CADEX: a new haloscope axion search from 330 to 460 μeV at the Canfranc Underground Laboratory (LSC)

Jordi Miralda-Escudé, on behalf of the CADEx Collaboration

ICREA, Institut de Ciències del Cosmos (Universitat de Barcelona)

miralda@icc.ub.edu

with special thanks to Alicia Gómez (CAB) and Bradley Kavanagh (IFCA) for help with this talk

COST Action COSMIC WISPers, Second General Meeting, Istanbul Sept. 3rd 2024.

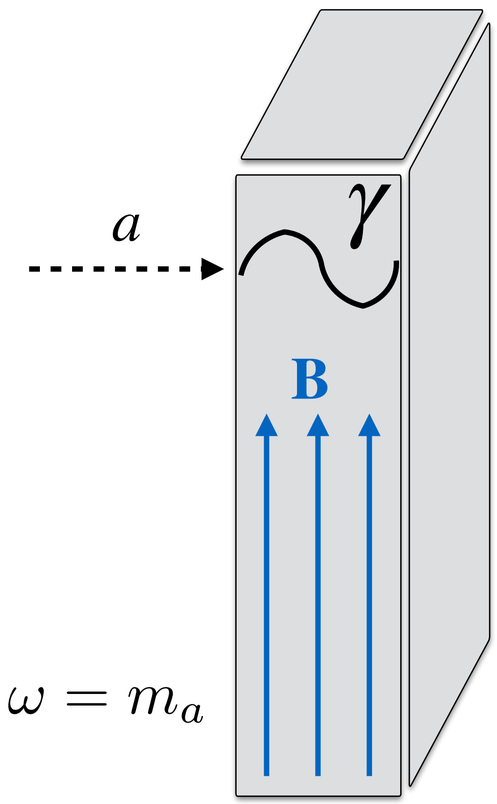
MINISTERIO DE CIENCIA E INNOVACIÓN
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
AGENCIA ESTATAL DE INVESTIGACIÓN

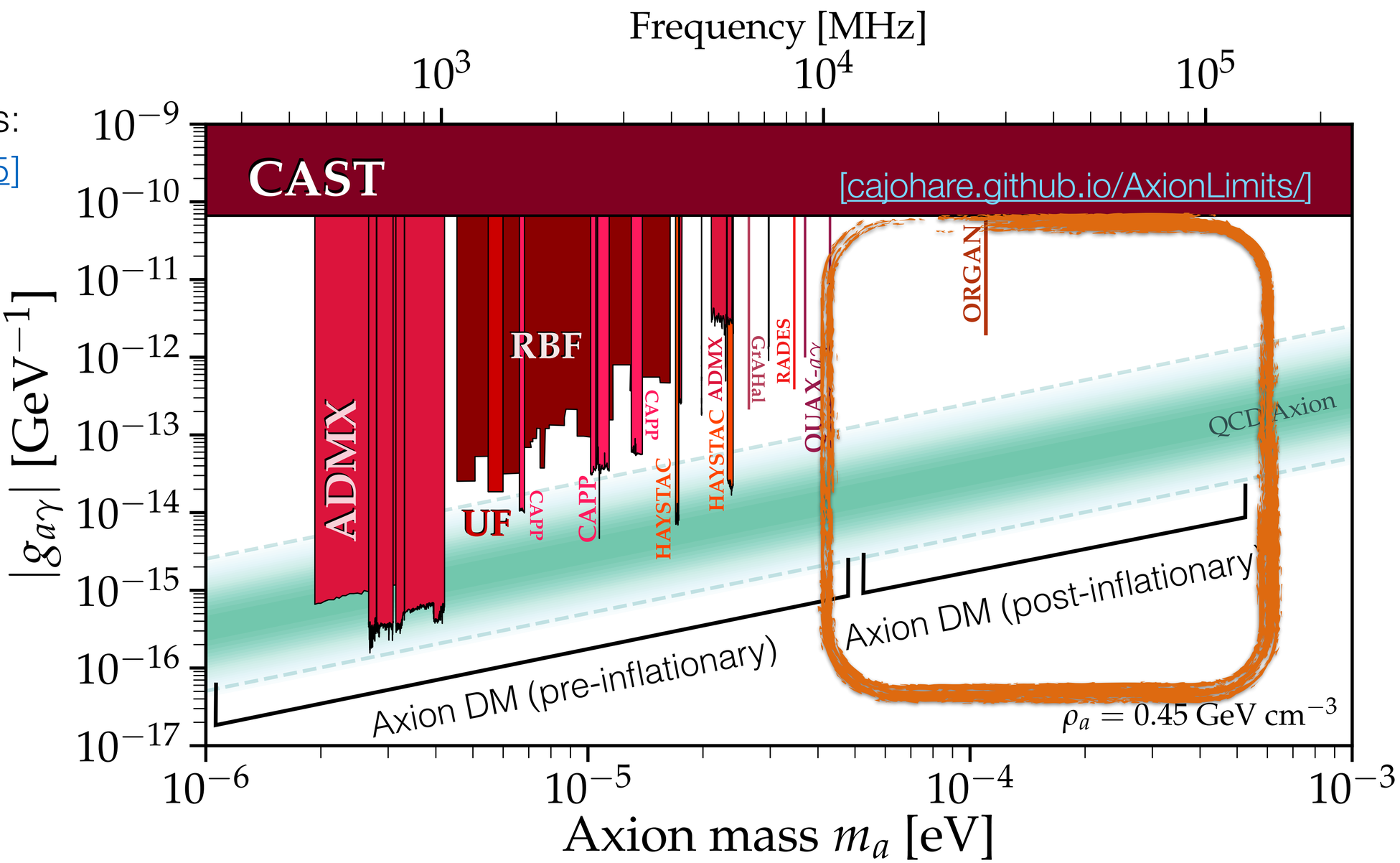
The QCD Axion

Axions, a, are light pseudo-scalar particles proposed to solve the Strong CP problem of QCD, and natural cold Dark Matter candidates!

The window 20 to 200 GHz is difficult but theoretically interesting (e.g. Saikawa+ 2024), and few experiments can explore it.

