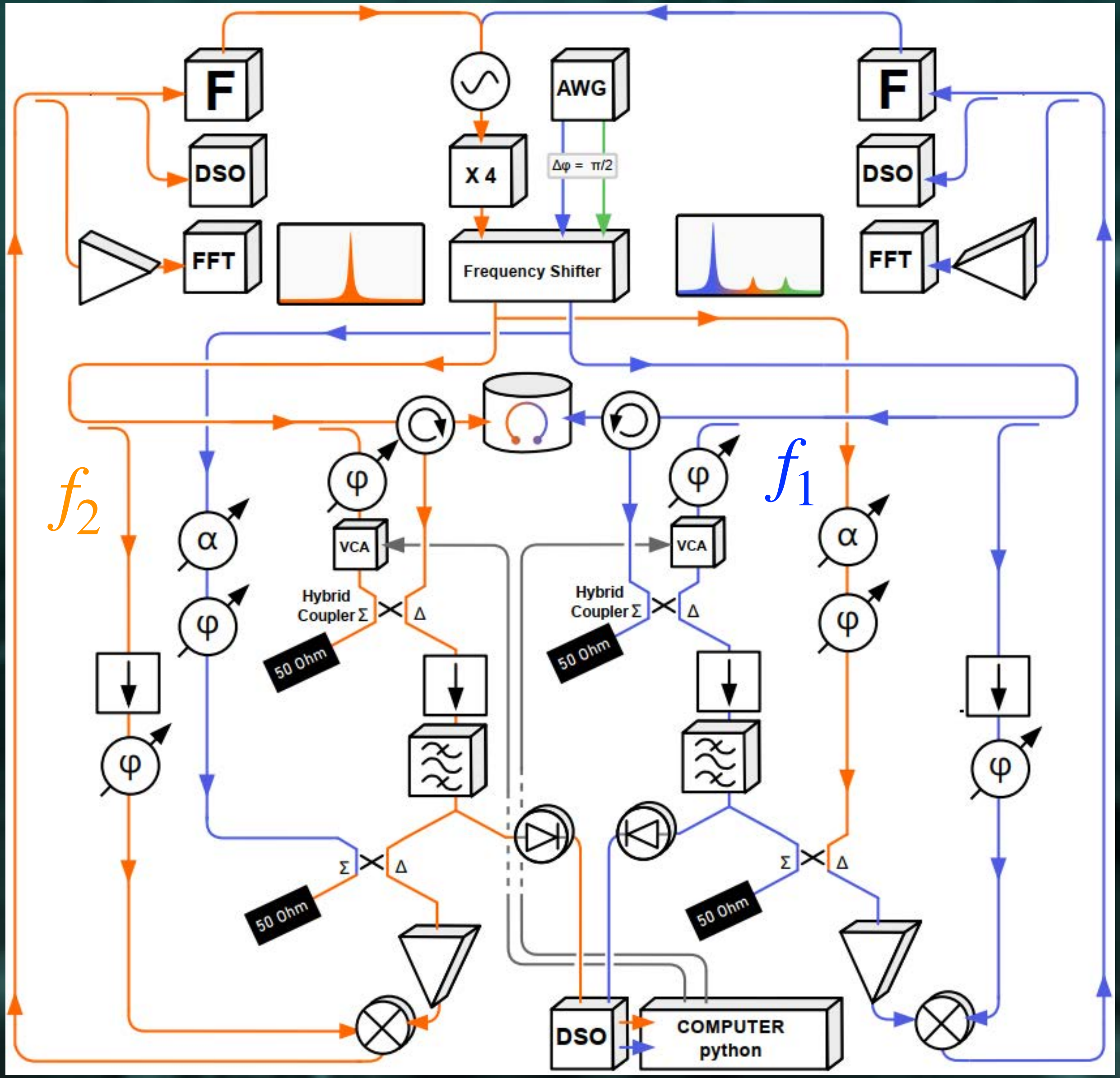

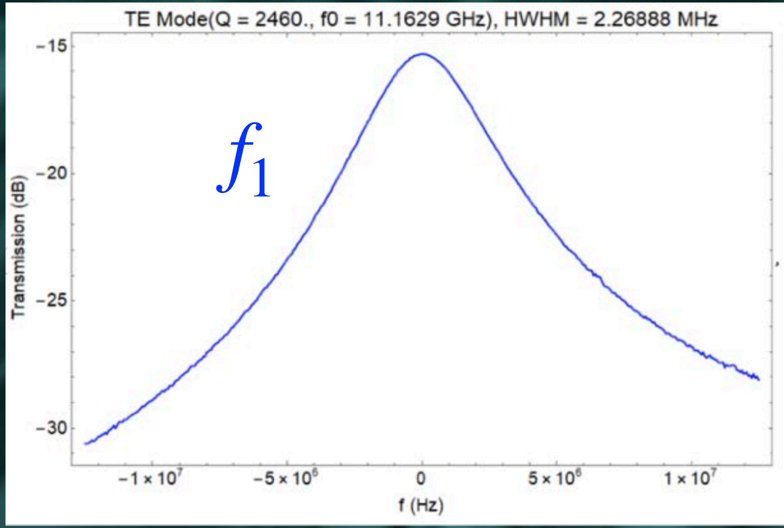

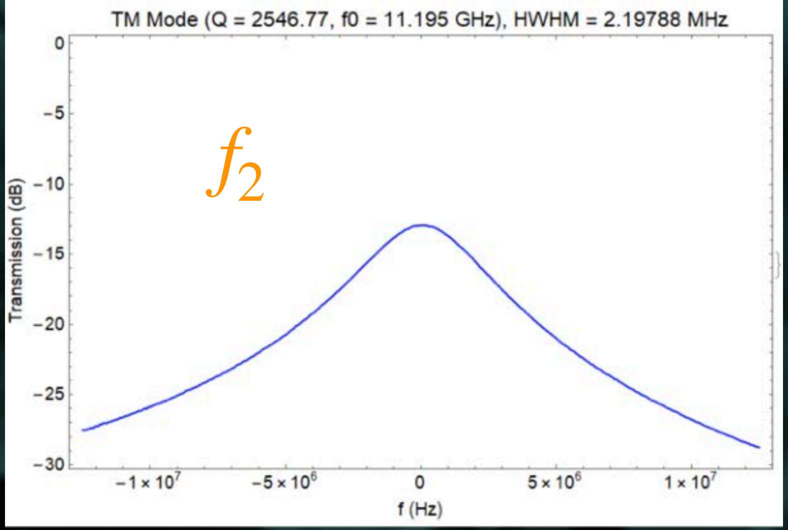

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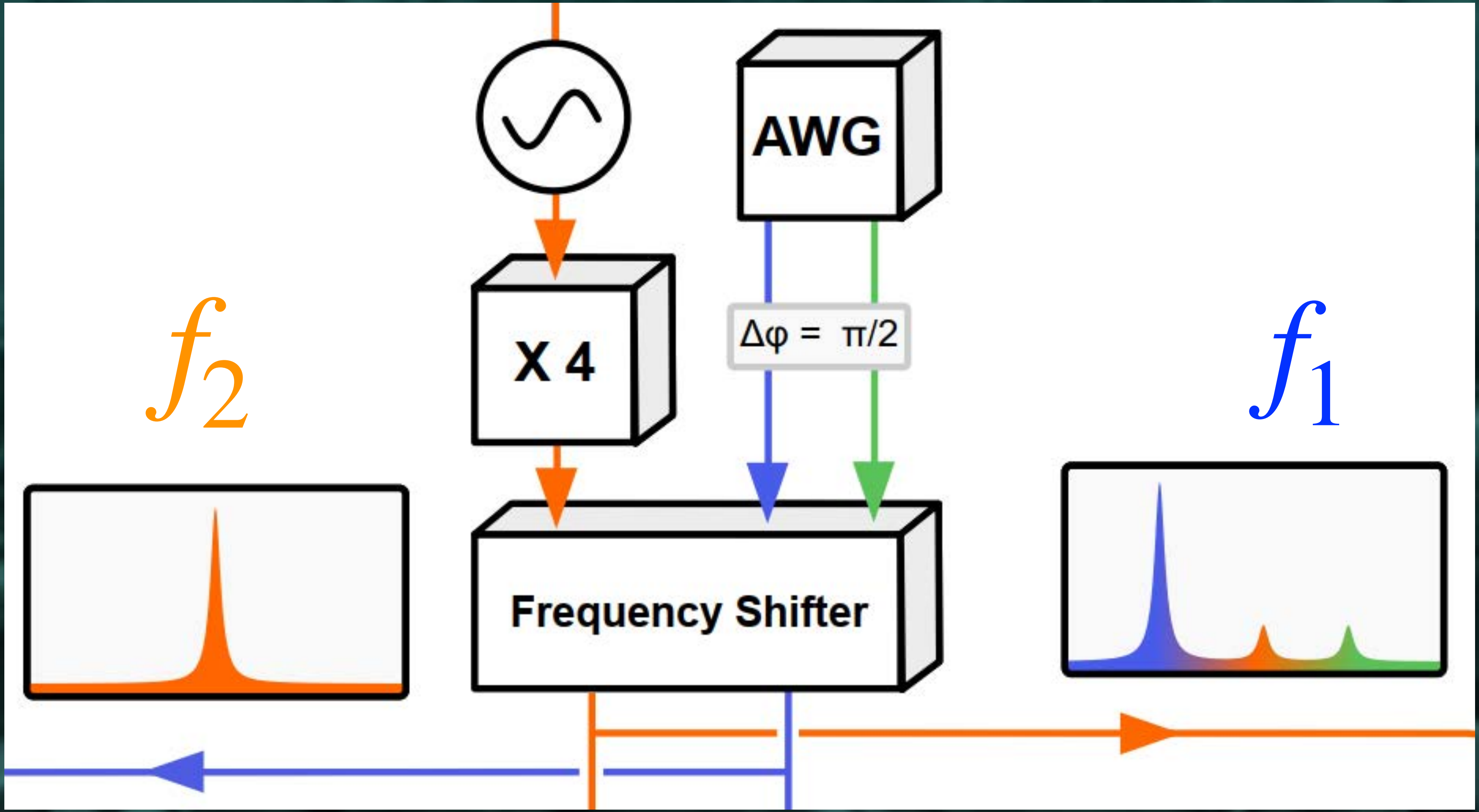

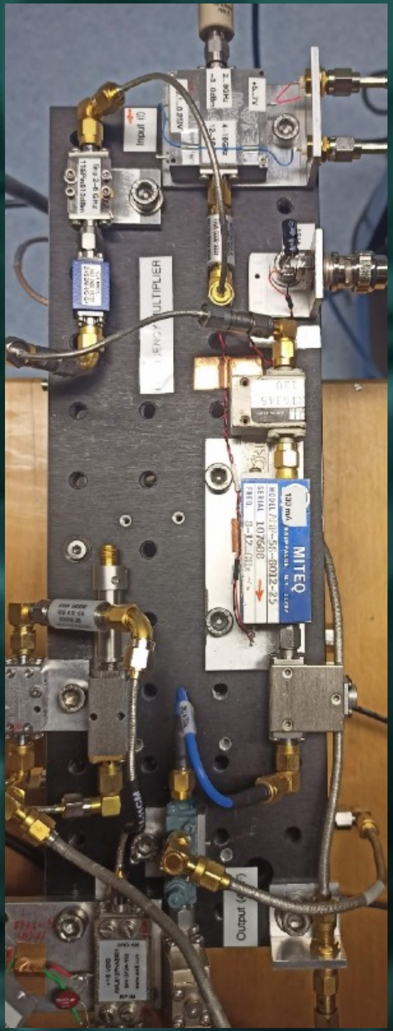

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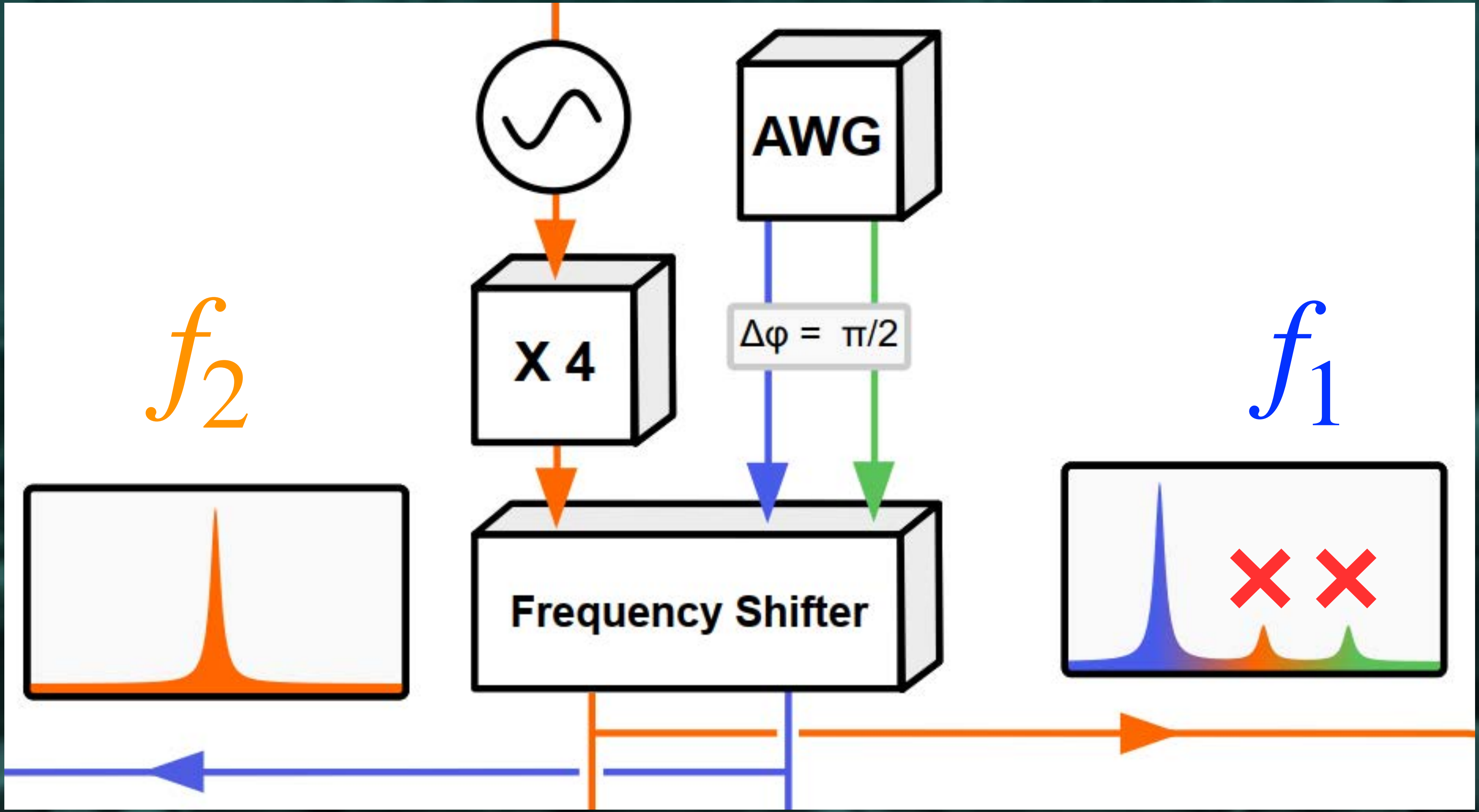

