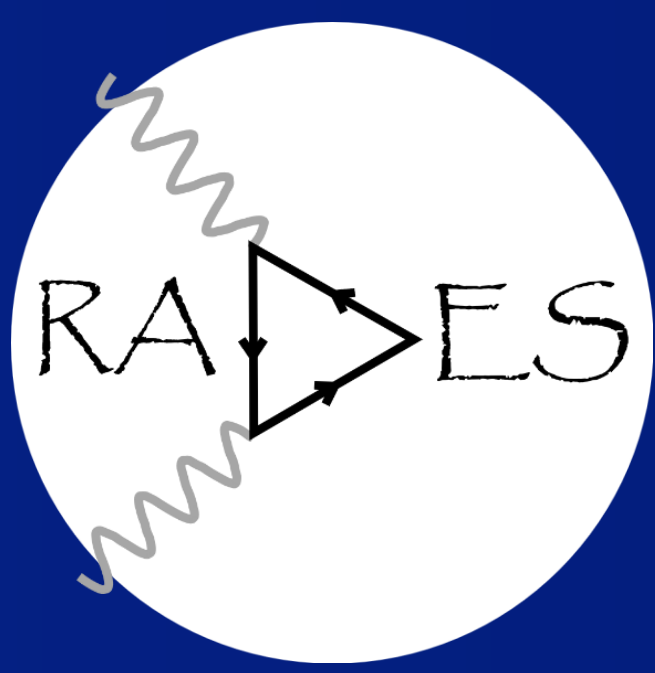
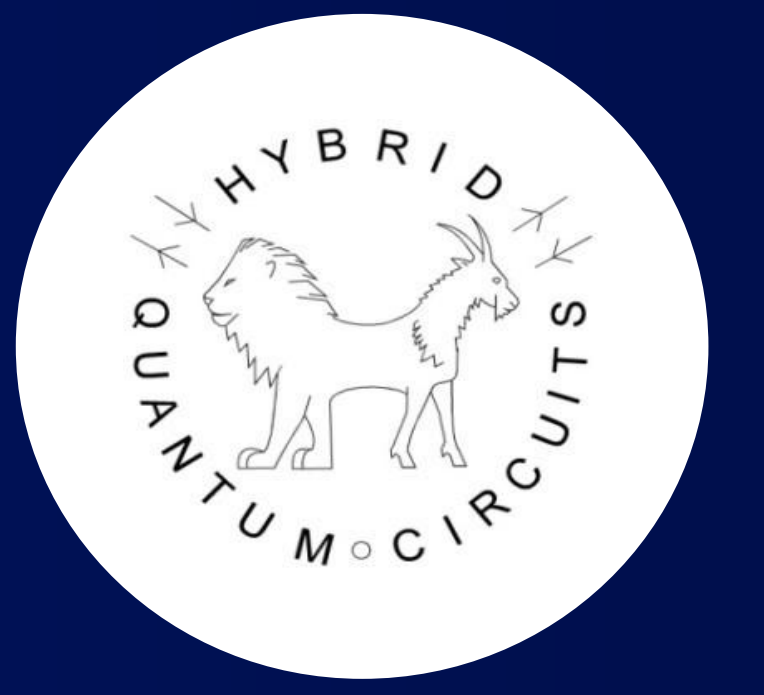




Phase resolved haloscope at LPENS Paris

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École Supérieure de Physique et de Chimie Industrielles (ESPCI)
RADES collaboration