Microwave cavity or "**Haloscope**" Searches:
[2003.02206, 2105.04565]





[Pre-inflationary axion abundance: e.g. 1810.07192, 2003.01100]

[Post-inflationary axion abundance: e.g. 1412.0789, 1906.00967,2007.04990]

Motivation for CADEx:

Novel detection system for 330-460 μeV range (W-band):

Haloscope + Kinetic Inductance Detectors (KIDs)

Axion-photon conversion power:

$$P_d \propto g_{a\gamma}^2 \frac{\rho_a}{m_a} B^2 V Q_0$$

Estimate 5σ sensitivity:

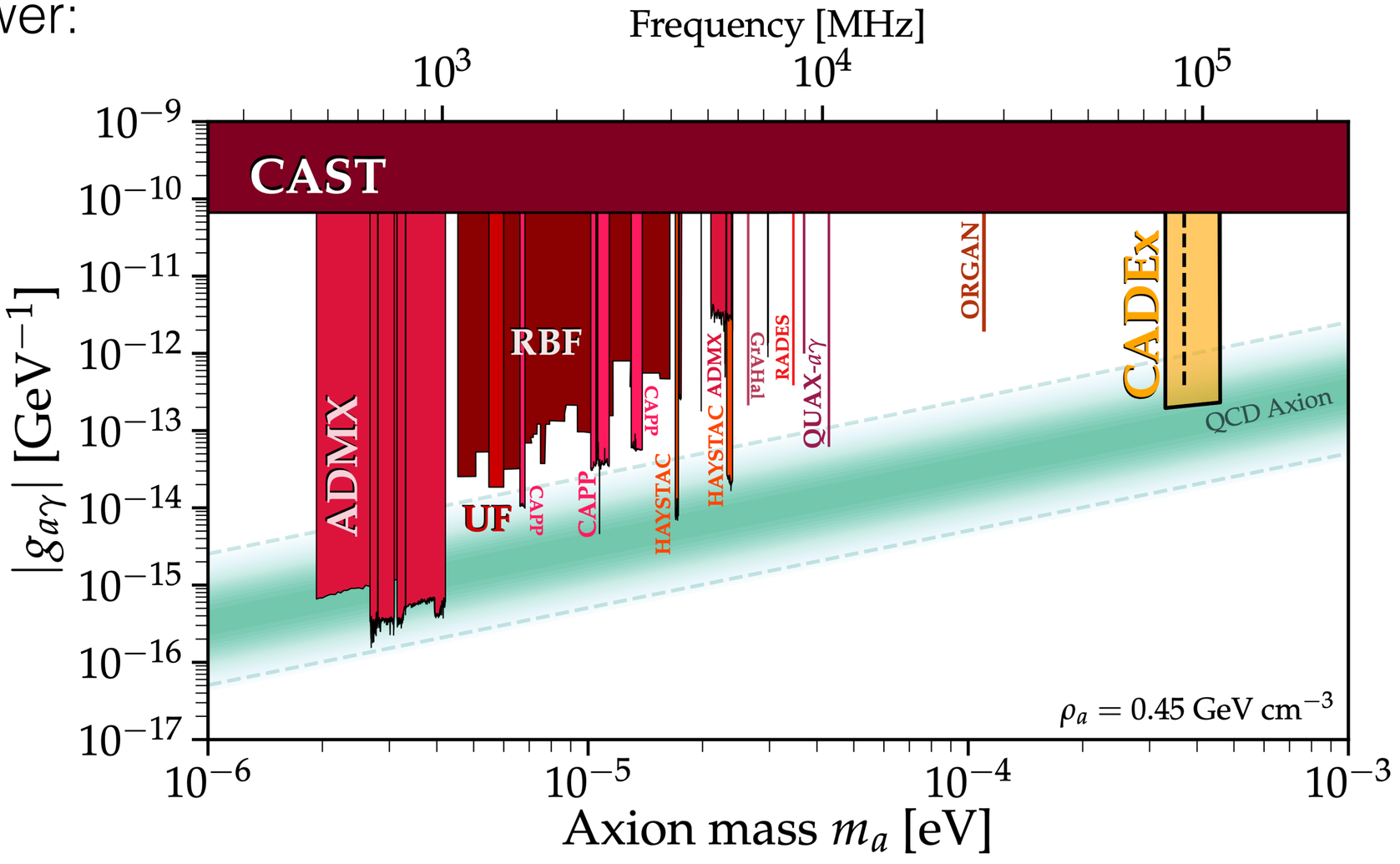
Magnetic field: $B = 8\mathrm{T}$

Total cavity volume:

$V = 0.2\mathrm{L}$

Cavity quality factor:

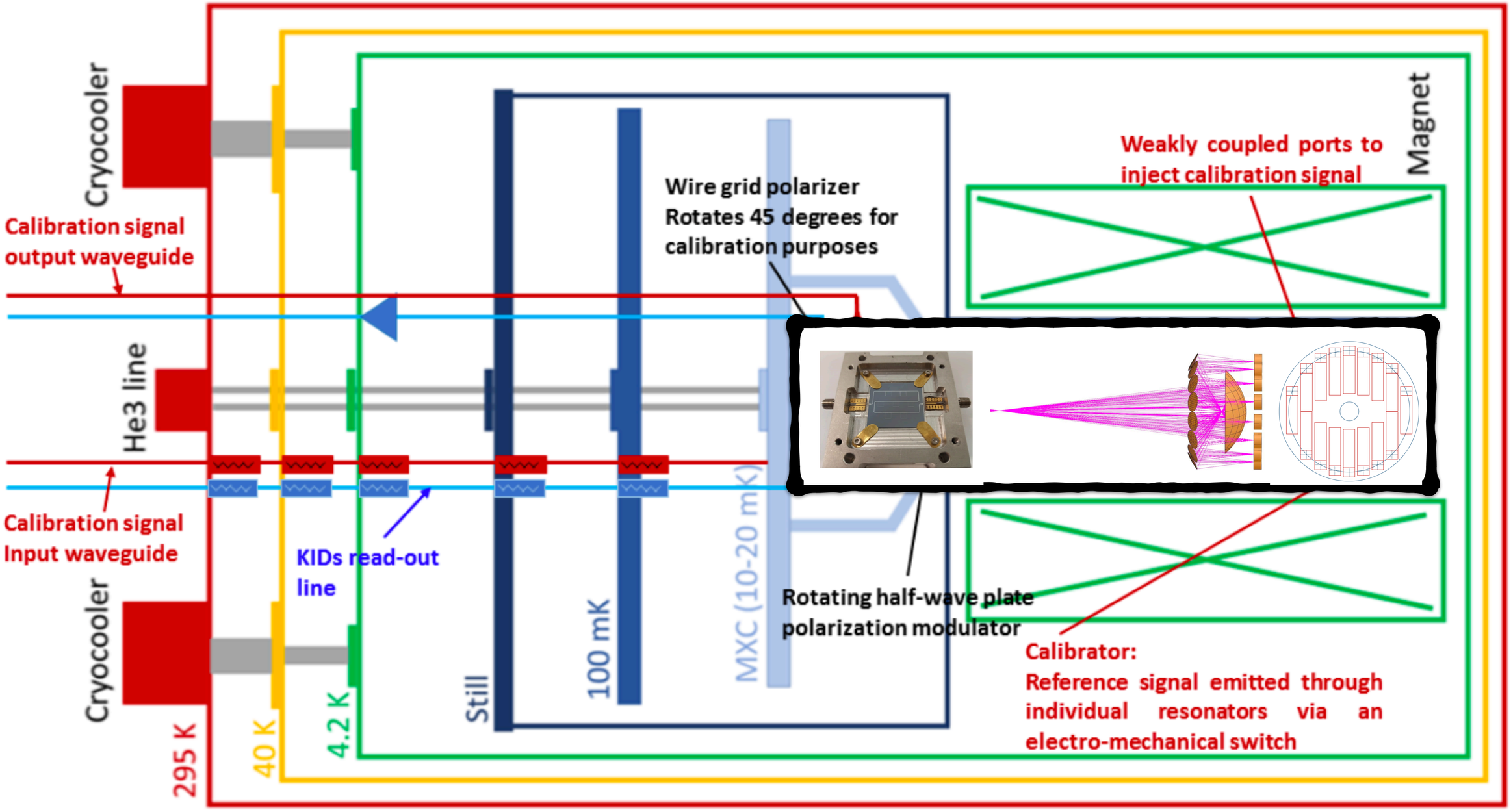
$Q_0 = 2 \times 10^4$



- - - - - - 3 month exposure with NEP = 10^{-19} W/$\sqrt{\mathrm{Hz}}$

——— 8 year scan with NEP = 3×10^{-20} W/$\sqrt{\mathrm{Hz}}$

CADEx Conceptual Design



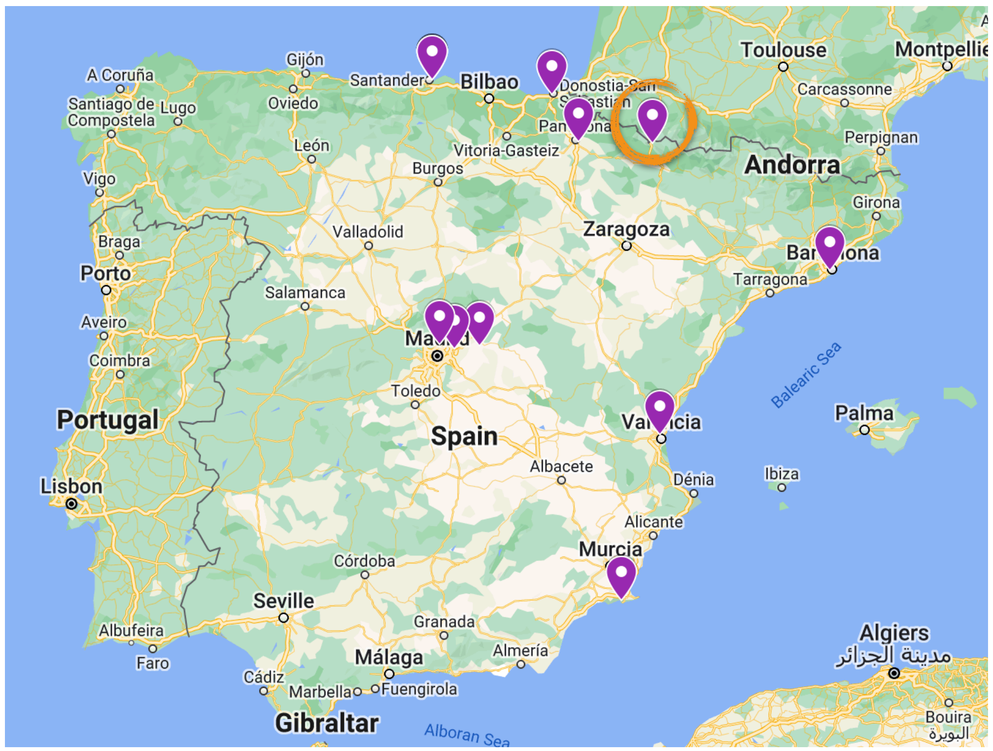
Immerse haloscope array in high static magnetic field of B = 8-10 T

Aim to **discriminate polarized axion-photon conversion signal** from unpolarized background.

The Canfranc Axion Detection Experiment (CADEx): search for axions at 90 GHz with Kinetic Inductance Detectors

Beatriz Aja,[a] Sergio Arguedas Cuendis,[b] Ivan Arregui,[c] Eduardo Artal,[a] R. Belén Barreiro,[d] Francisco J. Casas,[d] Marina C. de Ory,[e] Alejandro Díaz-Morcillo,[f] Luisa de la Fuente,[a] Juan Daniel Gallego,[g] Jose María García-Barceló,[f] Benito Gimeno,[h] Alicia Gomez,[e] Daniel Granados,[i] Bradley J. Kavanagh,[d] Miguel A.G. Laso,[c] Txema Lopetegi,[c] Antonio José Lozano-Guerrero,[f] Maria T. Magaz,[e] Jesús Martín-Pintado,[e,*] Enrique Martínez-González,[d] Jordi Miralda-Escudé,[b,j] Juan Monzó-Cabrera,[f] Francisco Najarro de la Parra,[e] Jose R. Navarro-Madrid,[f] Ana B. Nuñez Chico,[k] Juan Pablo Pascual,[a] Jorge Pelegrin,[k] Carlos Peña Garay,[k] David Rodriguez,[e] Juan M. Socuéllamos,[d] Fernando Teberio,[l] Jorge Teniente,[c] Patricio Vielva,[d] Iván Vila,[d] Rocío Vilar[d] and Enrique Villa[e]

[JCAP 11 (2022) 044, arXiv:2206.02980]



Science
- Instituto de Ciencias del Cosmos (UB)
- Donostia International Physics Center
- Laboratorio Subterráneo de Canfranc
- Instituto de Física de Cantabria (CSIC-UC)

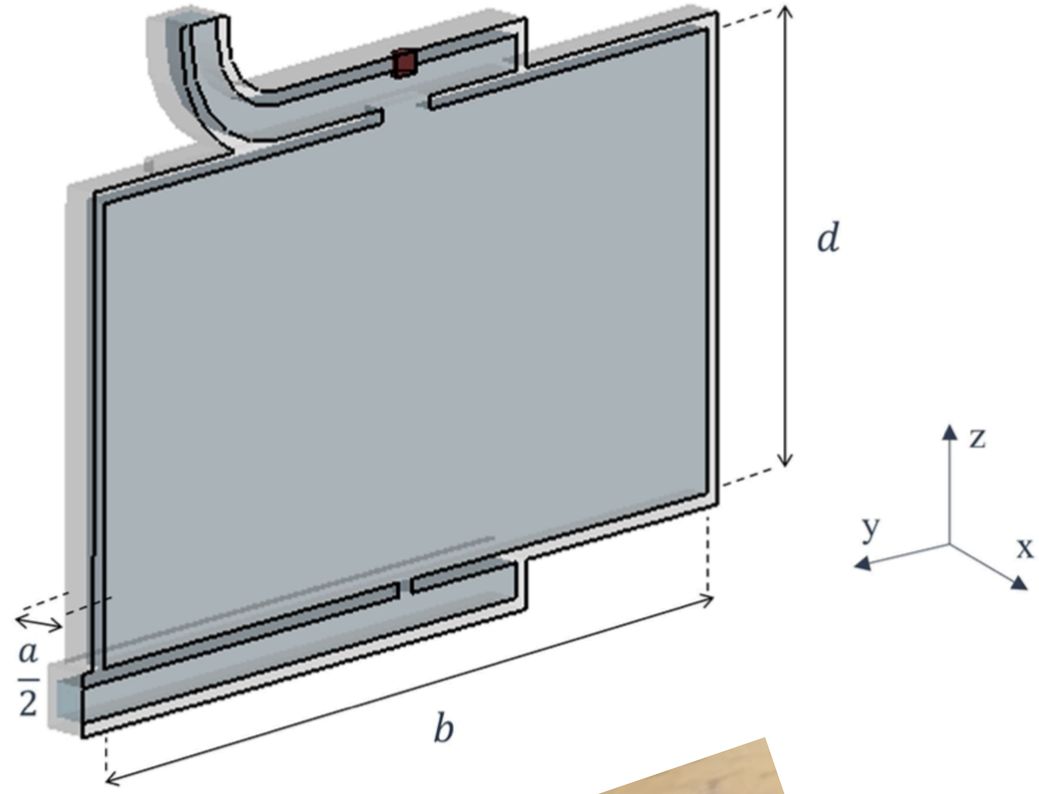
Haloscope
- Universidad Politécnica de Cartagena
- Instituto de Física Corpuscular (Universidad de Valencia, CSIC)