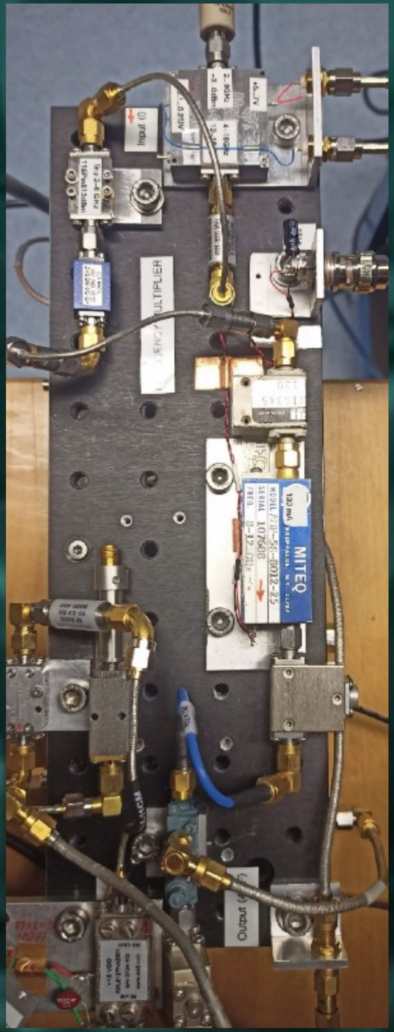

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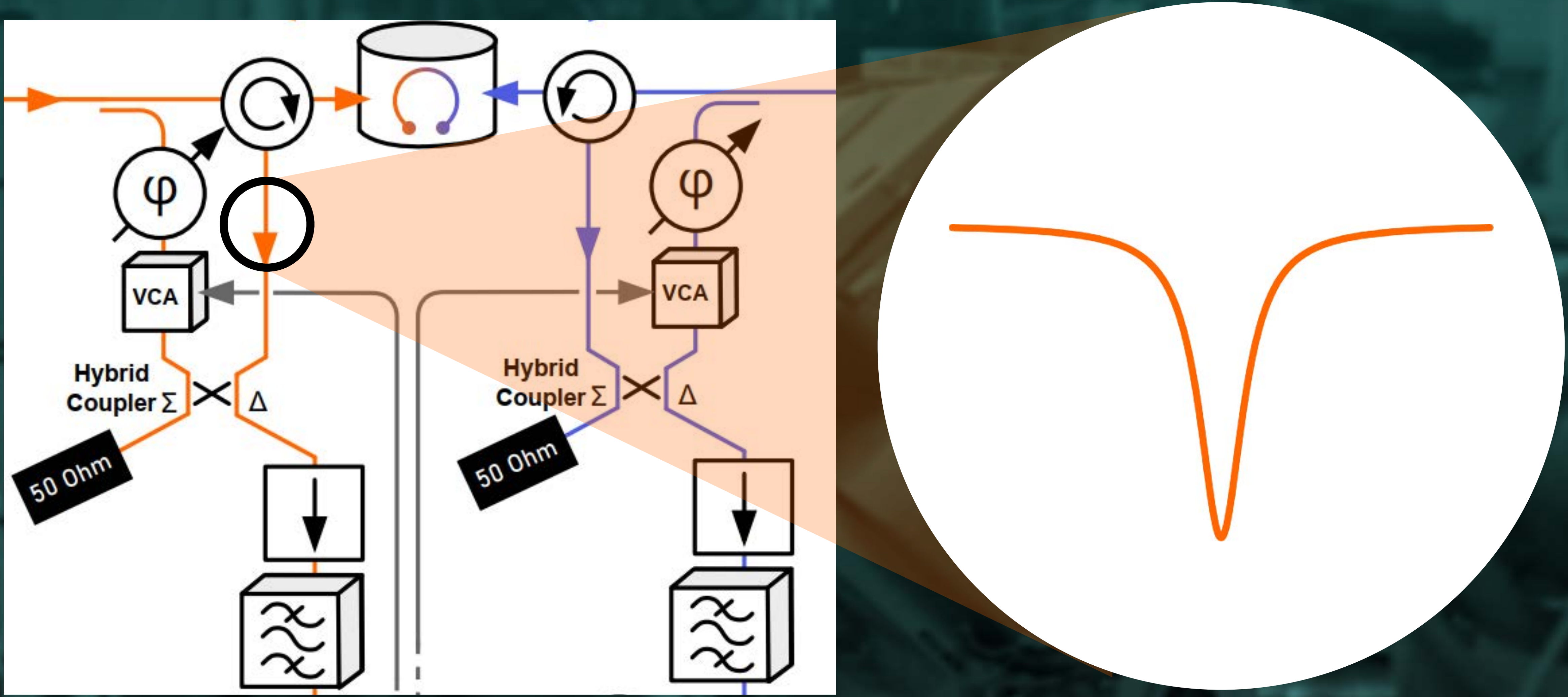

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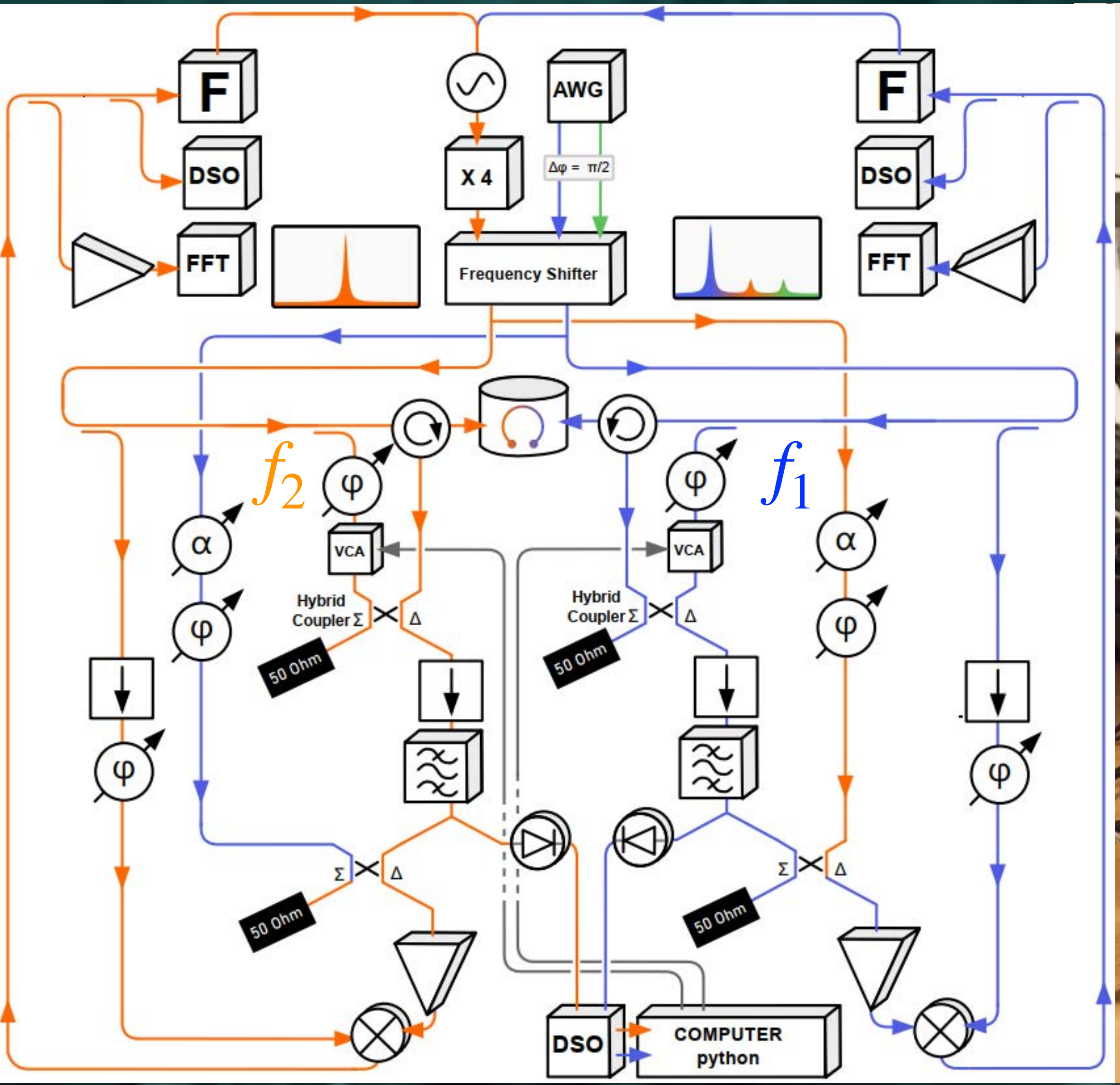
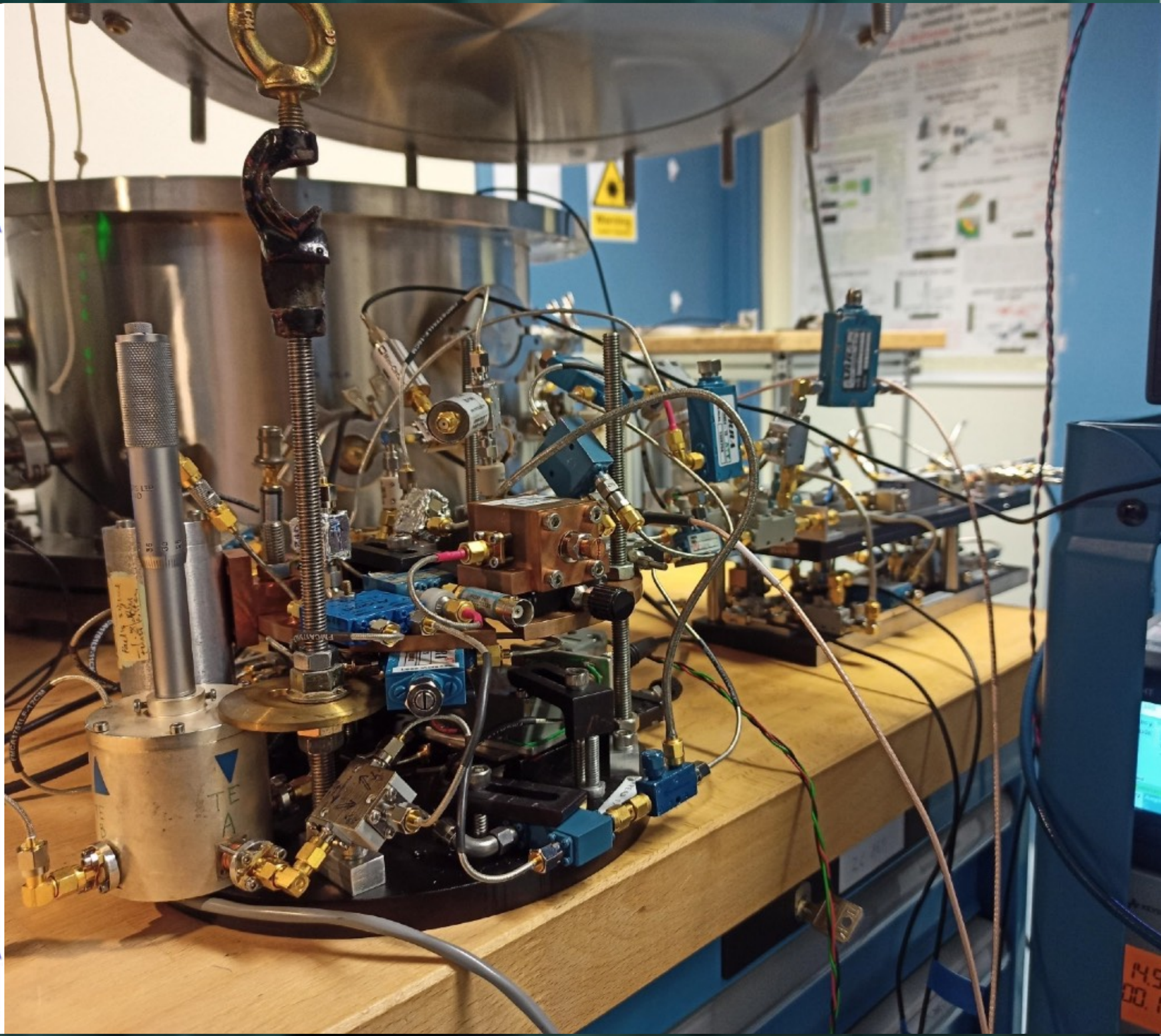
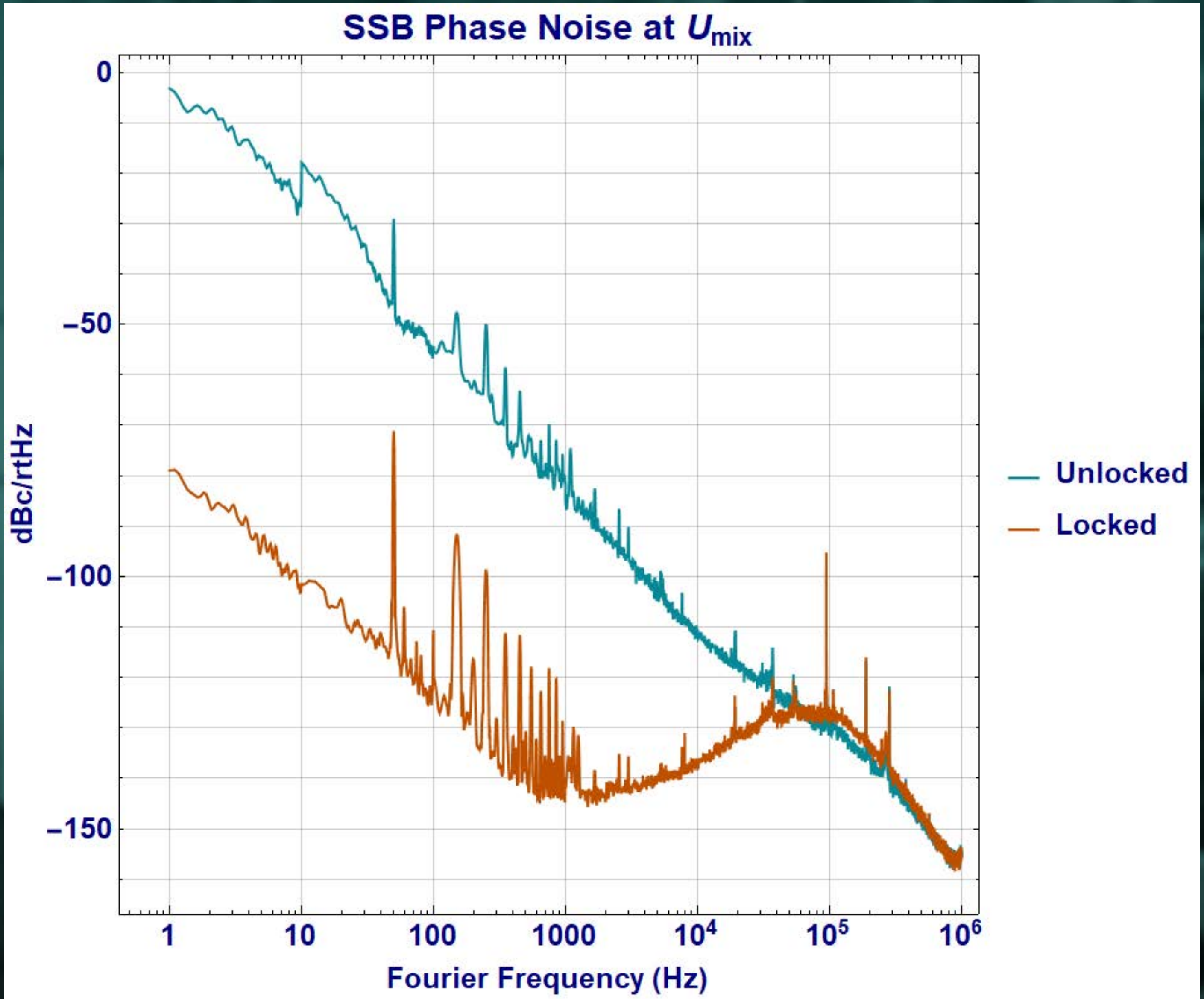