Axions and haloscopes

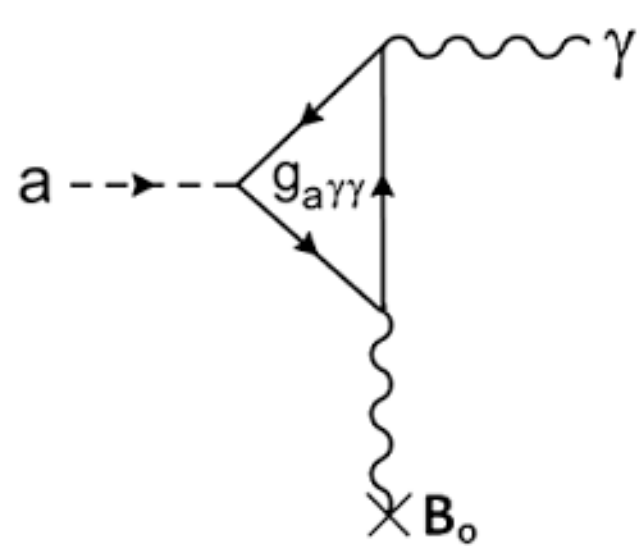
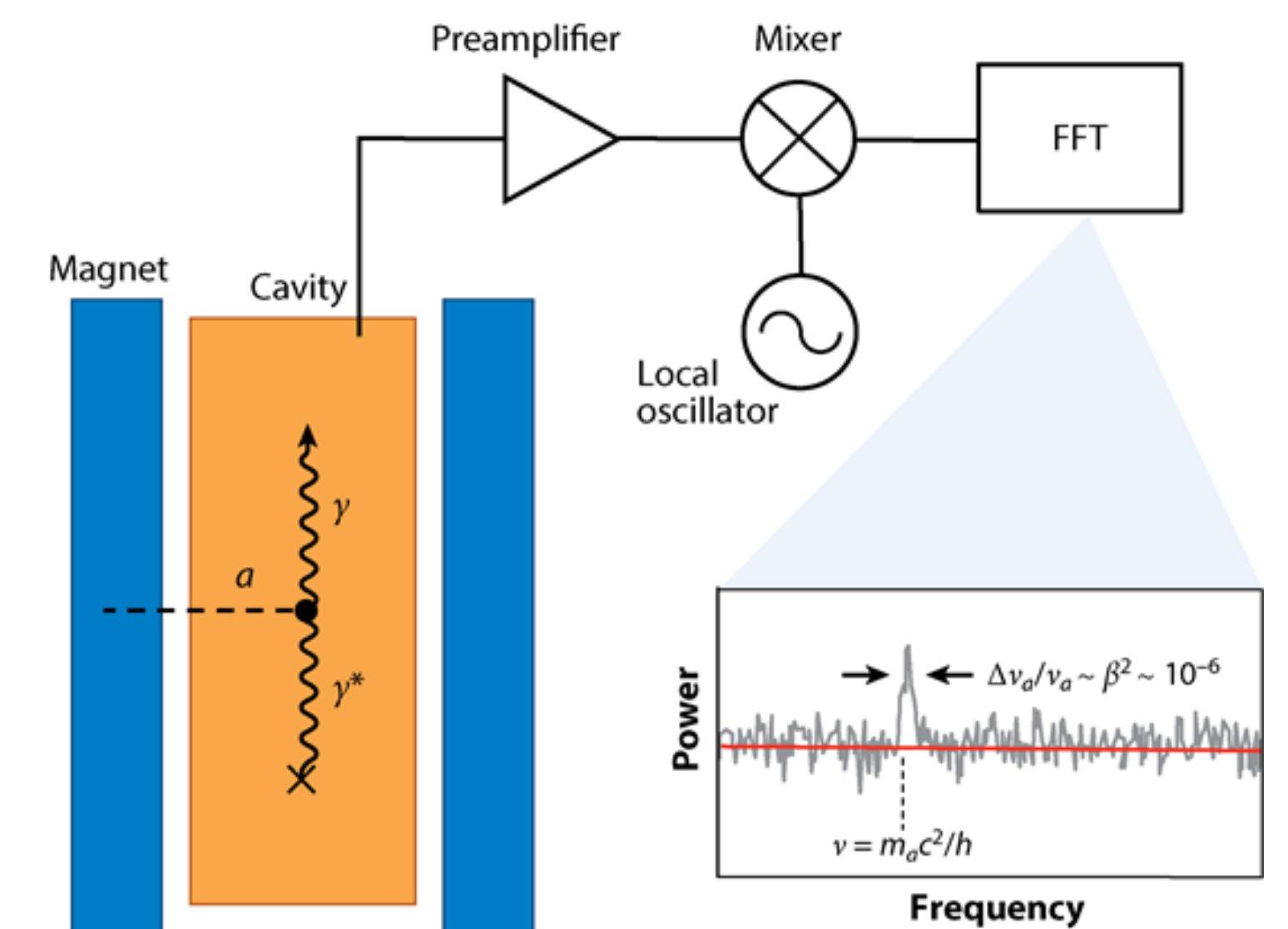


Diagram of the Primakoff effect (a-γ coupling)