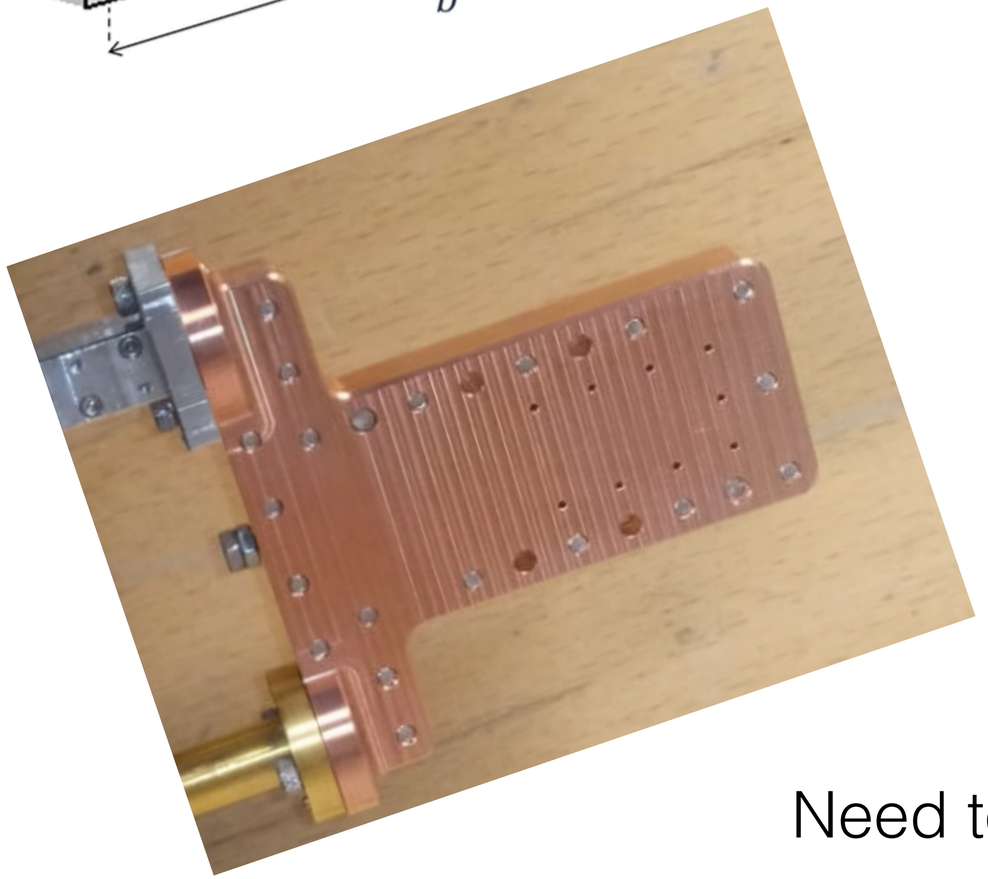
Optics
- Universidad Pública de Navarra
- Anteral S.L.

Detectors: Heterodyne & KIDs
- Observatorio de Yebes (IGN)
- Centro de Astrobiología (CSIC-INTA)
- Universidad de Cantabria
- Instituto de Física de Cantabria (CSIC-UC)
- Instituto Madrileño de Estudios Avanzados en Nanociencia

Calibration & data reduction
- Instituto de Ciencias del Cosmos (UB)
- Donostia International Physics Center
- Laboratorio Subterráneo de Canfranc
- Instituto de Física de Cantabria (CSIC-UC)
- Centro de Astrobiología (CSIC-INTA)

Haloscope





Need to scan over resonant frequency of haloscope cavity.

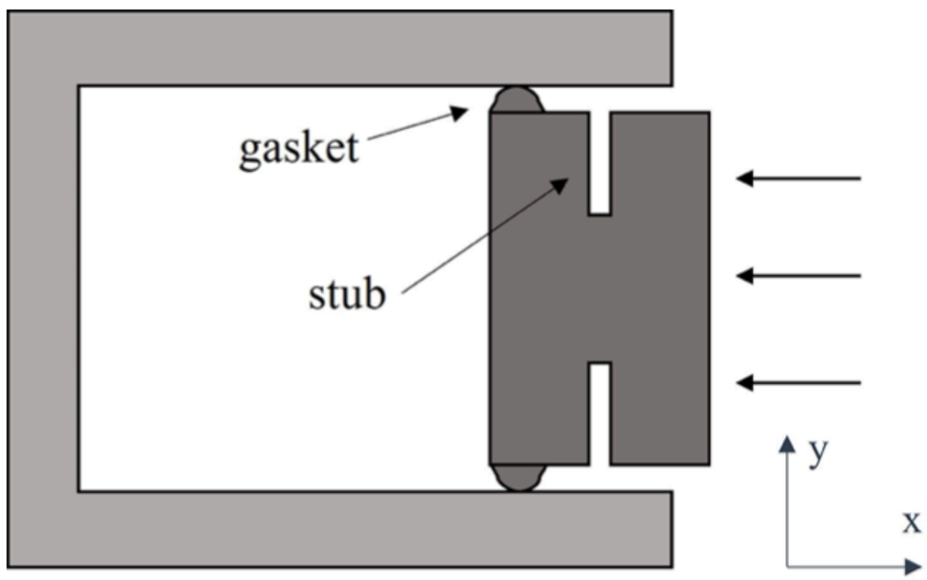
TM_{110} mode resonant frequency:

$$f_r = \frac{c}{2}\sqrt{\frac{1}{a^2}+\frac{1}{b^2}}$$

Example: $a \approx 1.7\,\mathrm{mm}$ and $b = 40\,a$ gives resonance frequency

$$f_r = 90\,\mathrm{GHz}$$

Develop **tunable cavities** to scan frequency range $f_r \in [86, 111]\,\mathrm{GHz}$