Results

THE PUMPED EXPERIMENT



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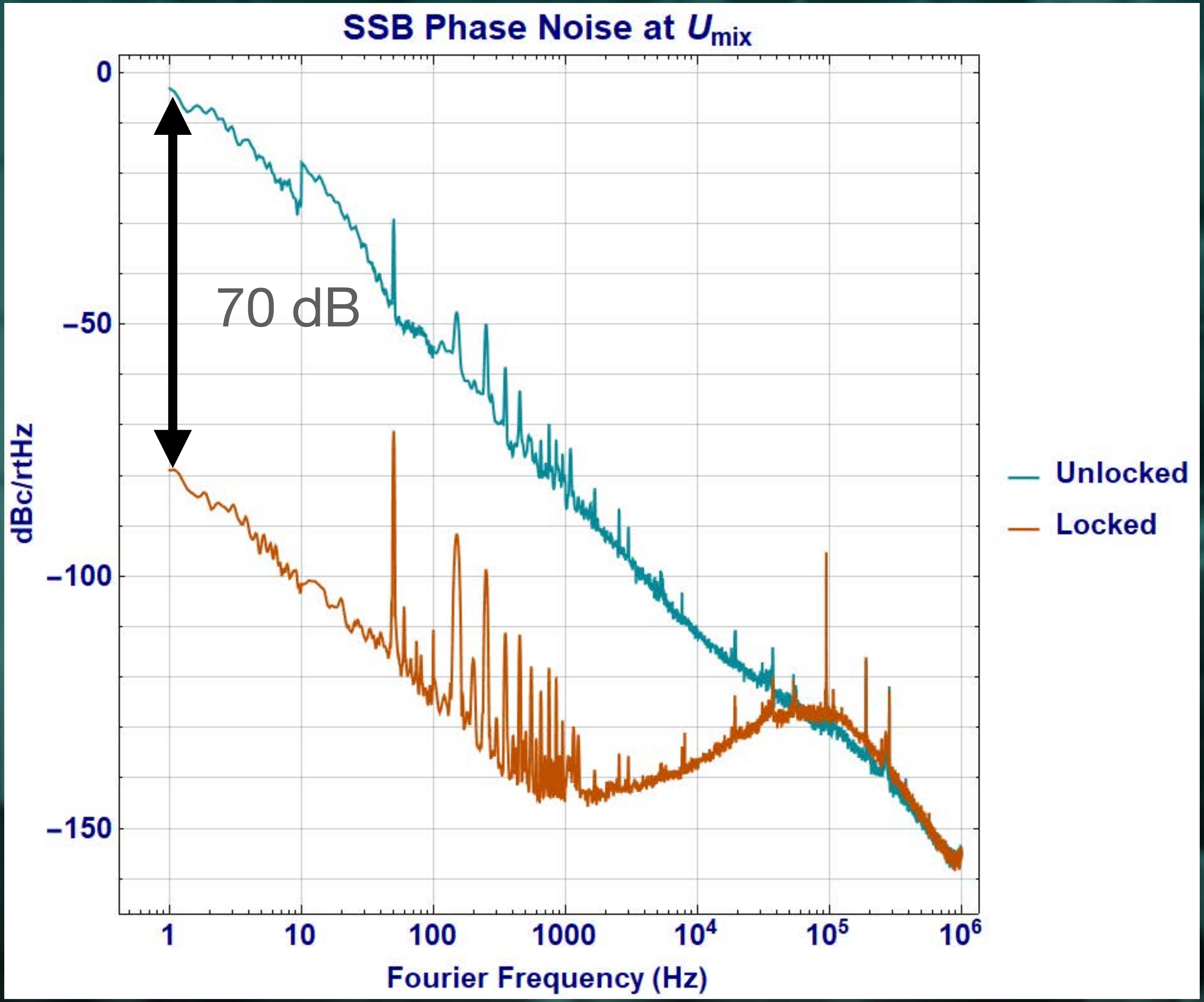

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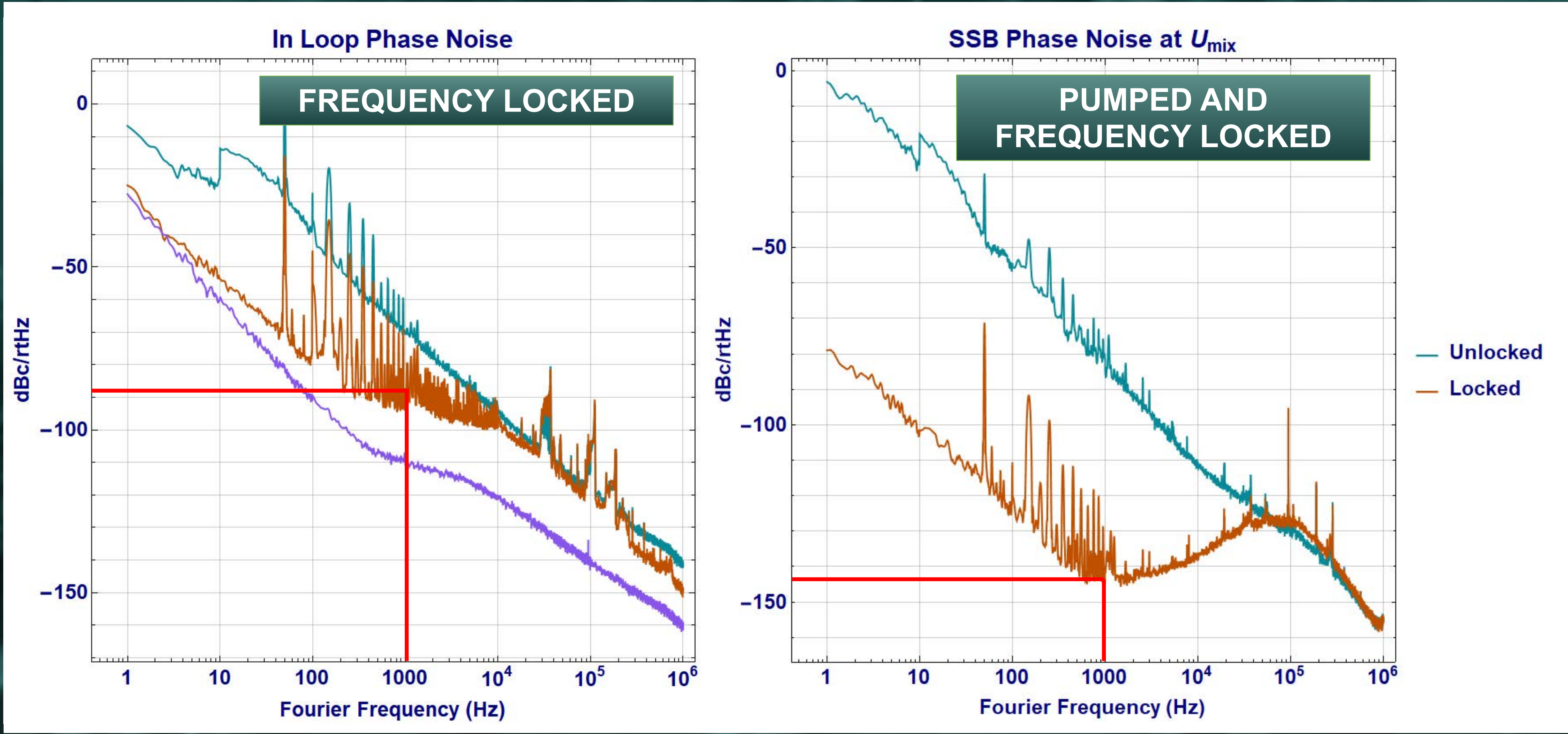

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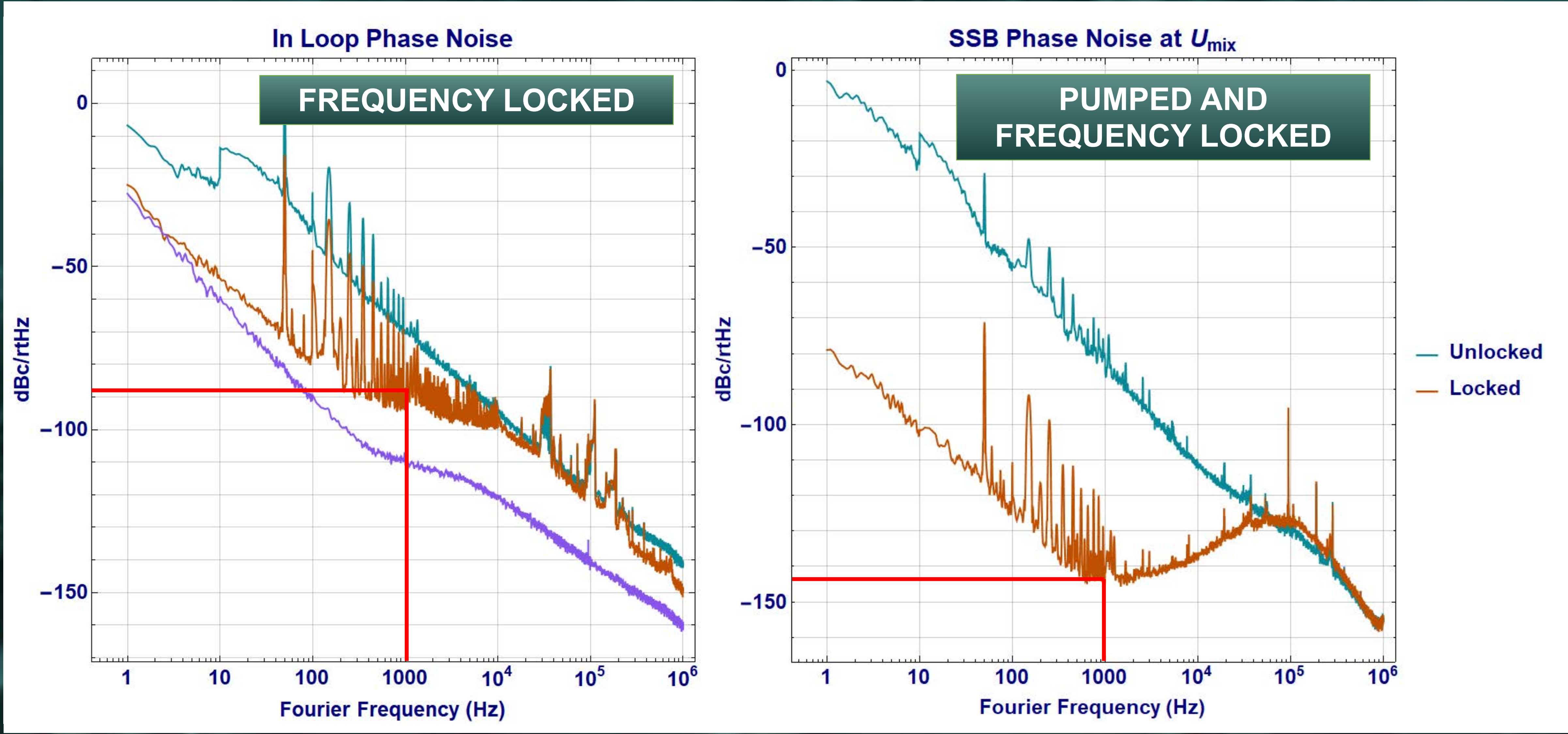

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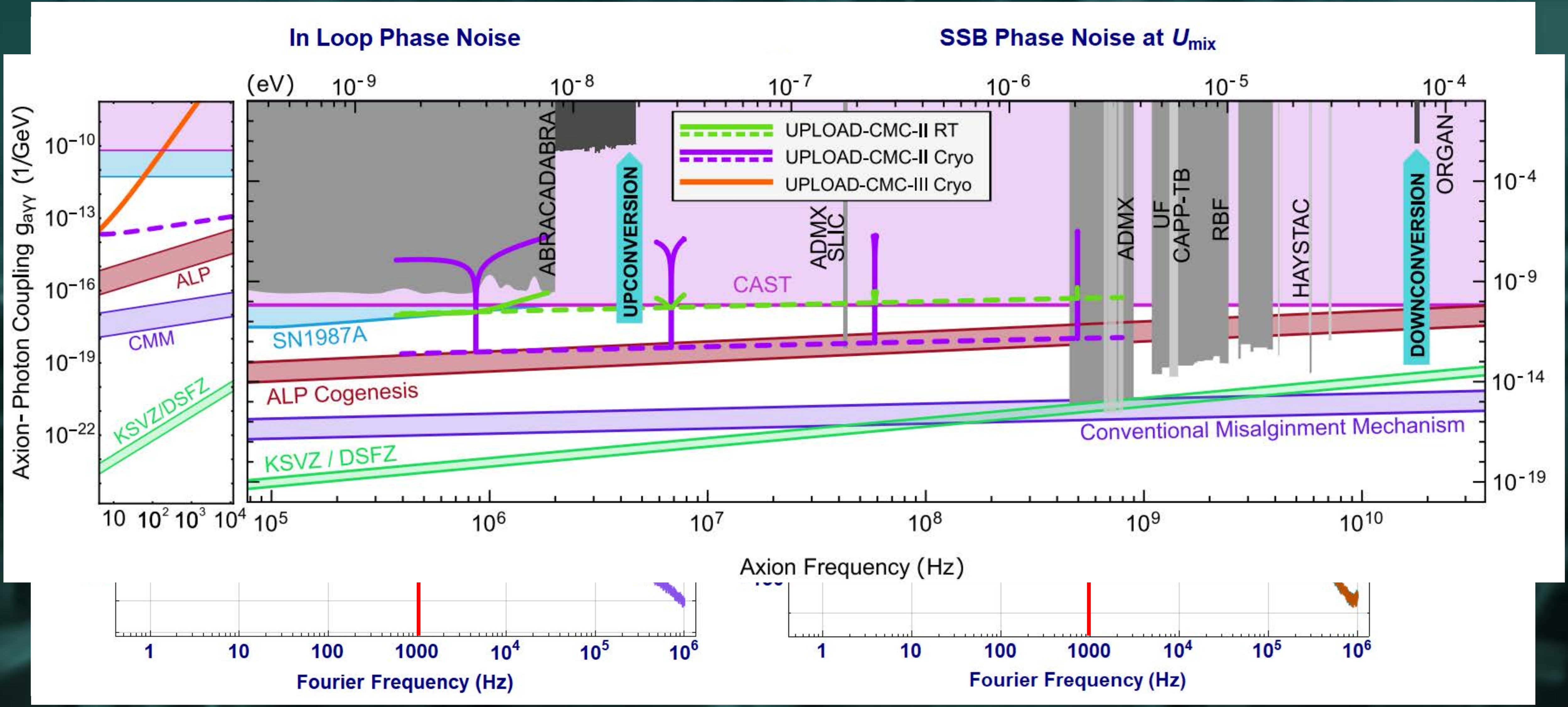
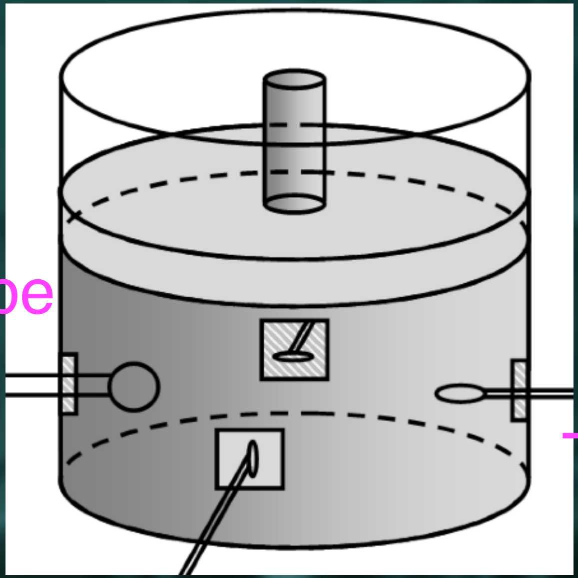