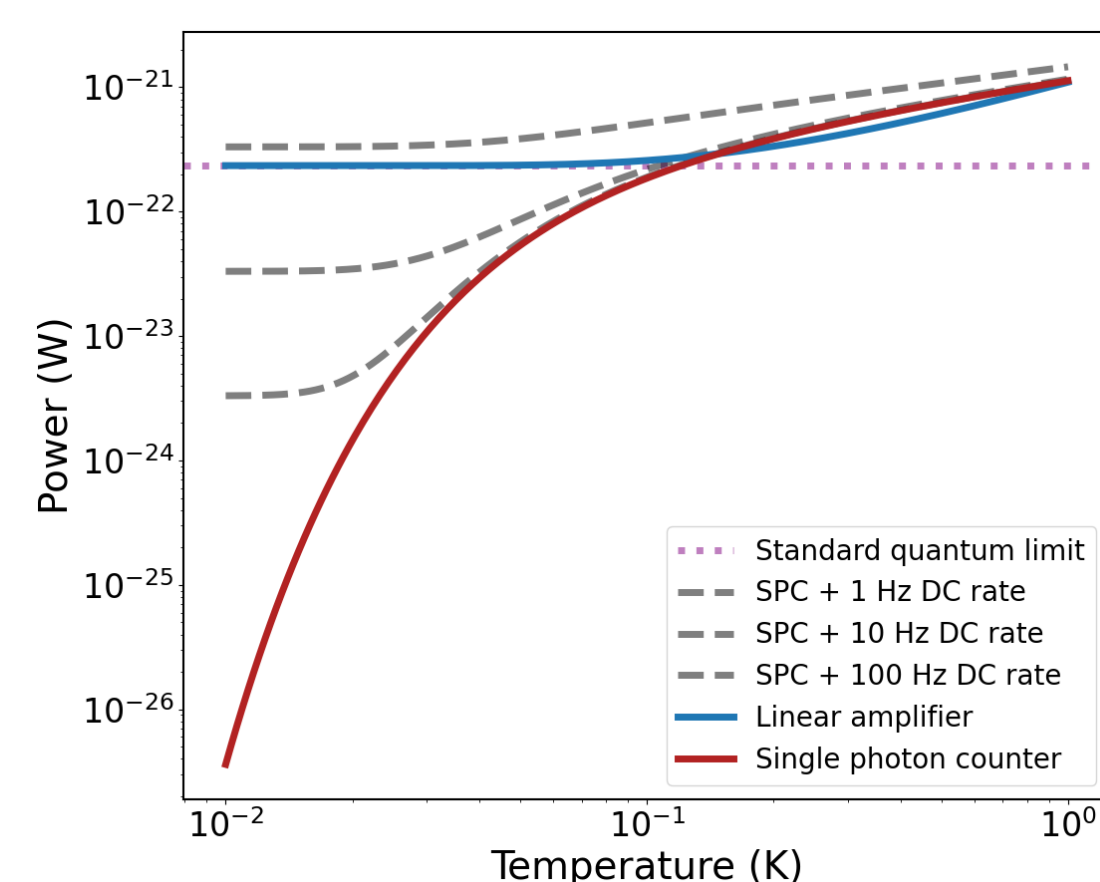
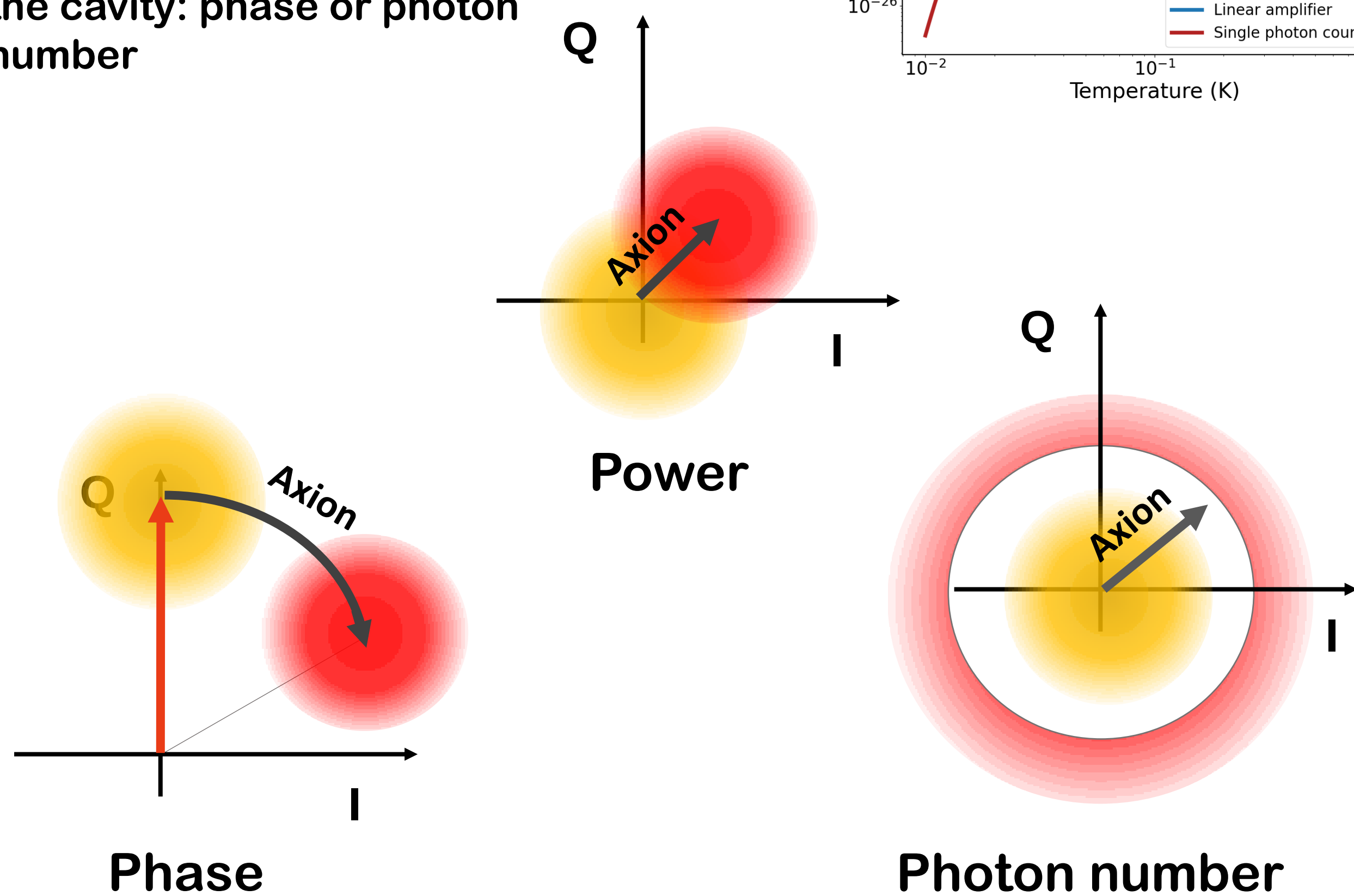
$$\mathcal{L}_{a\gamma\gamma} \propto g_{a\gamma} a \vec{E} \cdot \vec{B}_e$$