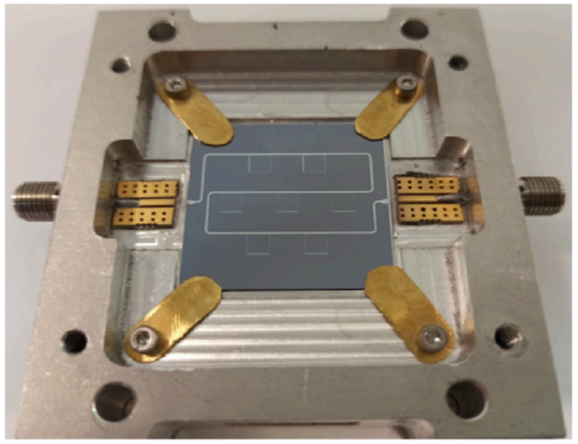


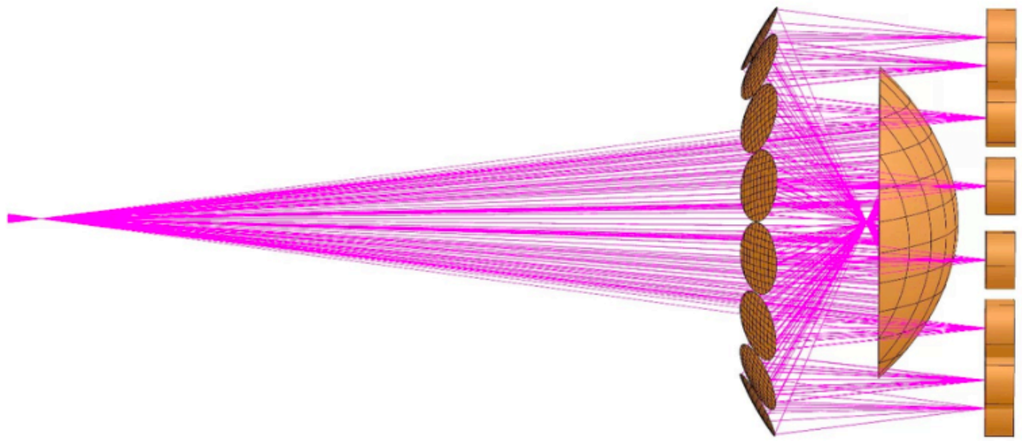
Need to maximize volume to increase the sensitivity →

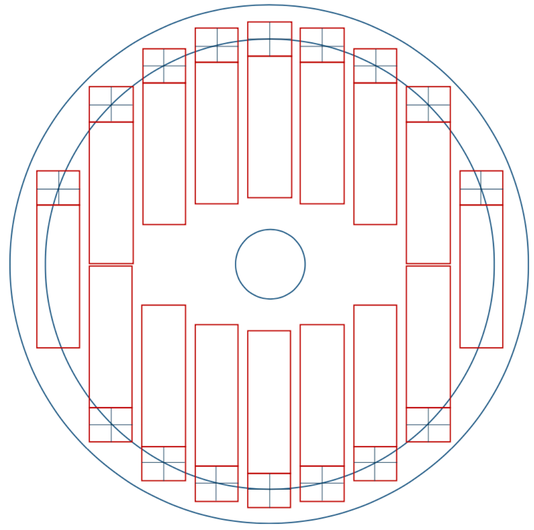
Parallelized haloscope of 7 cavities

Detection: KIDs

Quasi-optical system of16 horns + mirrors (now 7) focuses signal on broadband **Kinetic Inductance Detector (KID)** sensors







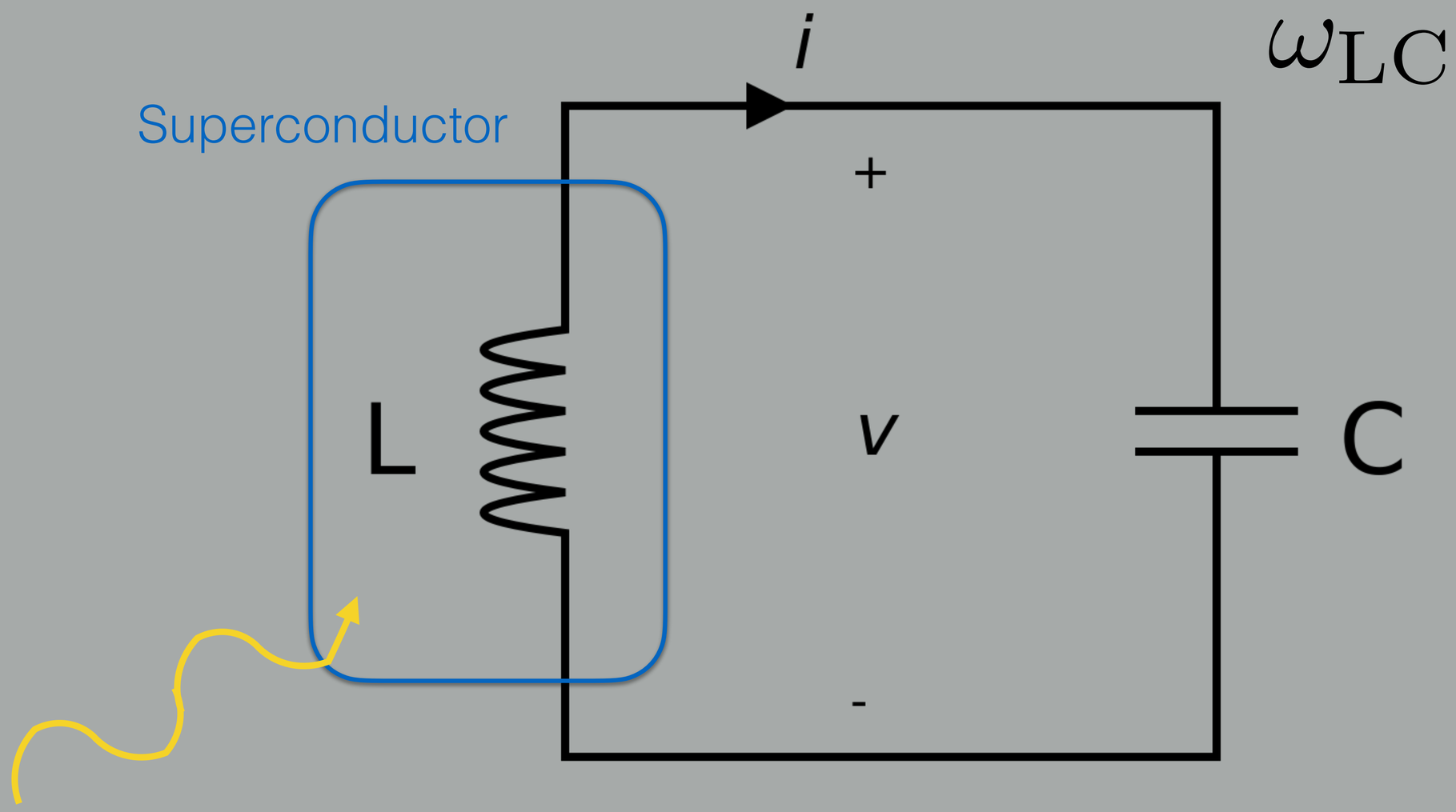
KIDs sensitivity characterized by Noise Equivalent Power (NEP); values of $3.8 \times 10^{-19}\ \mathrm{W}/\sqrt{\mathrm{Hz}}$ have been achieved.