Ultralight Axions: Frequency and Power technique



- Tuneable cavity height (lid attached to micrometer)
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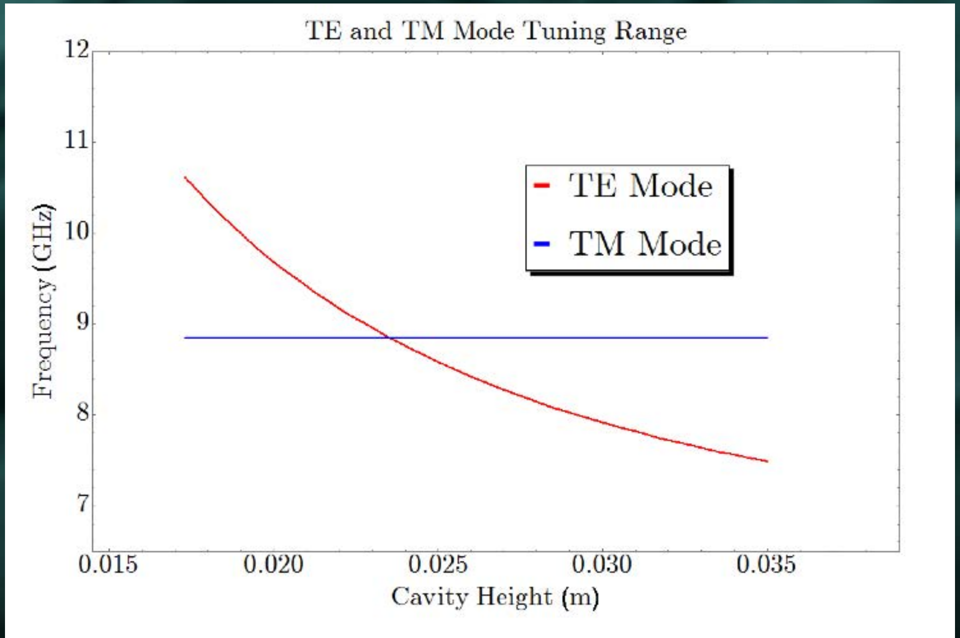

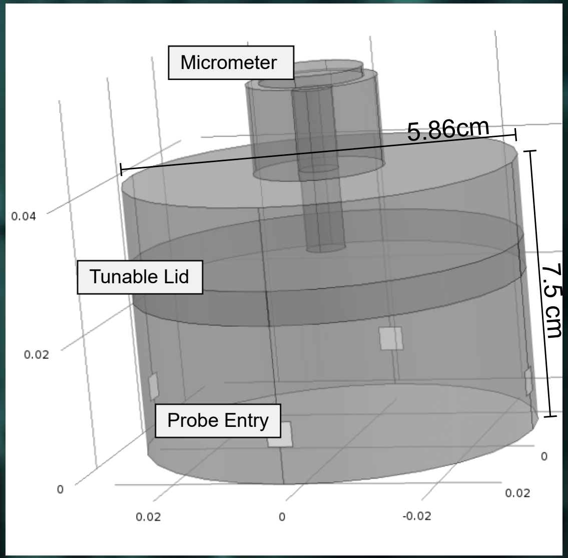

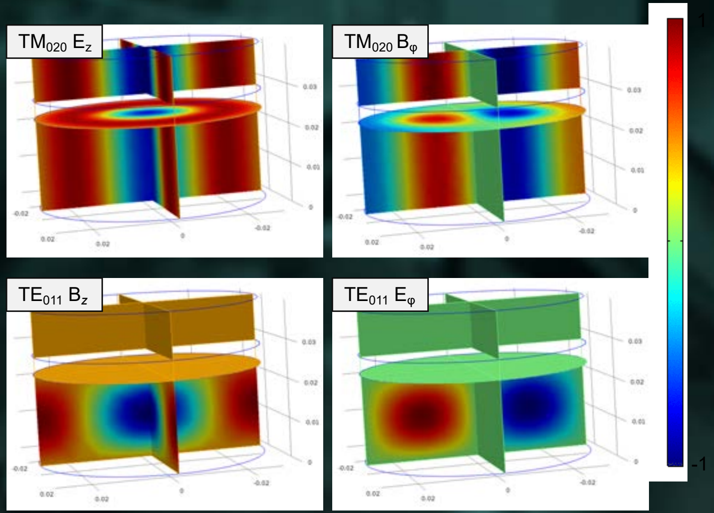

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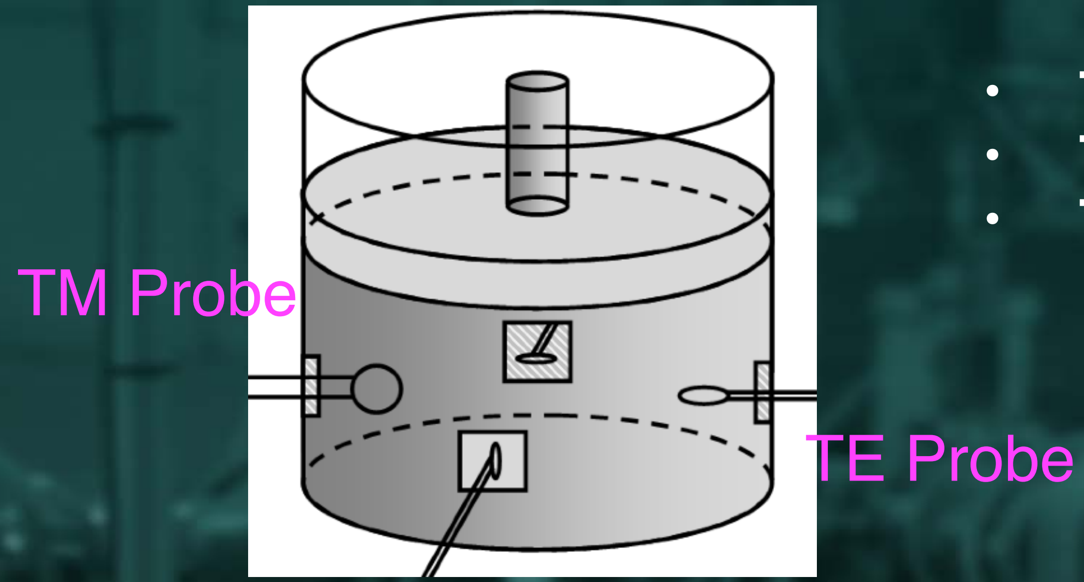

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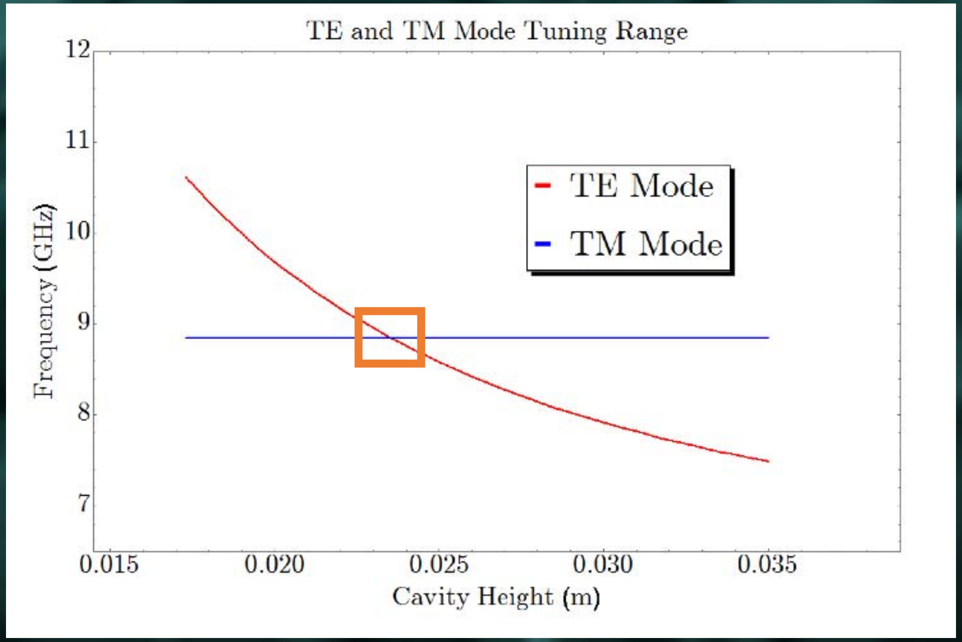

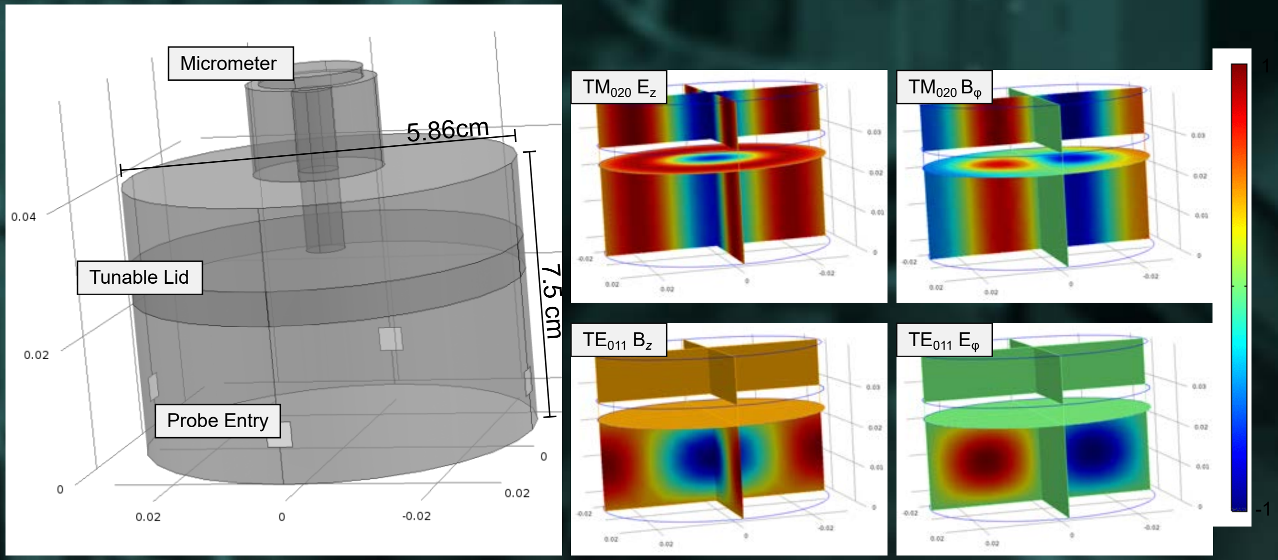

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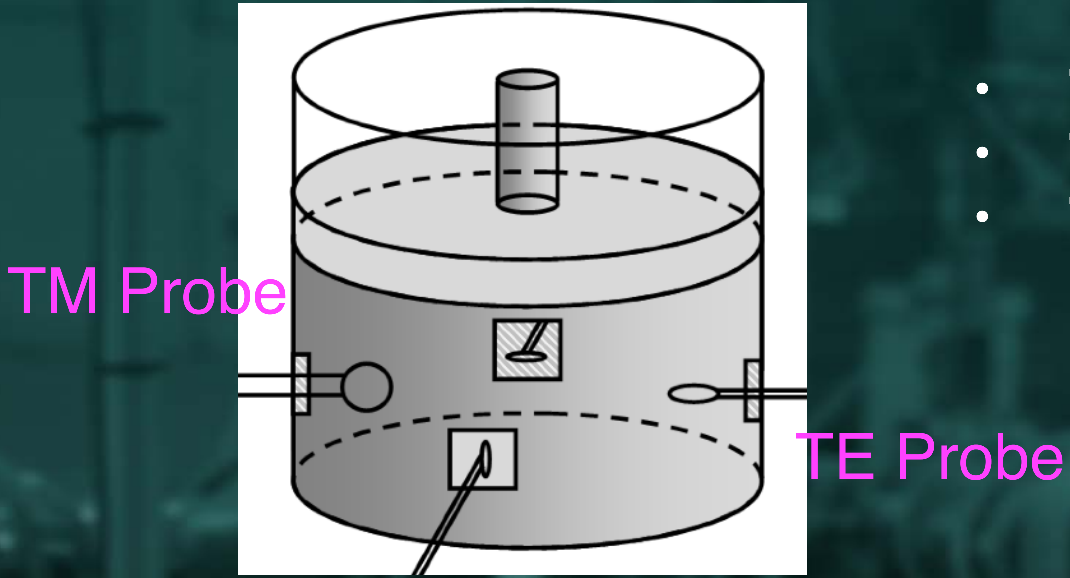

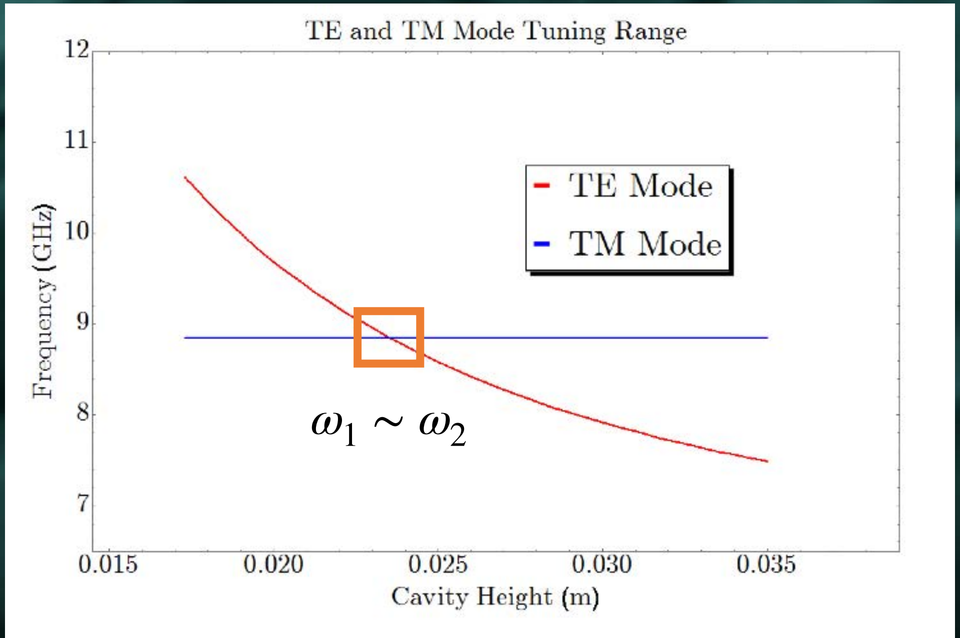

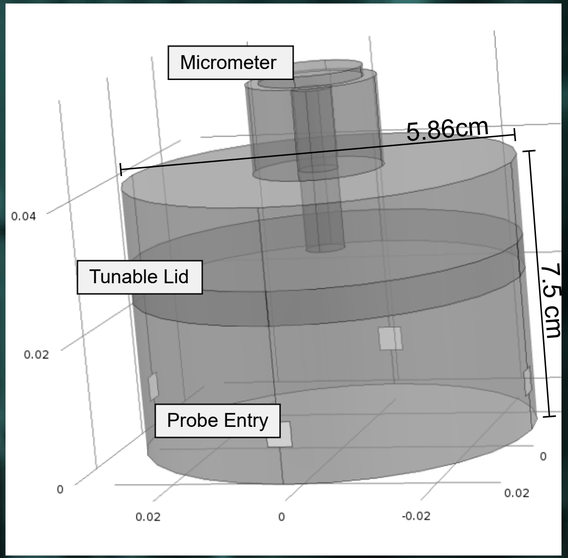

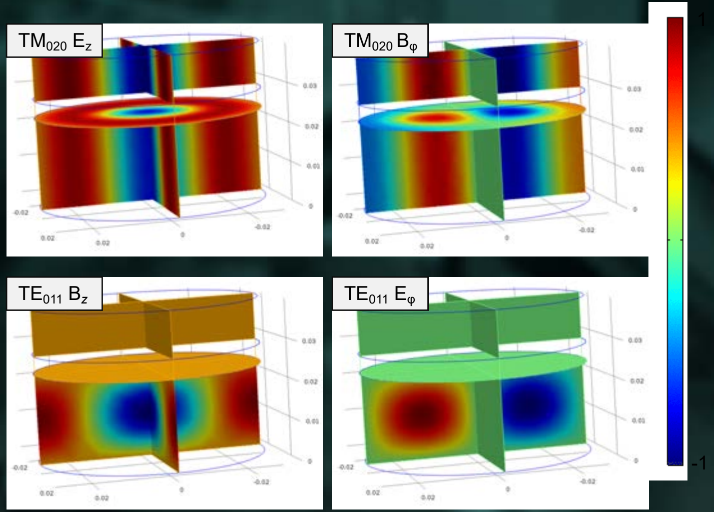

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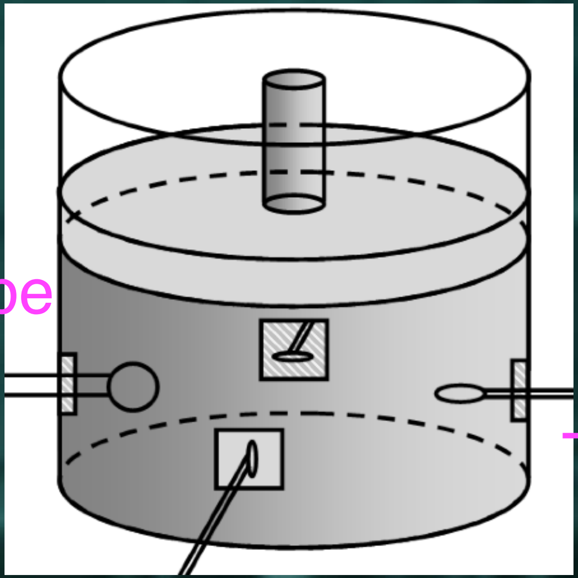