- Solve two problems: strong CP and dark matter
- Dark matter candidates between 1 μeV and 1 meV
- Principle of detection: Primakoff effect
- Haloscope: resonant cavity in the MHz-GHz range inside a magnetic field.



Quantum readout

Overcome standard quantum limit:
Instead of measuring power
use another observable to
characterize the state of
the cavity: phase or photon
number



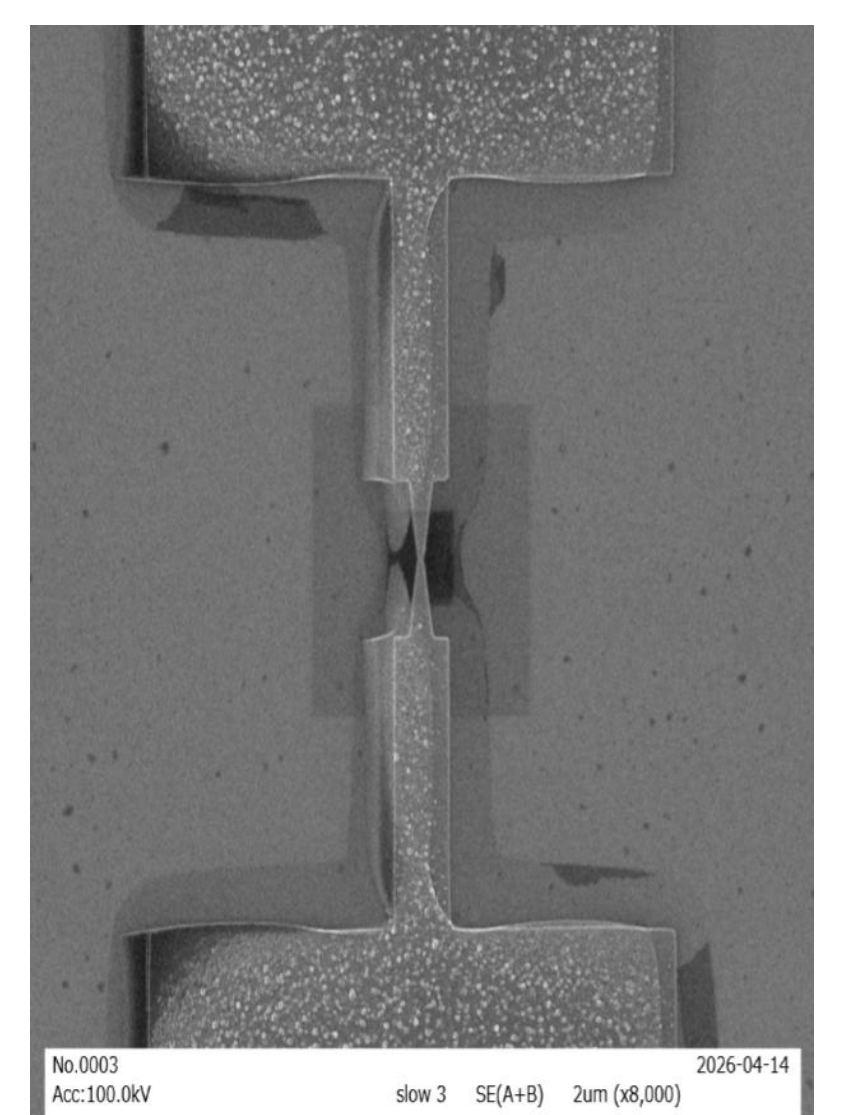
Phase haloscope

$$\Delta\omega_q = K [|\hat{a}|^2 + |\hat{a}_{ax}|^2 + 2|\hat{a}||\hat{a}_{ax}| \cos(\varphi_{ax})]$$

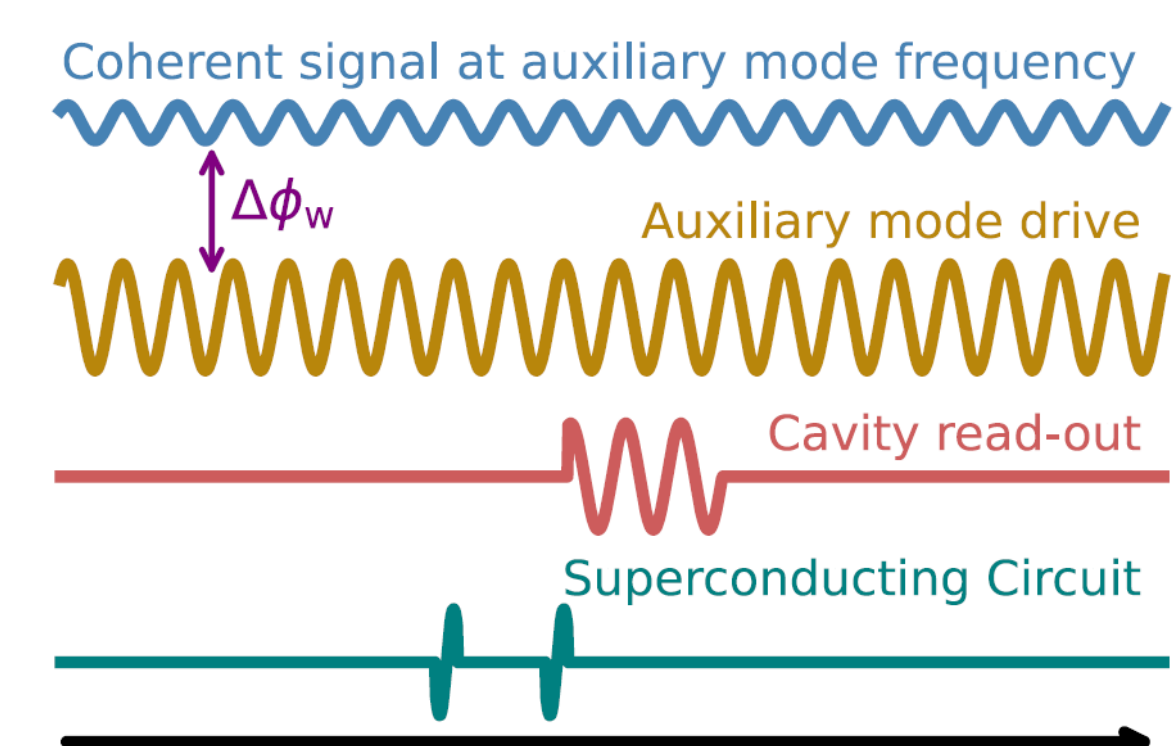
Interference term between pump ($\hat{a}$) and axion induced signal ($\hat{a}_{ax}$).
It shifts frequency of superconducting circuit ($\Delta\omega_q$).

• GrAI superconducting circuits

Anharmonicity of superconducting circuit allows
interference term ⁽¹⁾.
Cross – Kerr: $K \approx 200 \pm 50 \text{ kHz}$ ⁽²⁾
Granular aluminium to stand magnetic fields and
highly populated cavity states.