Aim to reduce NEP by a factor of 4-10.

[1306.4238, S. Hailey-Dunsheath et al. (2021)]

Detection: KIDs

Kinetic Inductance Detectors (KIDs)



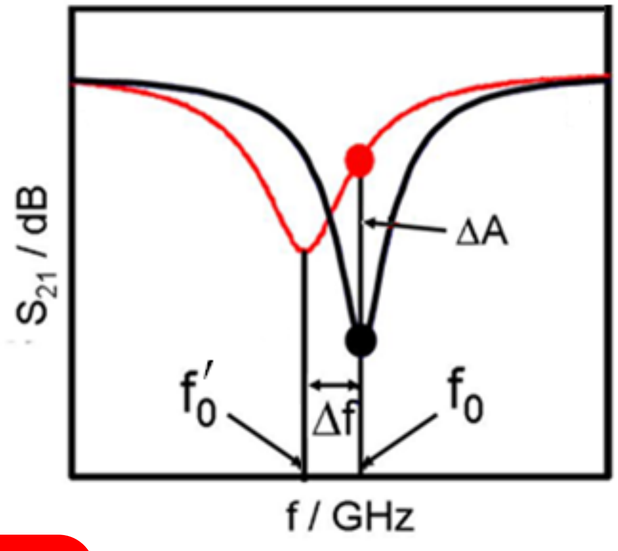
Photon absorbed by superconductor reduces kinetic inductance, altering the resonant frequency of the LC circuit

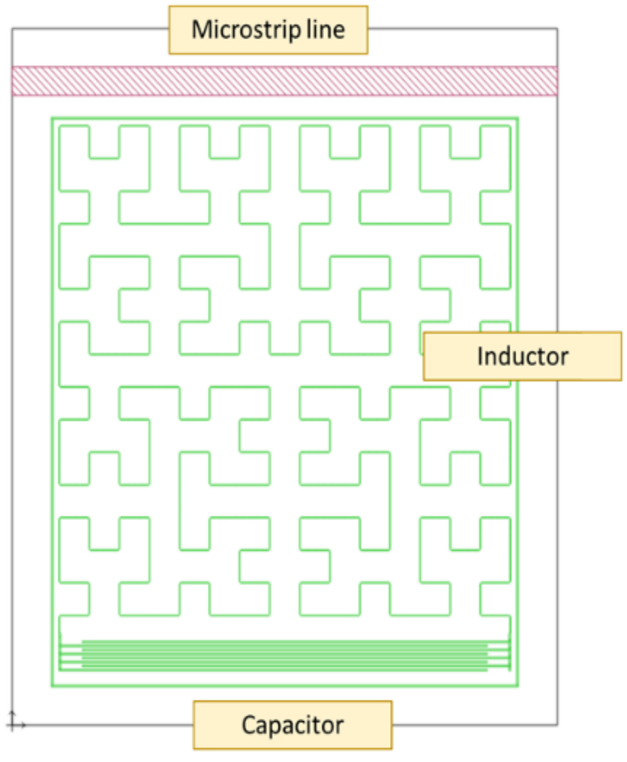
CADEx Status: Kinetic Inductance Detectors

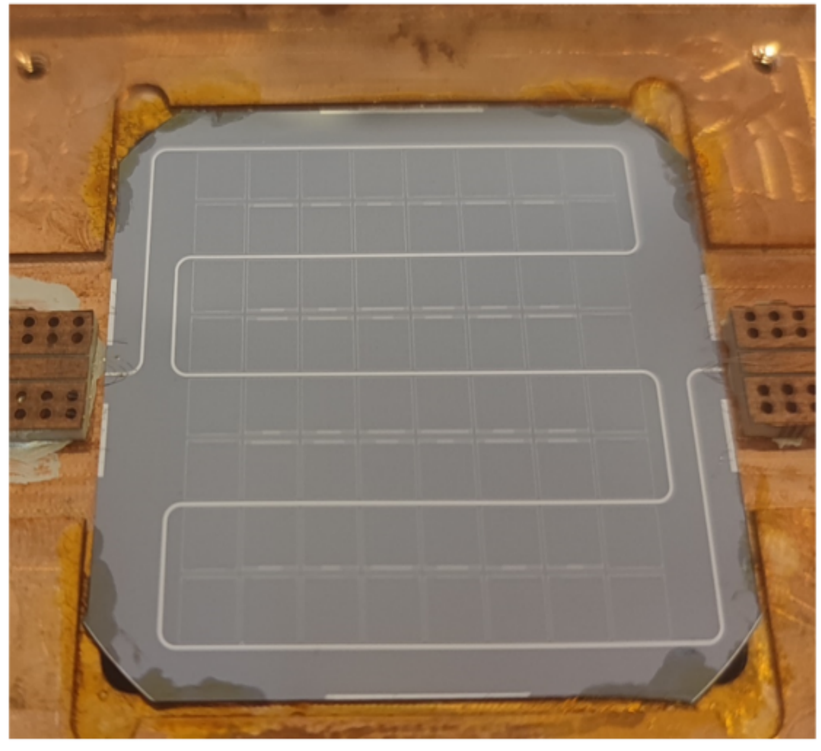
➢ Detection system based on superconducting **Kinetic Inductance Detectors**.

➢ A 64 LEKID camera based on **Ti/Al bilayer** is being developed and characterized.