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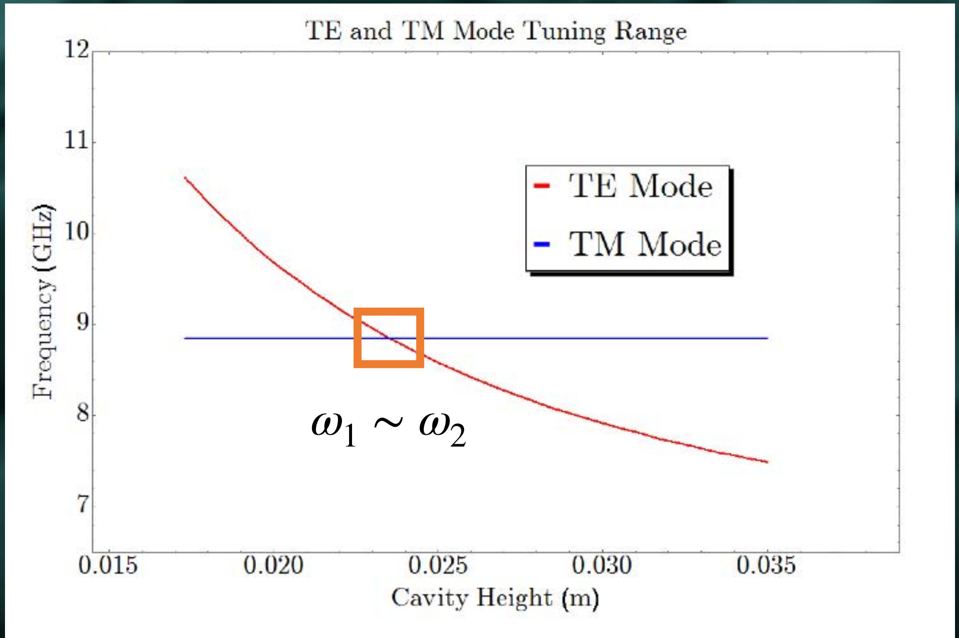

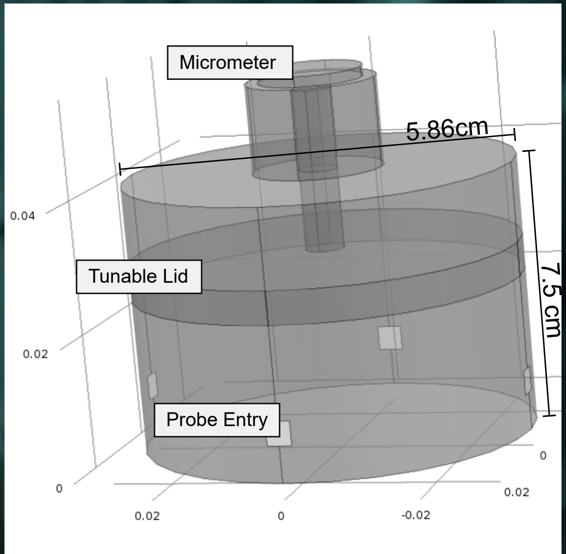

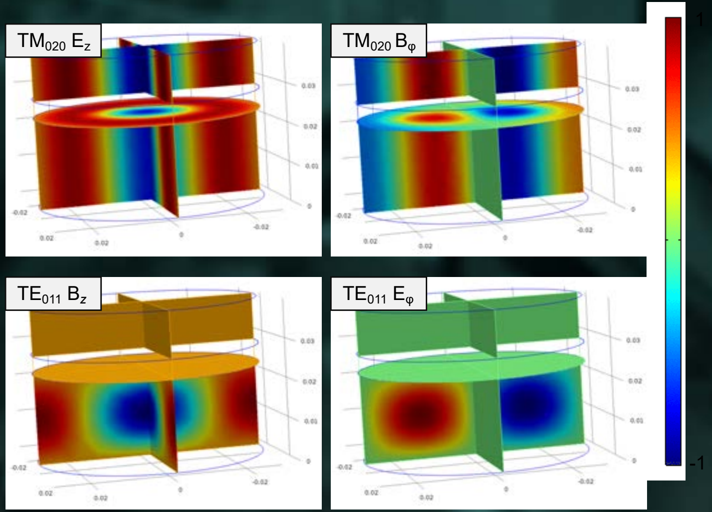

$$\omega_a = \delta\omega \pm \Omega$$

Ultralight Axions: Frequency and Power technique

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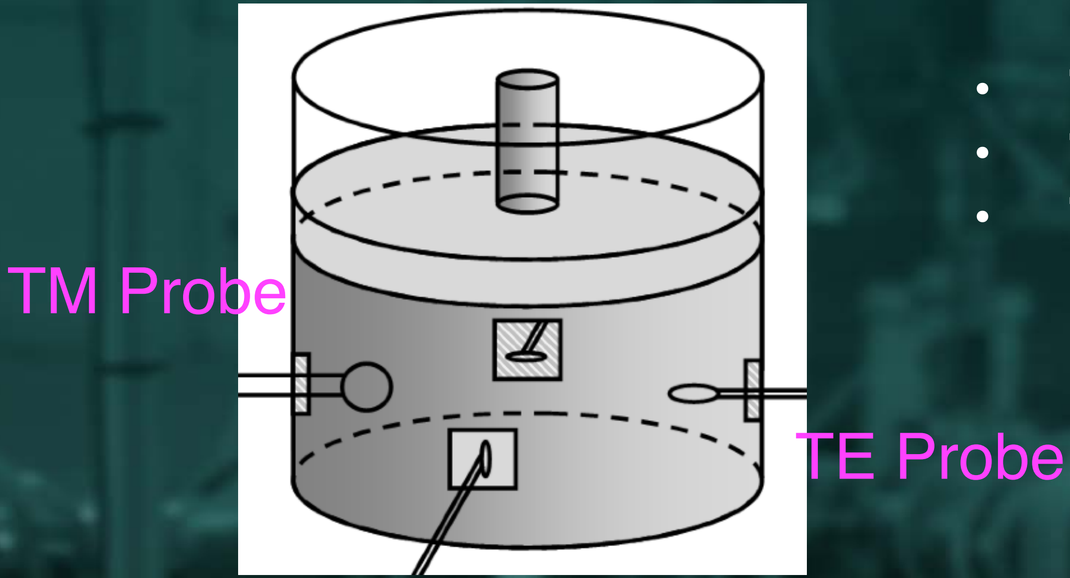

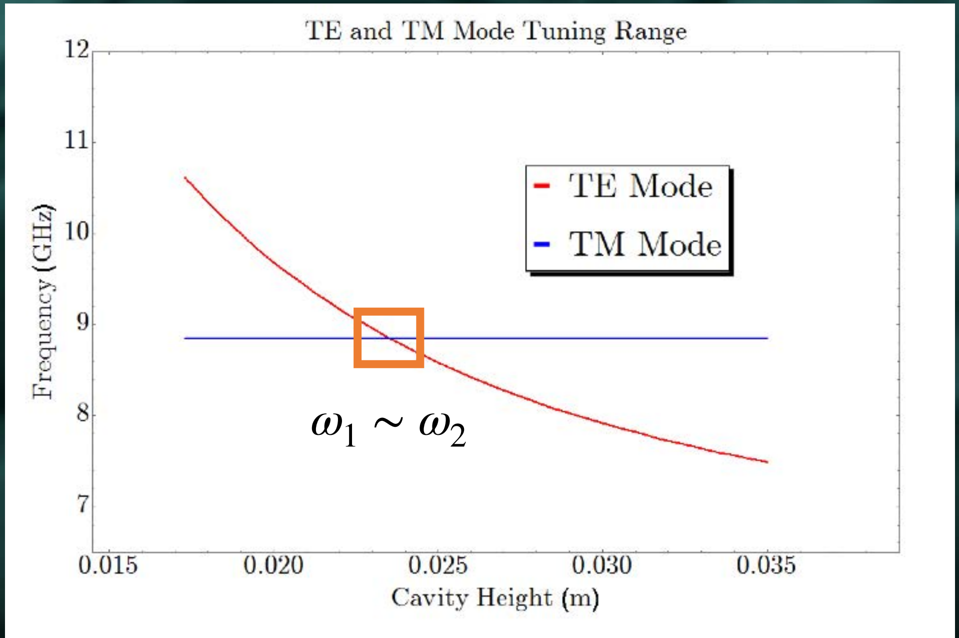

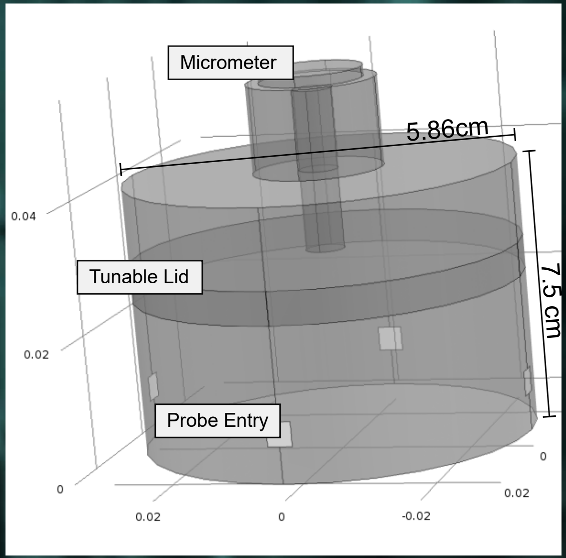

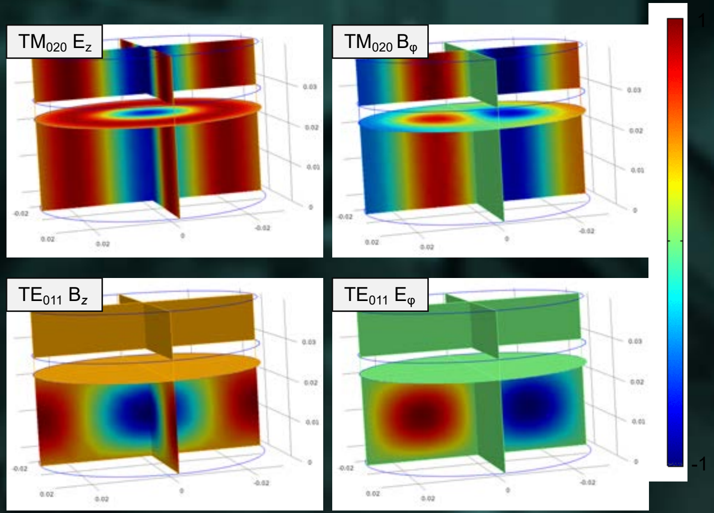

$$\omega_a = \delta\omega \pm \Omega$$

Detuning

Ultralight Axions: Frequency and Power technique

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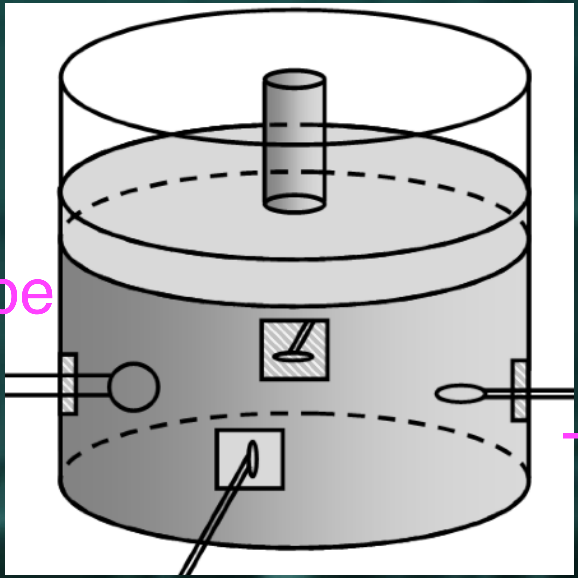
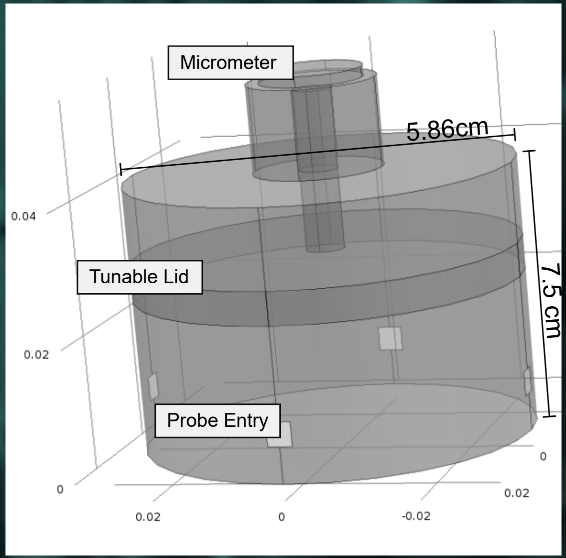
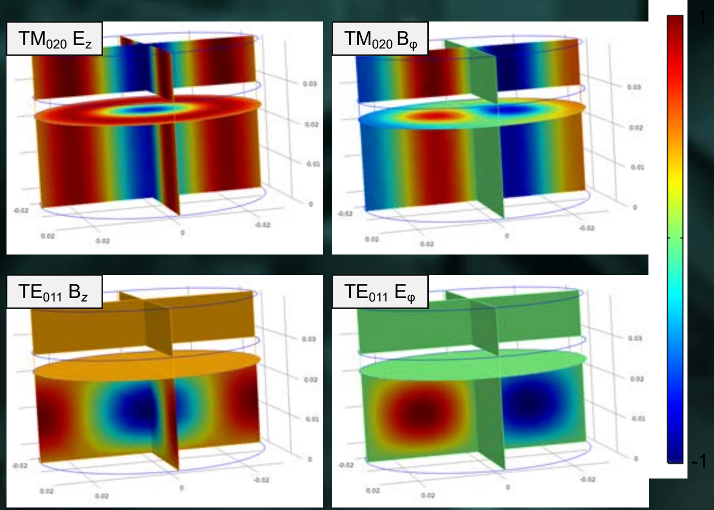
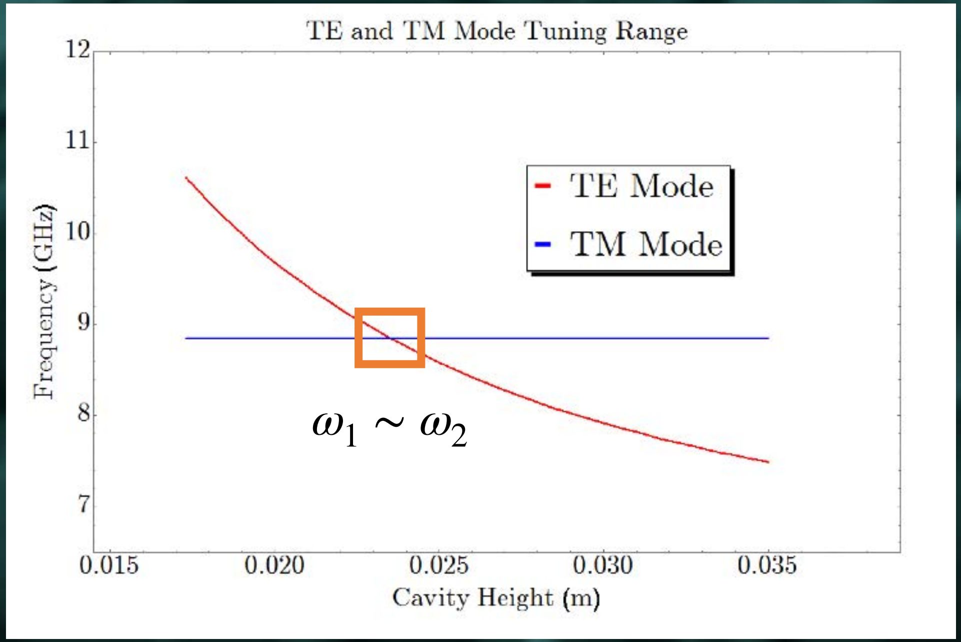