• Pulse sequence



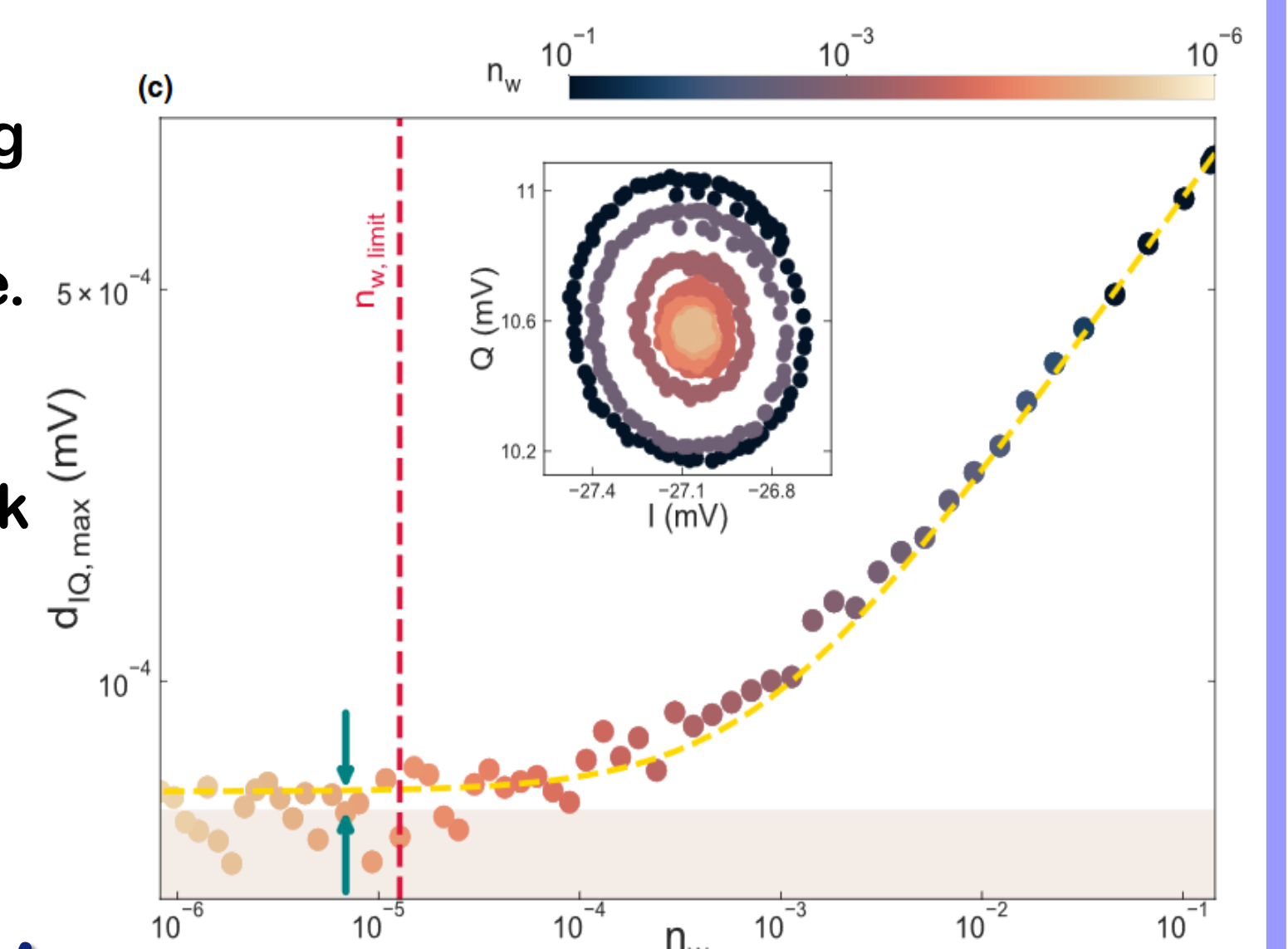
Pulse sequence:

- Continuous reference tone and DM coherent signal at scanning mode (5.065 GHz).
- Cavity readout pulse (6.193 GHz).
- GrAI Ramsey sequence (5.919 GHz).