$$f_0 = \frac{1}{\sqrt{LC}}$$





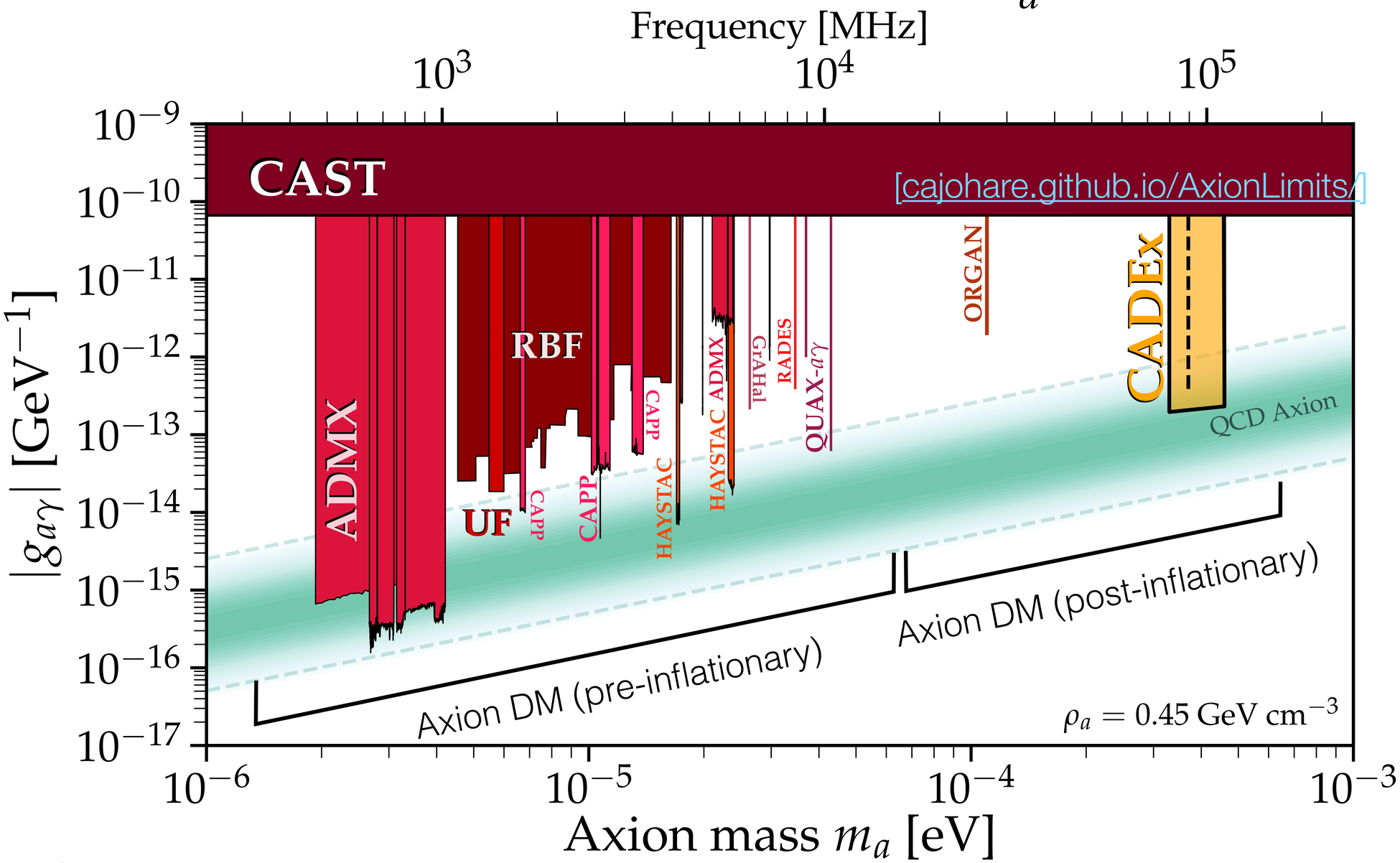


$$f' = \frac{1}{\sqrt{L'C}}$$

We can detect incident power by monitoring the shift in f_0

CADEx Axion Sensitivity

Axion-photon conversion power: $P_d \propto g_{a\gamma}^2 \frac{\rho_a}{m_a} B^2 V Q_0$



Estimate 5σ sensitivity assuming:

Magnetic field: $B = 8\,\mathrm{T}$
Total cavity volume: $V = 0.2\,\mathrm{L}$
Cavity quality factor: $Q_0 = 2 \times 10^4$

- - - - - - 3 month exposure with NEP = 10^{-19} W/$\sqrt{\mathrm{Hz}}$

——— 8 year scan with NEP = 3×10^{-20} W/$\sqrt{\mathrm{Hz}}$

CADEx Timeline

CADEx already accepted by Canfranc Underground Laboratory (LSC) under EoI-31-2021

Design and Demonstration phase (2 years)

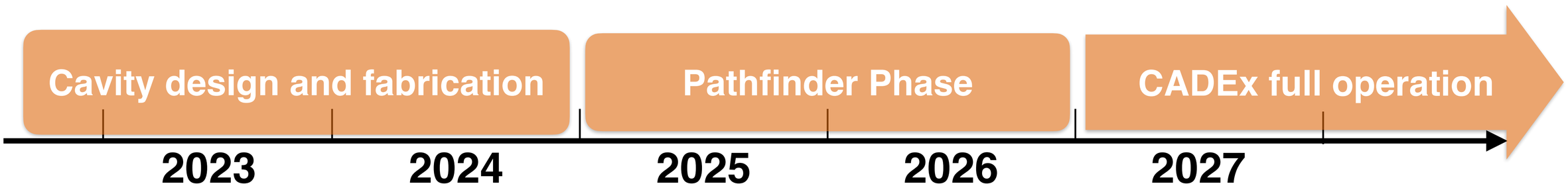
Cryostat acquisition, installation and operation. Design and fabrication of cavities. Demonstration of key technology (haloscope, detectors, etc.) in the lab.

Pathfinder phase (2 years)

Development of first prototype of CADEx and installation in the LSC facility in the first year (haloscope + KIDs + calibration). During the second year, the pathfinder experiment will be carried out.