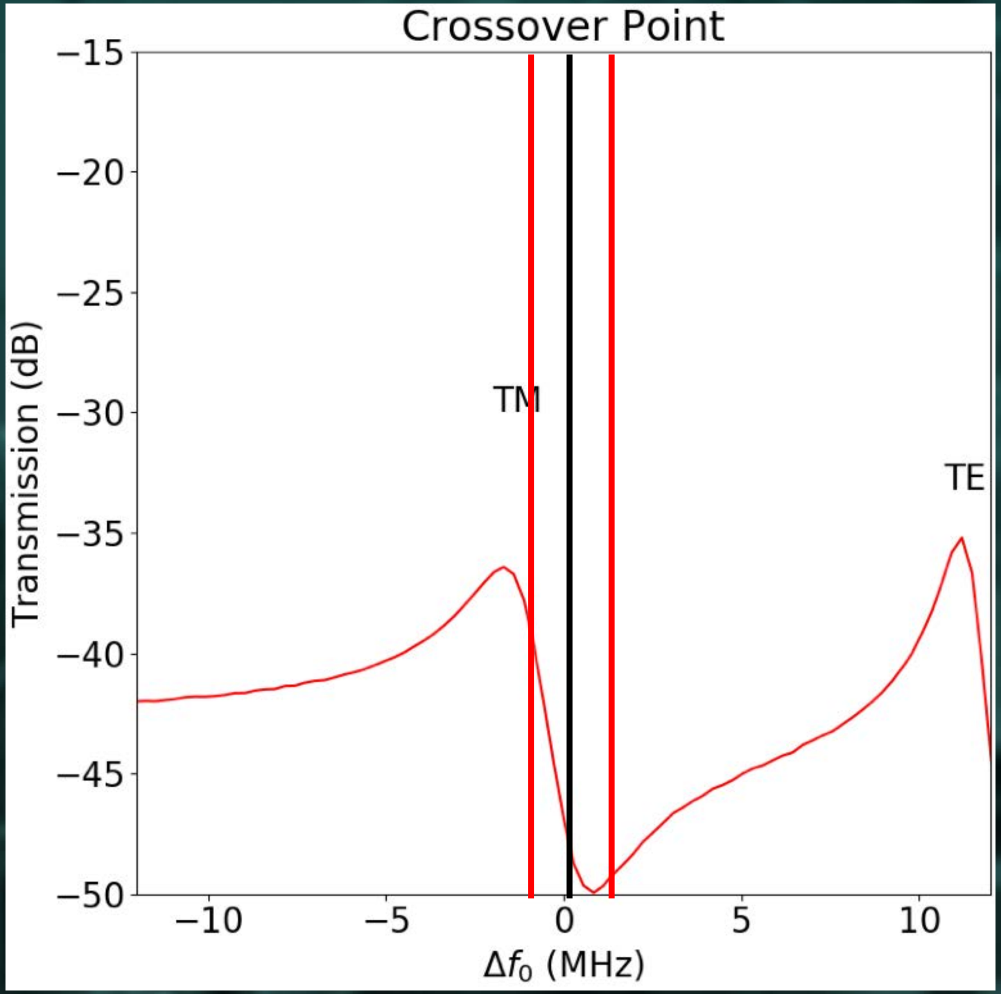


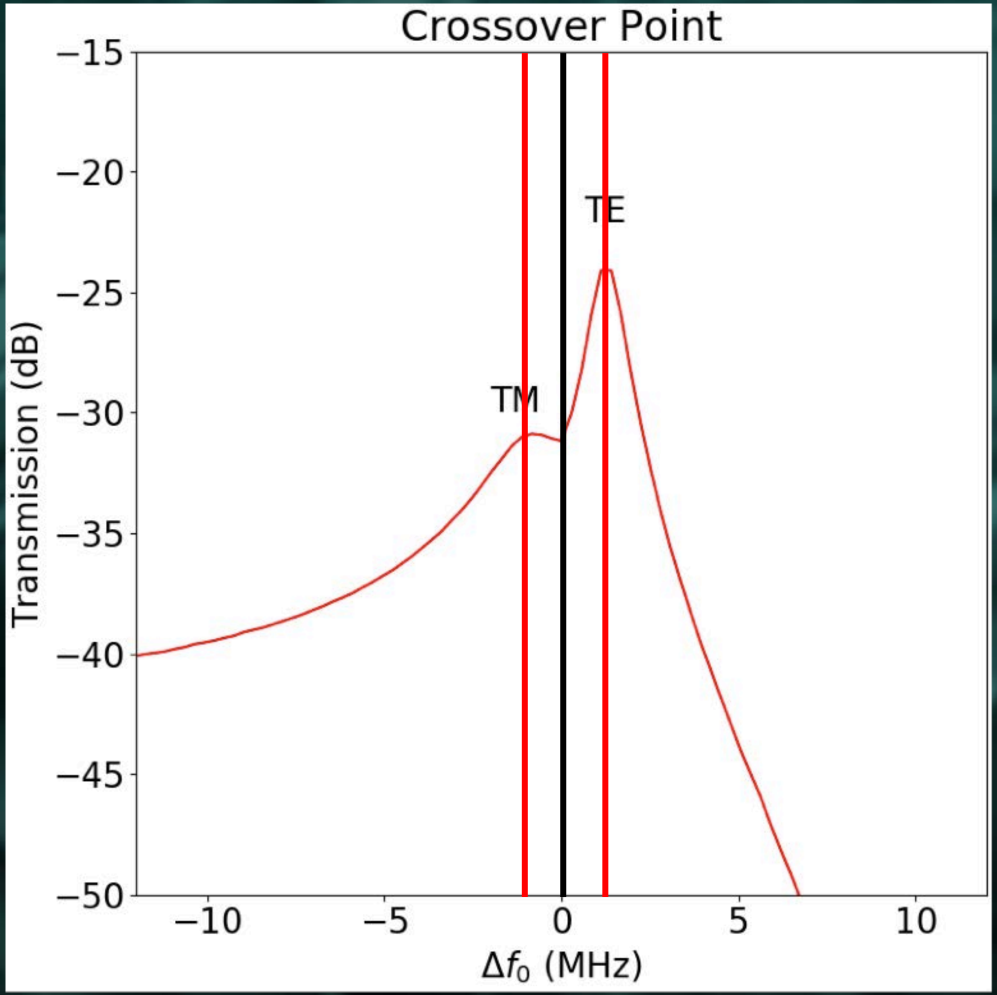
$$\omega_a = \delta\omega \pm \Omega$$

Detuning ($\delta\omega$) — Fourier Frequency (Ω)

Problems for Ultralight Axions

$\delta f = 2MHz$





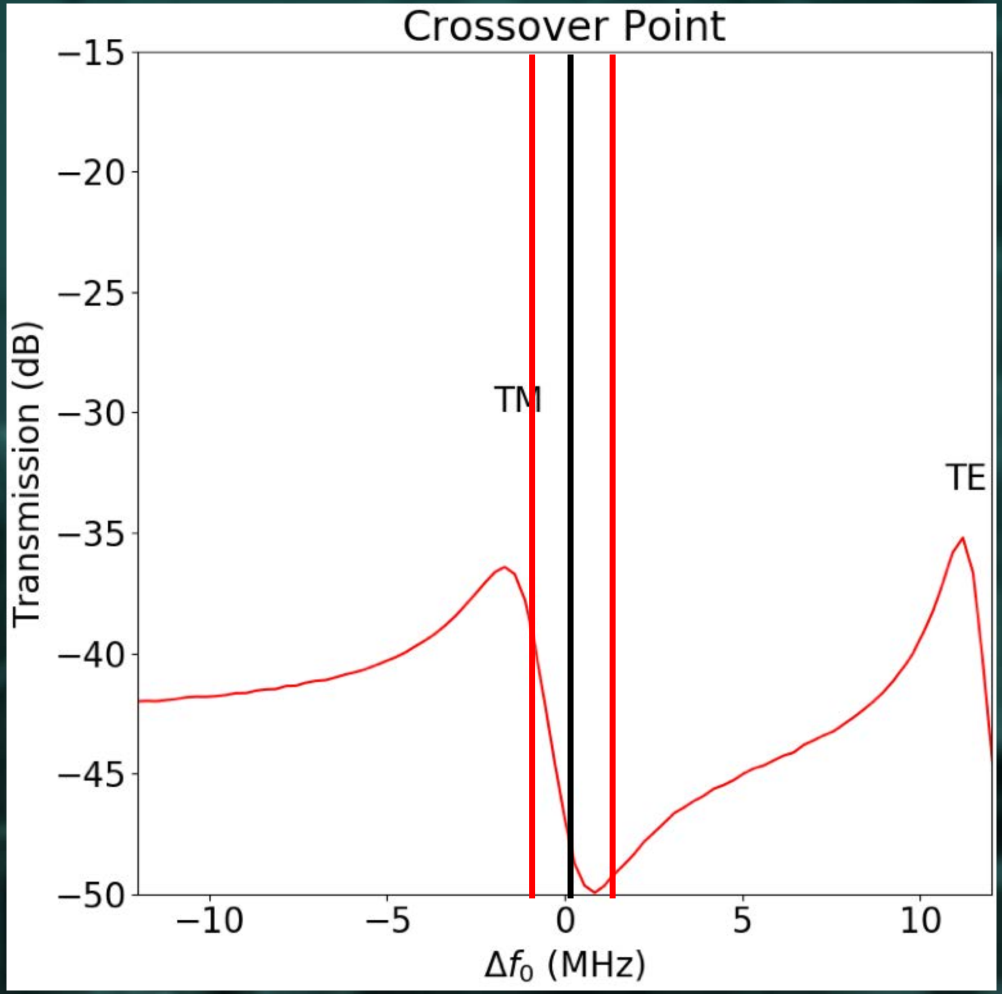
δf and Mode Orthogonality? Calculate overlap v tuning

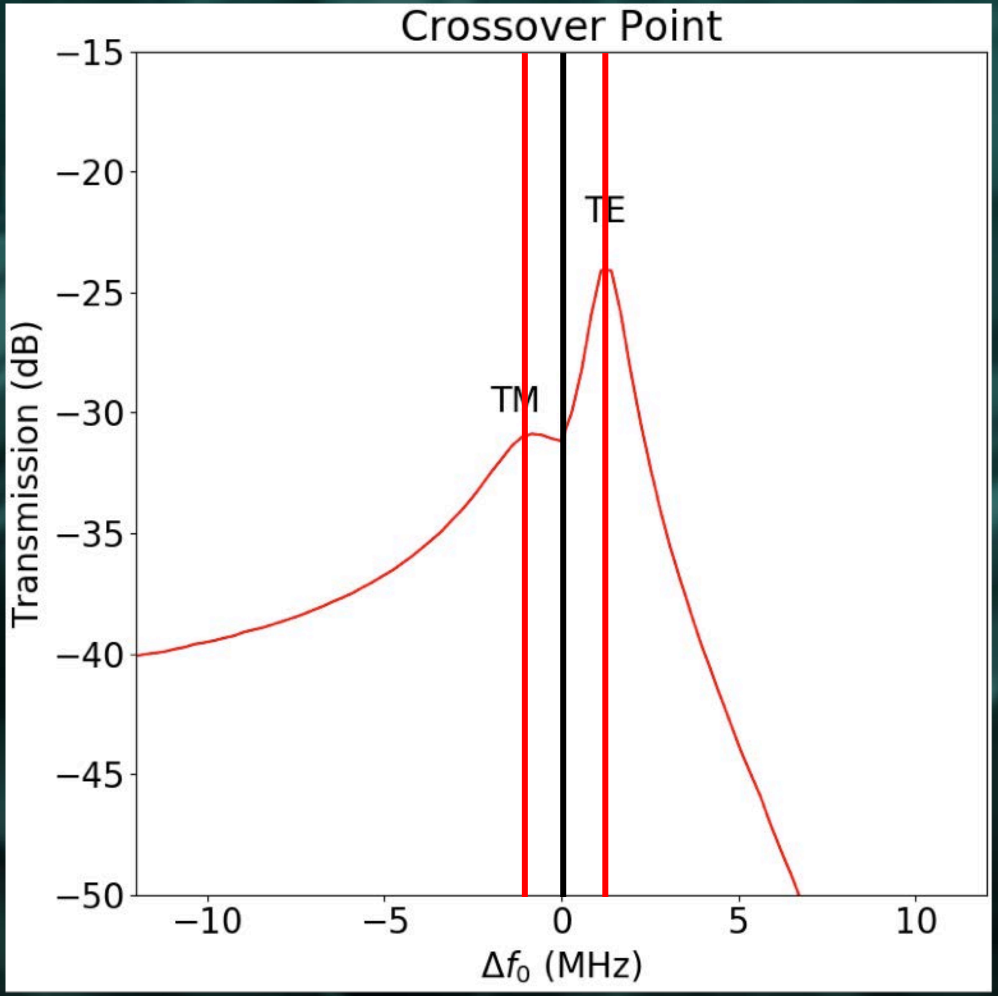
$-1 \quad 1$

Non Lorentzian line shape distorts phase noise

Problems for Ultralight Axions

$\delta f = 2MHz$





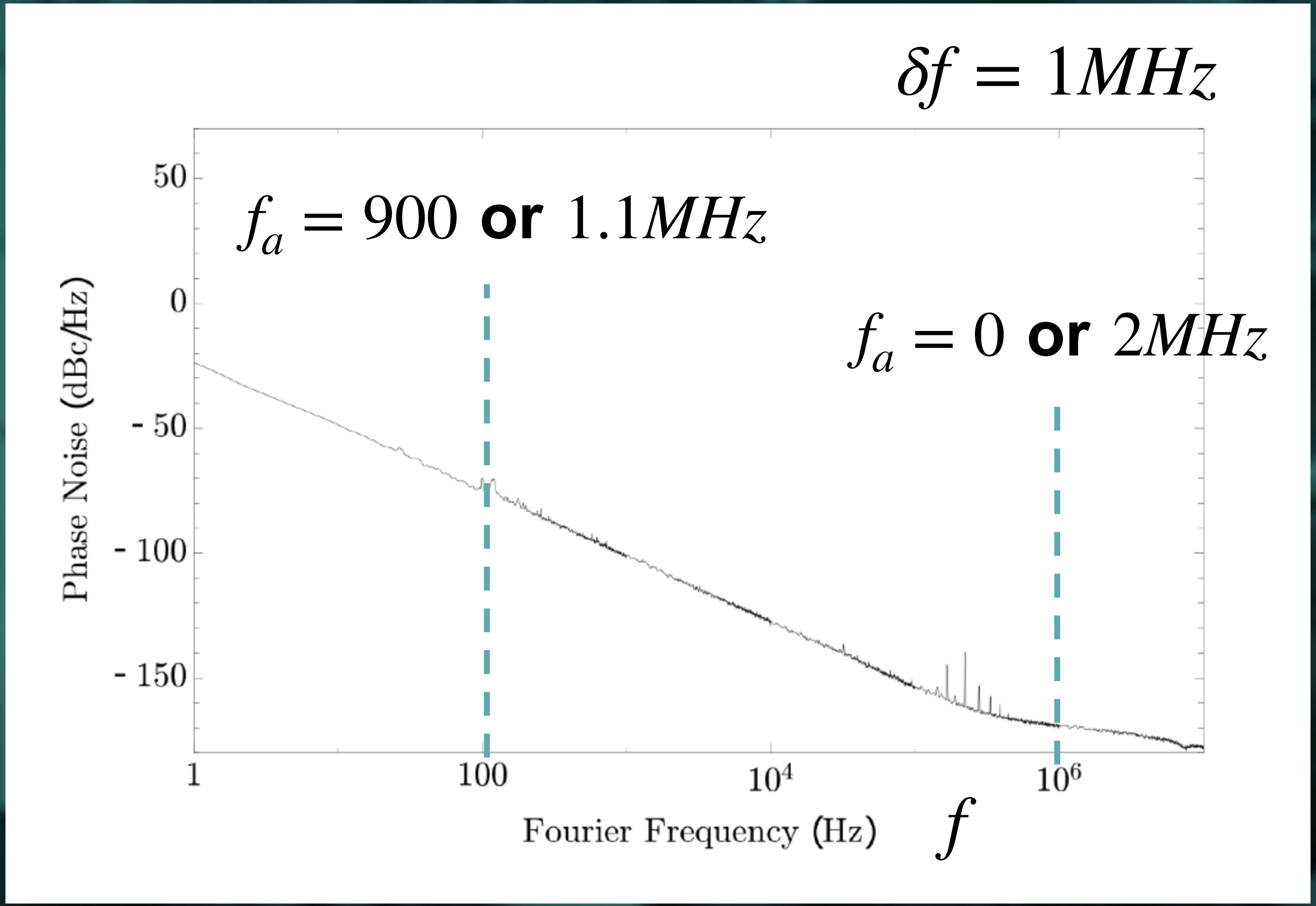
δf and Mode Orthogonality? Calculate overlap v tuning