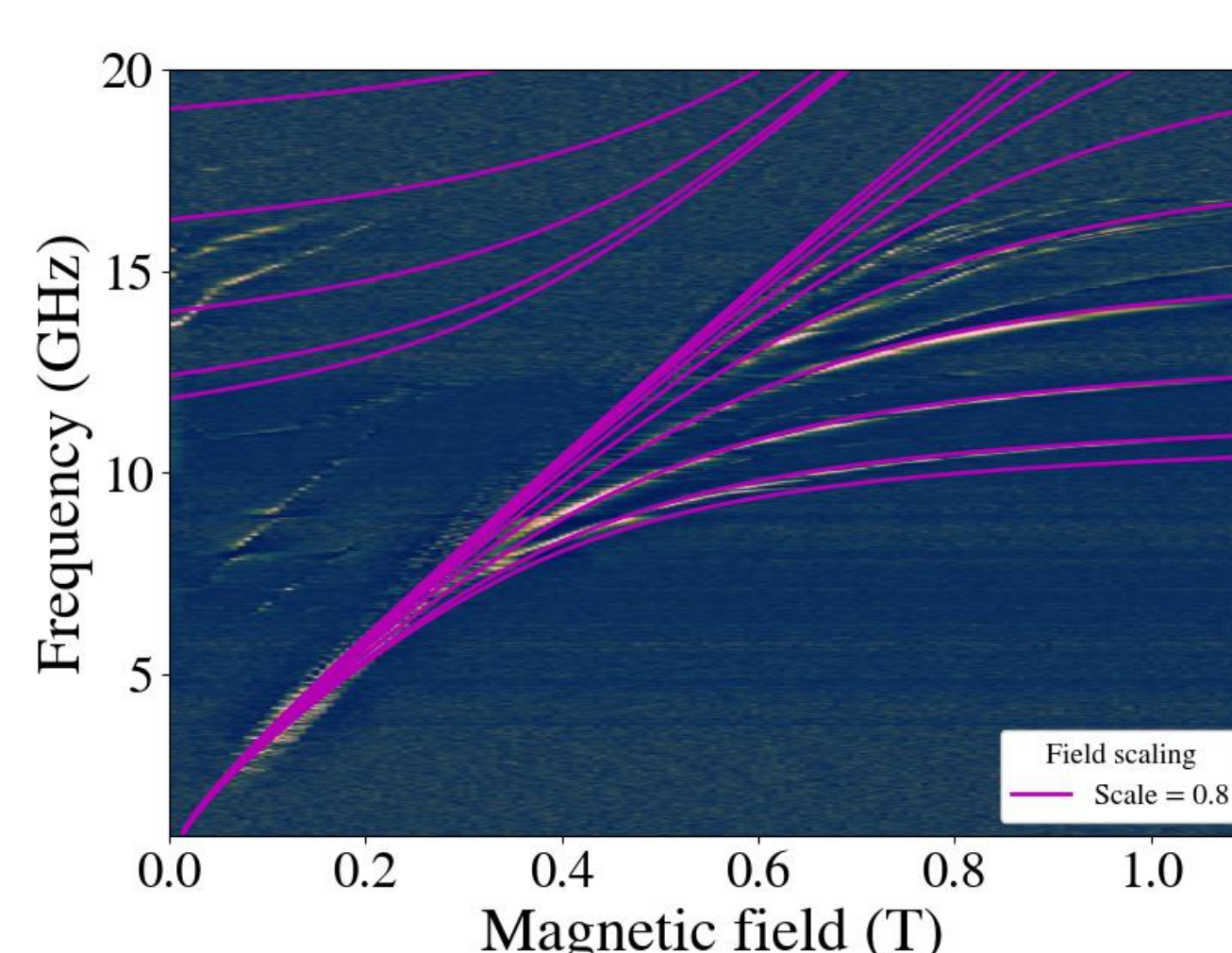
Power sensitivity achieved in calibrations of $S_p = 1.2 \cdot 10^{-22} \text{ W}/\sqrt{\text{Hz}}$ ⁽²⁾⁽³⁾

Calibration:

- Fake axion signal with decreasing amplitude.
- Injected signal with known phase.
- Same mode for scanning and reading out the state.
- Every point is the average of 100k traces of 4 us each (400ms integration time).



• Magnetic tunability



YIG crystal in a resonant cavity.

Magnetic field to tune gyromagnetic modes in YIG crystal.

Simulations ongoing to identify axion mode.