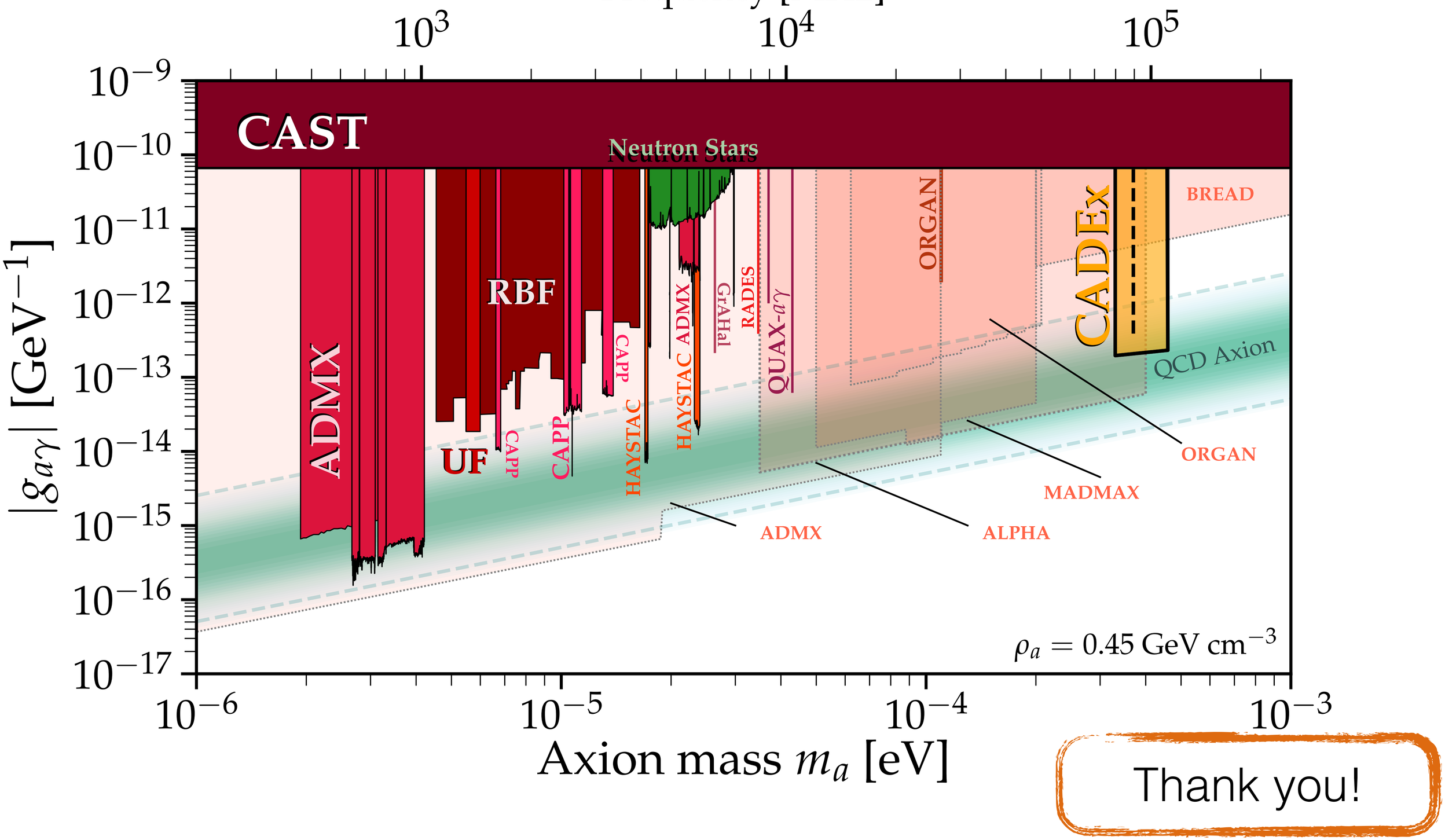
Operation phase (8 years)

Upgrade the experiment to improve the sensitivity & efficient non-resonant waveguide haloscope. Installation & Commissioning. Full Operation to cover mass range $m_a \in [330, 460]\,\mu\mathrm{eV}$



Outlook and Landscape

CADEx: a novel haloscope search for Dark Matter axions in the mass range 330–460 μeV (86–111 GHz)



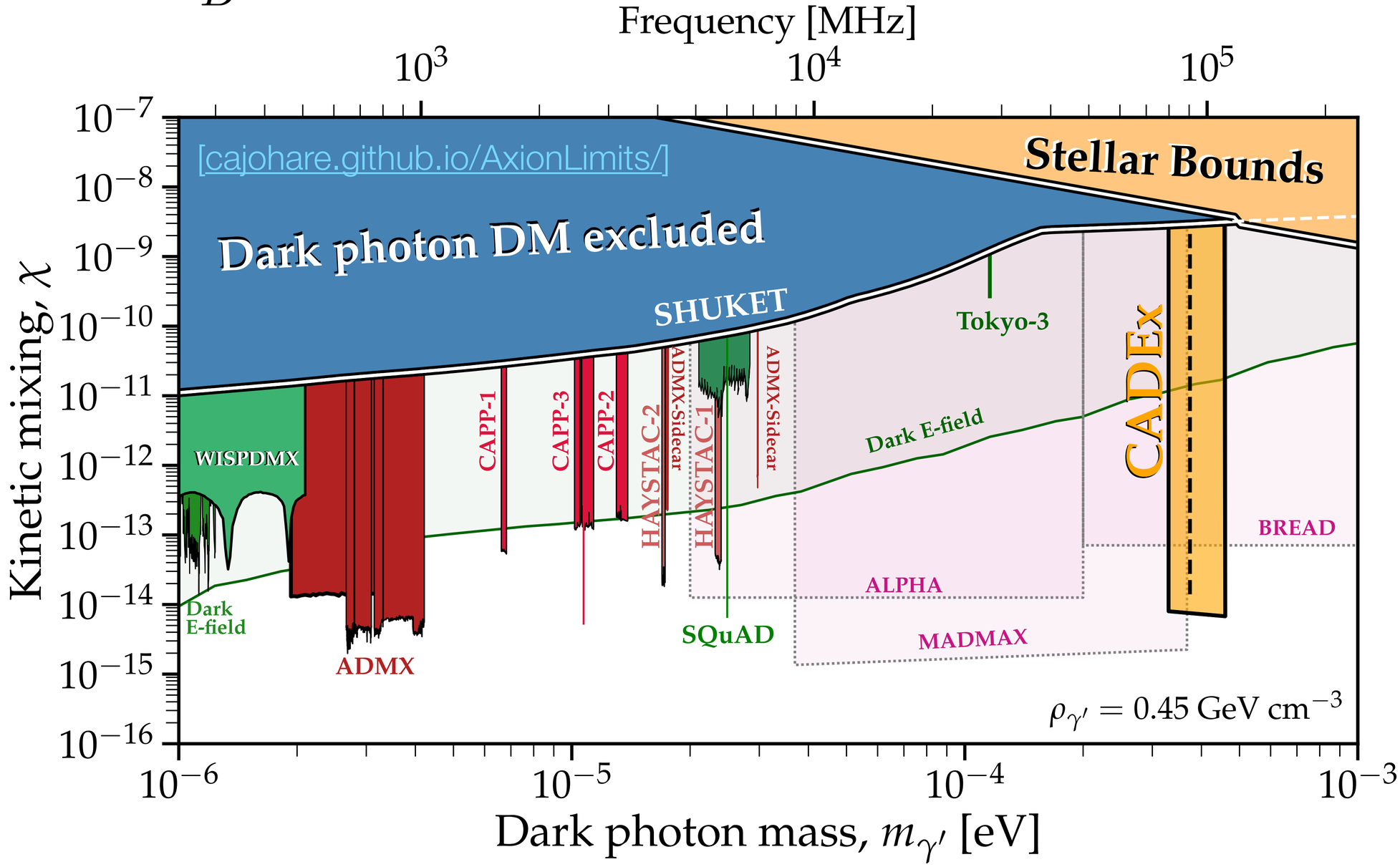
Thank you!

Additional Slides

Dark Photon Sensitivity

CADEx is sensitive to conversion of photons to **Dark Photon γ'** even without a magnetic field

$$g_{a\gamma} \to \frac{\chi m_{\gamma'} \sqrt{\cos^2 \theta_{\rm pol}}}{B}$$



Other possibilities too:
e.g. GHz Gravitational Waves

- - - - - - 3 month exposure with NEP = 10^{-19} W/$\sqrt{\rm Hz}$

——— 8 year scan with NEP = 3×10^{-20} W/$\sqrt{\rm Hz}$