$-1 \quad 1$

Non Lorentzian line shape distorts phase noise

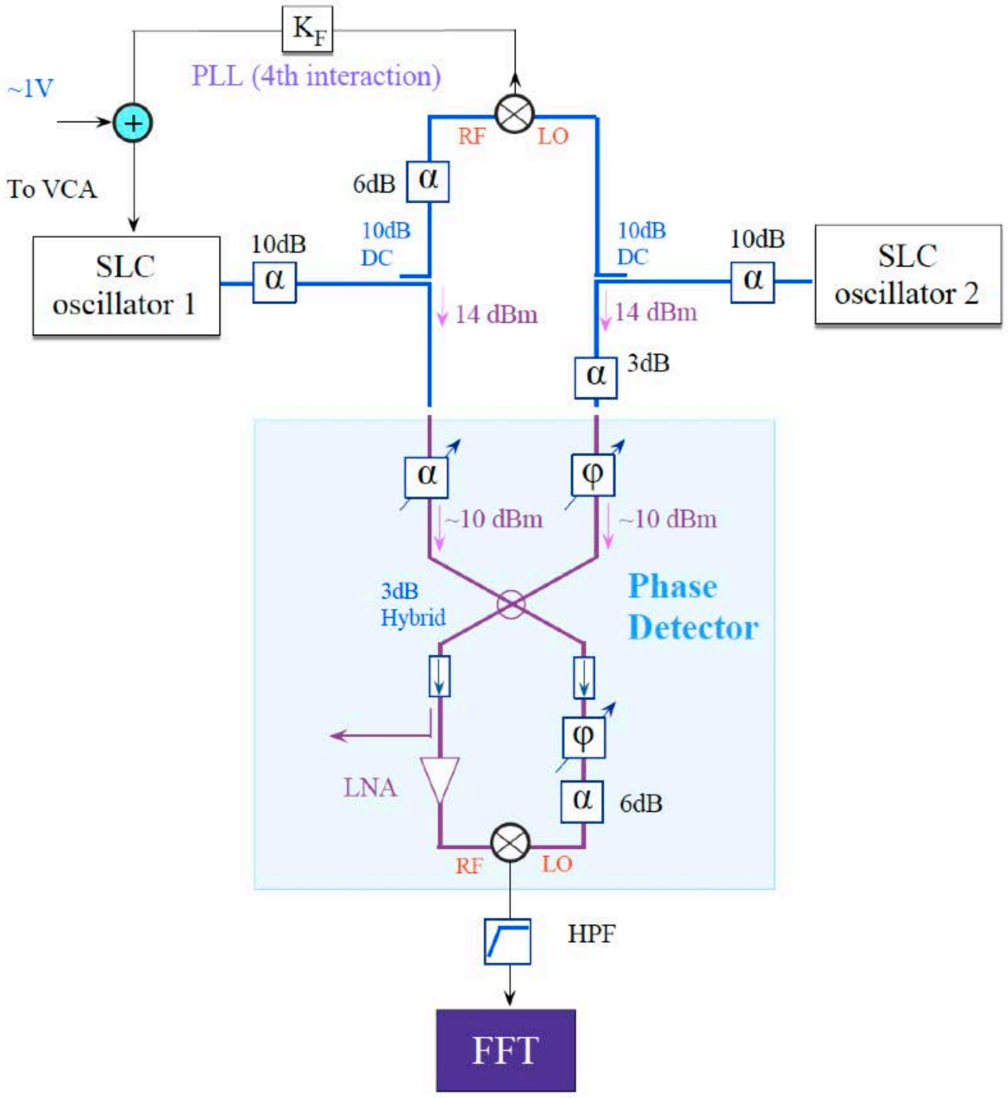
Ultralight Axions: Frequency and Power technique

$$f_a = \delta f \pm f$$



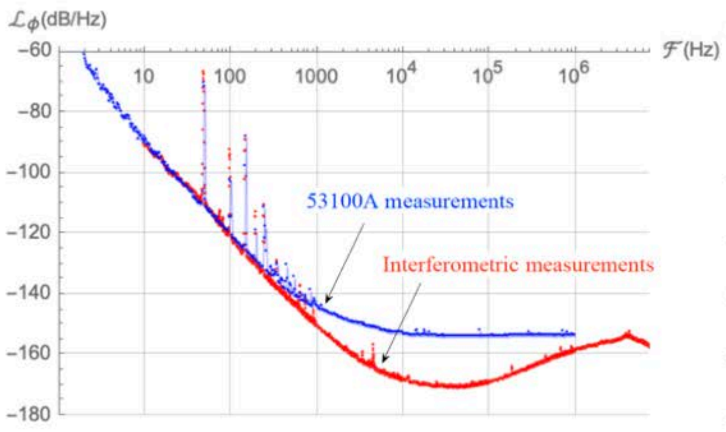
Interferometric Phase Noise Measurements Syste

$$\delta f = 0$$

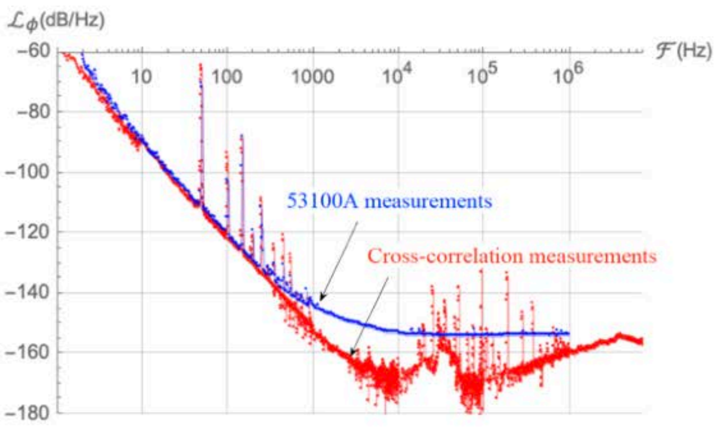


Results of Phase Noise Measurements

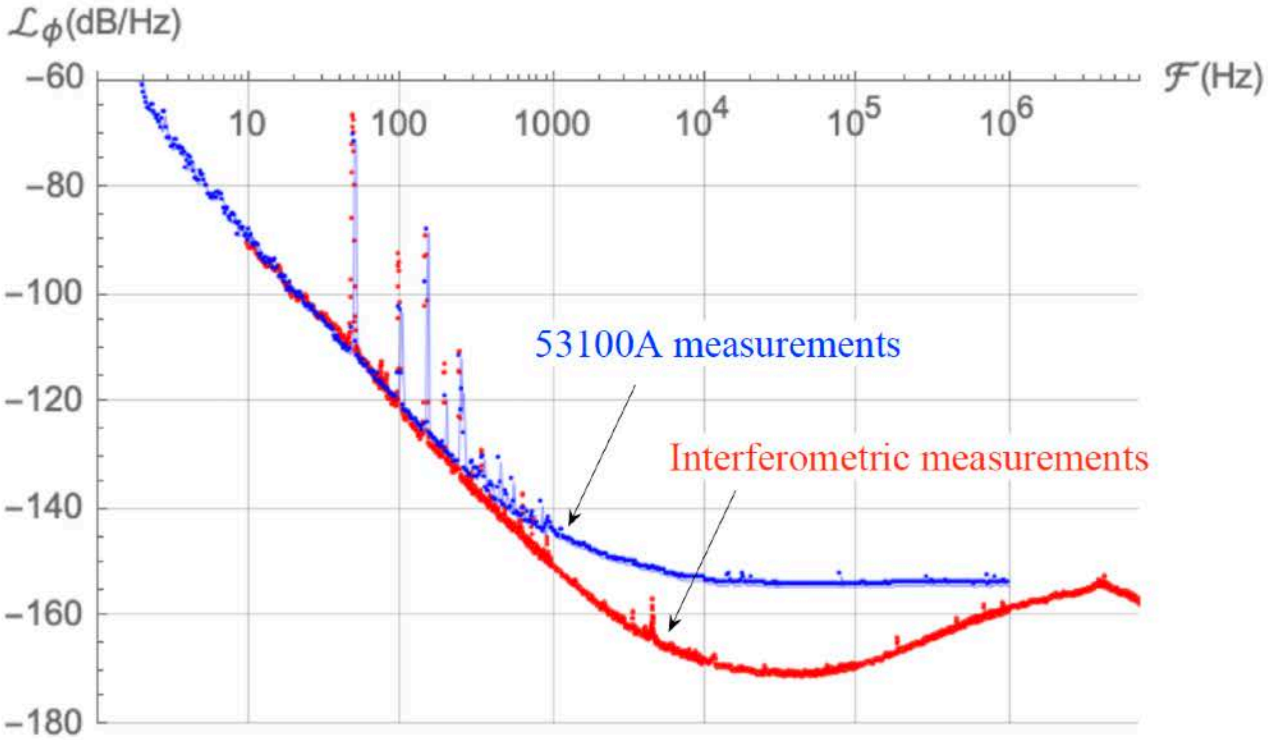
$$\delta f = 2MHz$$



SSB phase noise of an individual 9 GHz oscillator:
53100A (f_{beat} ~ 2 MHz) vs Interferometric detection



SSB phase noise of an individual 9 GHz oscillator:
53100A (f_{beat} ~ 2 MHz) vs Cross-correlation detection



SSB phase noise of an individual 9 GHz oscillator:
53100A (f_{beat} ~ 2 MHz) vs Interferometric detection

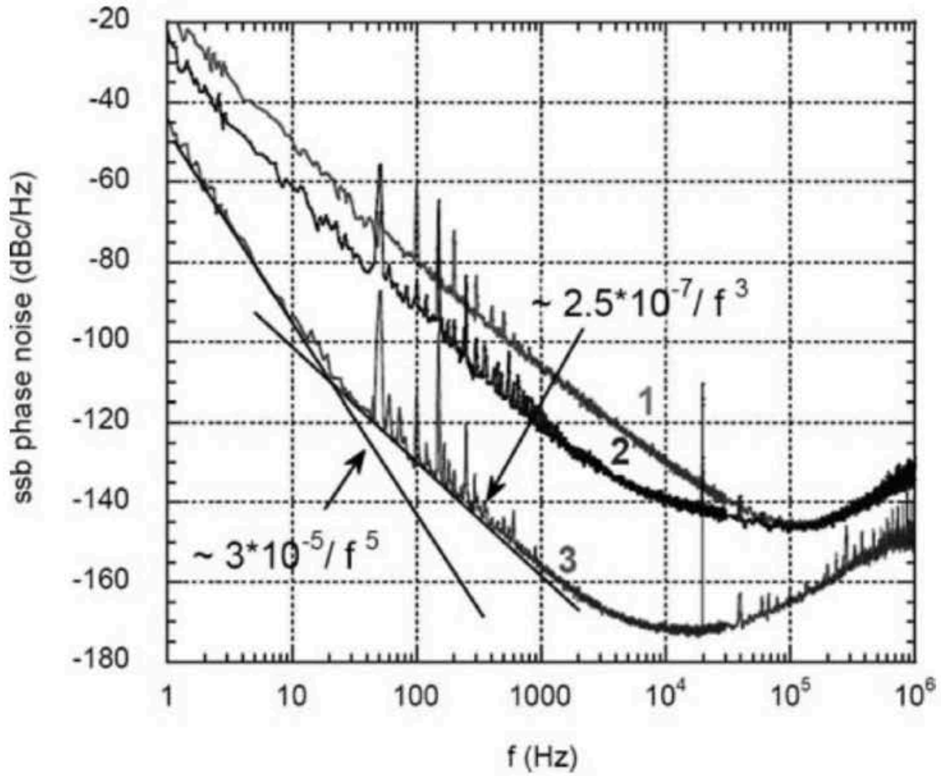


Fig. 9. The SSB phase-noise spectra of a high-power microwave oscillator in different modes of operation: (a) free-running oscillator, (b) free-running oscillator with an additional phase control system, and (c) frequency-stabilized oscillator.