Sensitivity prospects

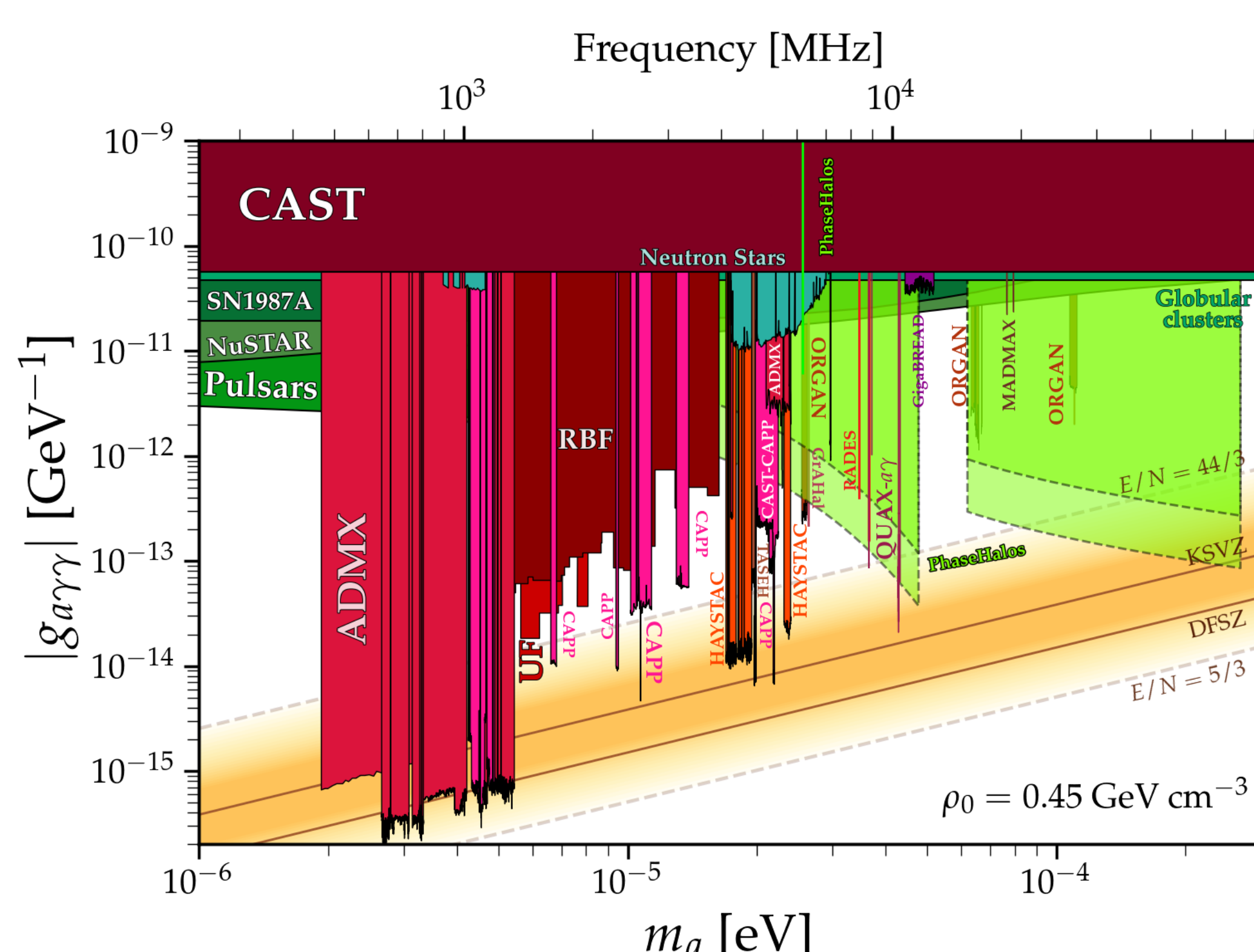
For 90% C.L. $\rightarrow \text{SNR} = 1.28$

$$\text{SNR} = \frac{P_{sig}}{\sigma_{noise}} = \frac{P_{sig}}{S_p} \sqrt{t}$$

Axion prospects ⁽⁴⁾:

$$P_{sig} = g^2 \frac{\rho}{m_a} B^2 V G Q \frac{\beta}{1 + \beta}$$

Parameter	Value
S_p	$1.2 \cdot 10^{-22(23)} \text{ W}/\sqrt{\text{Hz}}$
Integration time (t)	10^3 s
V	30 cm^3
Q	10^5
B	0.2 T
G	0.5
β	2



(1) A. Cottet, T. Kontos, "Wide-mass-scanning-range setup and phase-resolved protocol for axion dark matter detection", New J. Phys. (2026)
(2) C. Fruy et al., "Time-domain nonlinear quantum interferometry", Physical Review A (2026)
(3) L. Balembois et al., "Cyclically operated microwave single-photon counter with sensitivity of $10^{-22} \text{ W}/\sqrt{\text{Hz}}$ ", Physical Review Applied (2024)
(4) C. O'Hare, "cajohare/AxionLimits: AxionLimits", 10.5281/zenodo.3932430, <https://cajohare.github.io/AxionLimits/>