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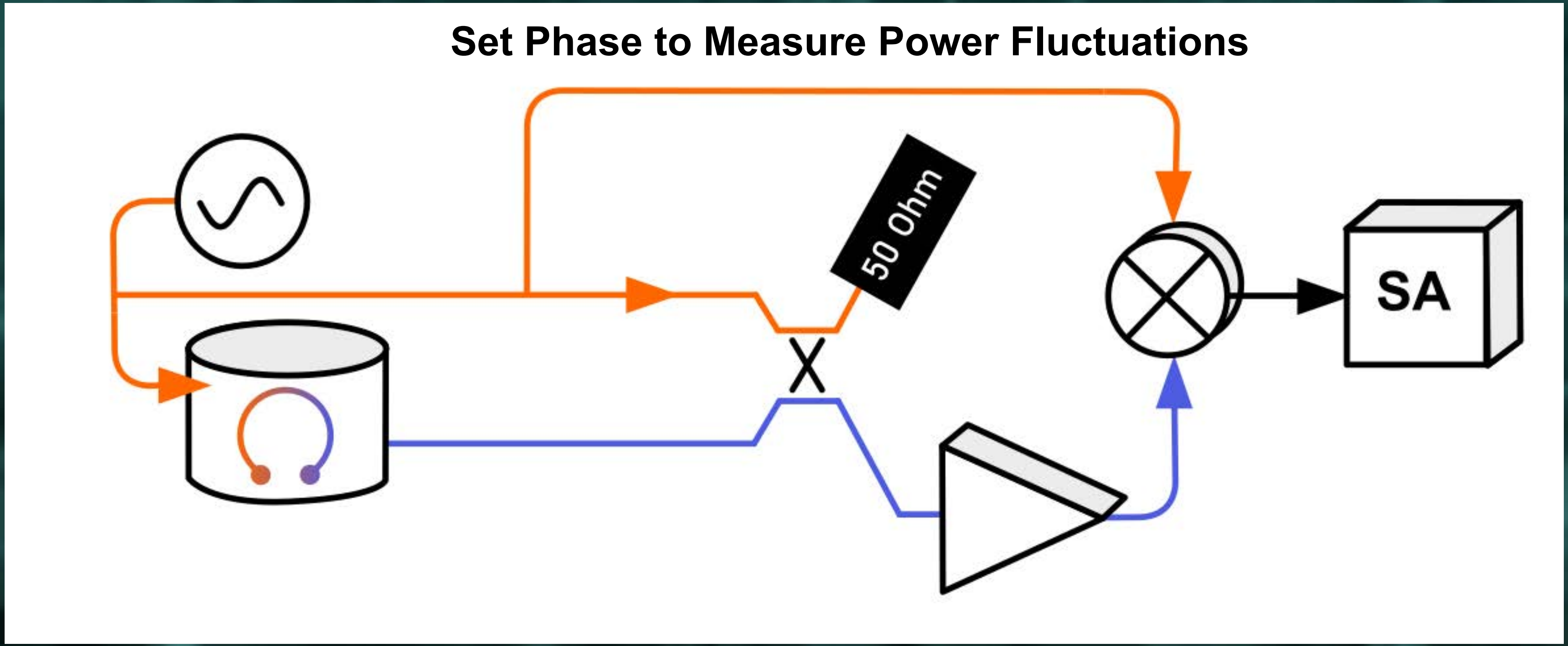
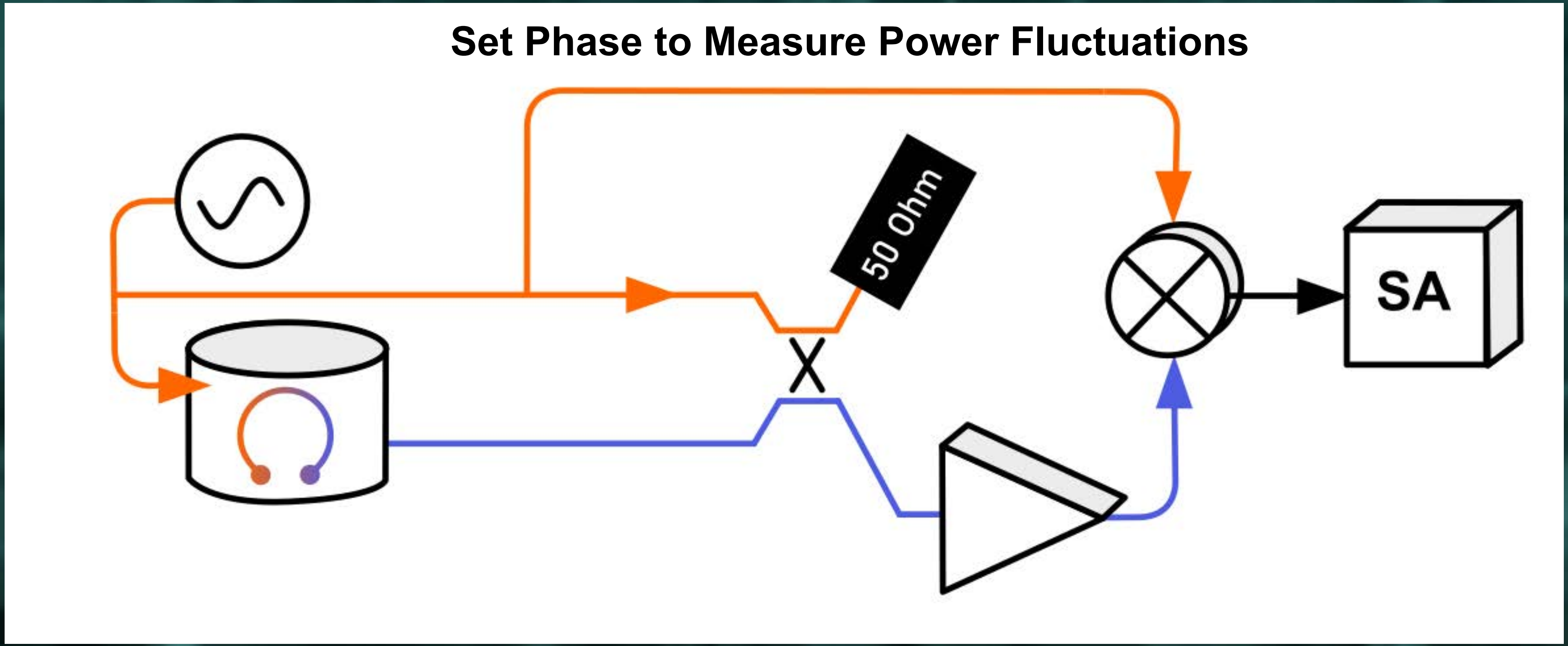
Low Phase-Noise Sapphire Crystal Microwave Oscillators: Current Status

Eugene N. Ivanov and Michael E. Tobar, *Senior Member, IEEE*

Proposal for Power Technique



Proposal for Power Technique

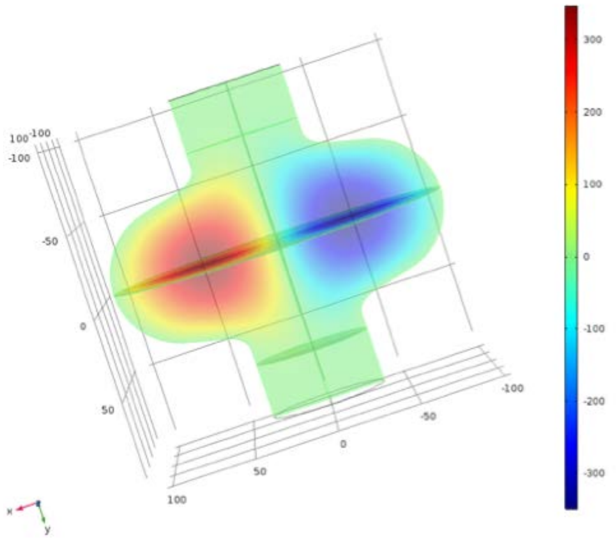


$$\omega_a = |\omega_1 - \omega_2| \pm \Omega \quad \text{where} \quad \Omega << \omega_1$$

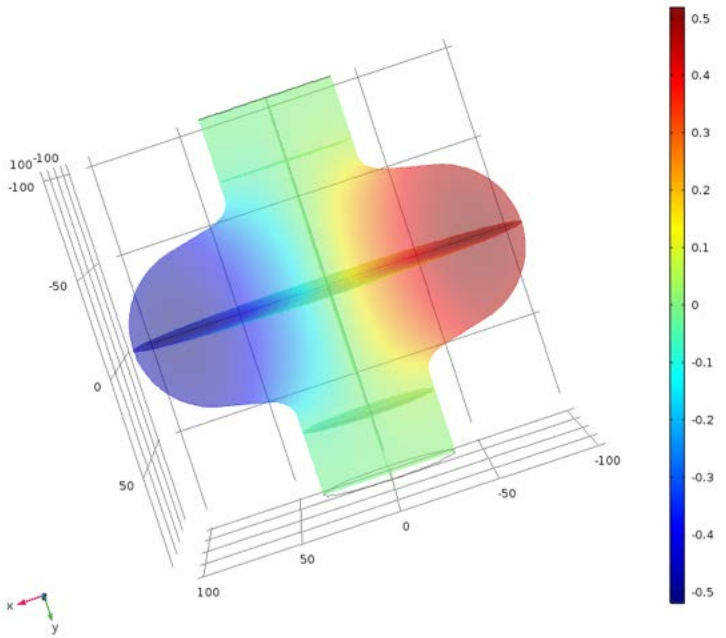
Cryogenic UPLOAD Experiment

Nb Tesla Cavities

TE 011 MODE, 2.5 GHz



TM 010 MODE, 1.3 GHz



We would like to gain interest from Fermilab to collaborate on this project and add to the LOI

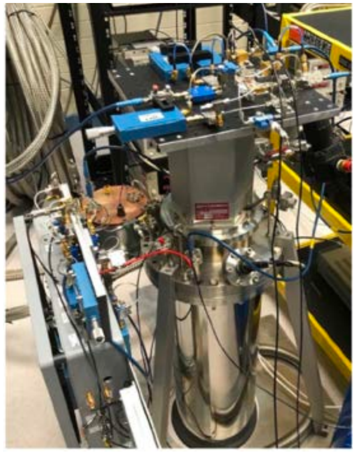
Sapphire Low Noise Oscillators under Development at UWA

Cryogenic Version Under development < -180 dBc/Hz.

IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, VOL. 31, NO. 4, APRIL 2021

Noise Suppression With Cryogenic Resonators

Eugene N. Ivanov and Michael E. Tobar, *Fellow, IEEE*



$Q_L = 10^9$

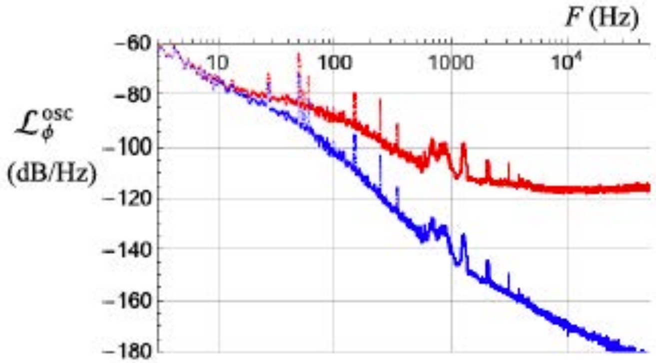


Fig. 7. SSB phase noise spectra of the E8257D at 11.2 GHz: top trace is the measured phase noise of the incident signal; bottom trace is the inferred phase noise of the transmitted signal.

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Low Phase-Noise Sapphire Crystal Microwave Oscillators: Current Status

Eugene N. Ivanov and Michael E. Tobar, *Senior Member, IEEE*

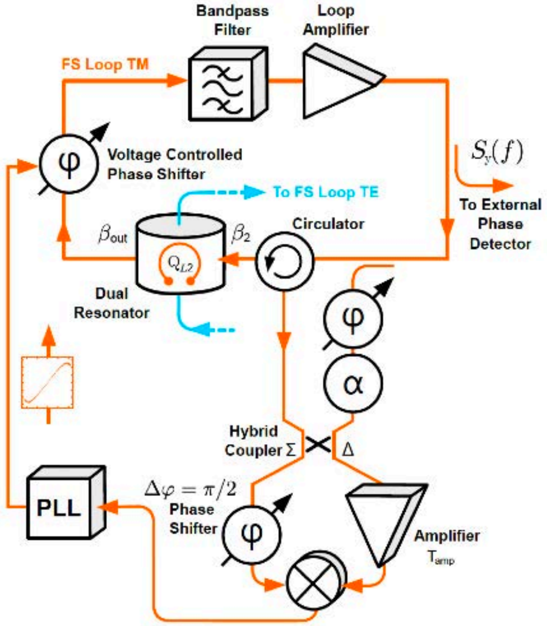


FIG. 5: Schematic of a frequency stabilized (FS) feedback oscillator with interferometric signal processing.

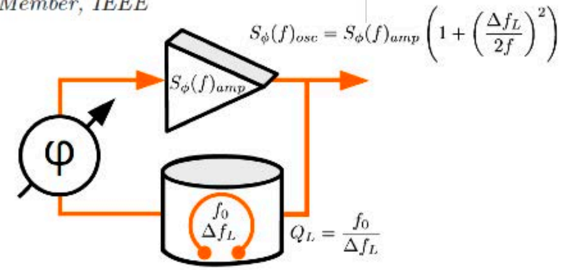
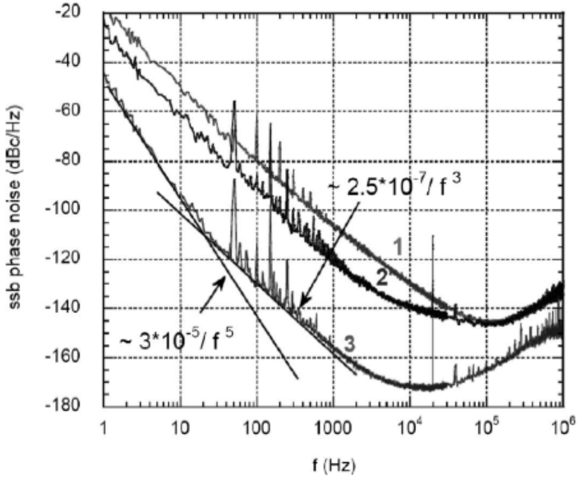


FIG. 4: Schematic of a simple feedback oscillator, with resonator loaded Q-factor Q_L, and amplifier phase noise of $S_\phi(f)_{amp}$. Shown is the simple relation to the oscillator phase noise, $S_\phi(f)_{osc}$.



E. N. Ivanov and M. E. Tobar, "Noise Suppression with Cryogenic Resonators," in

CA Thomson, BT McAllister, M Goryachev, EN Ivanov, ME Tobar, "Upconversion Loop Oscillator Axion Detection Experiment: A Precision Frequency Interferometric Axion Dark Matter Search with a Cylindrical Microwave Cavity," Phys. Rev. Lett., vol. 126, 081803, 2021.

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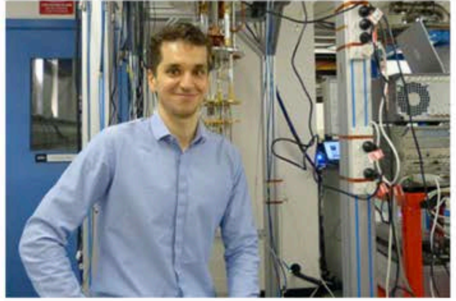

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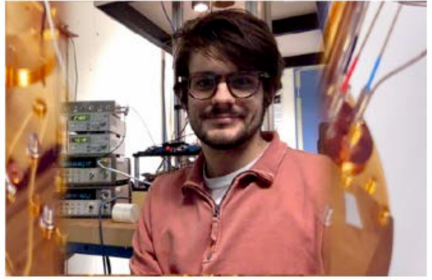

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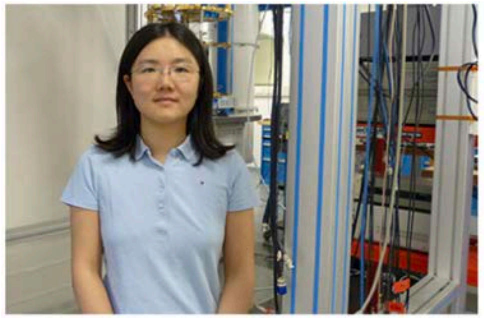

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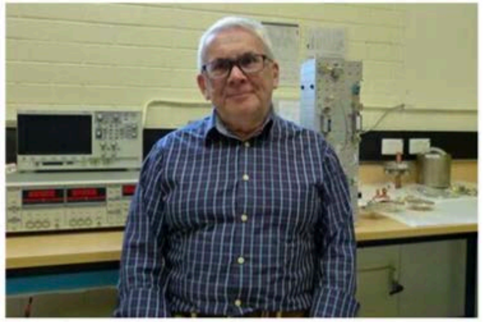

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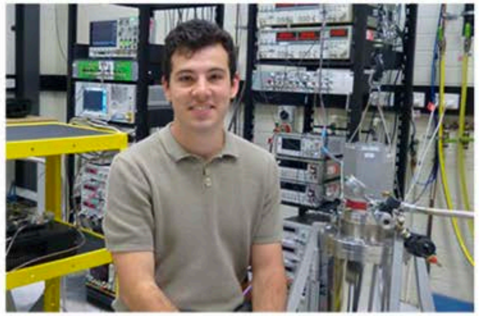

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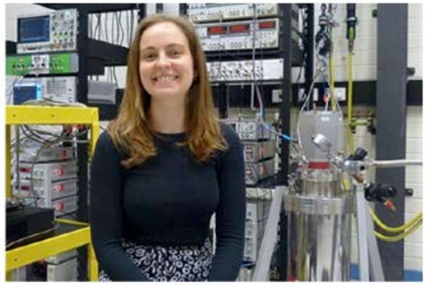

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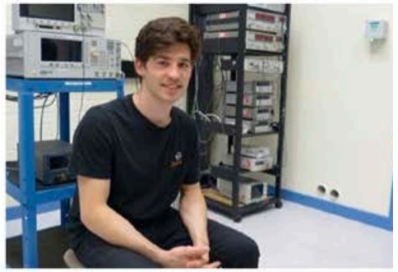

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Michael Hatzon
BPhil (Hons)Placement

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