“CADEx: A New Approach to Axion Dark Matter Searches with Kinetic Inductance Detectors”

Alicia Gómez, on behalf of the CADEx Collaboration

Centro de Astrobiología (CSIC-INTA)

agomez@cab.inta-csic.es

CENTRO DE ASTROBIOLOGÍA · CAB
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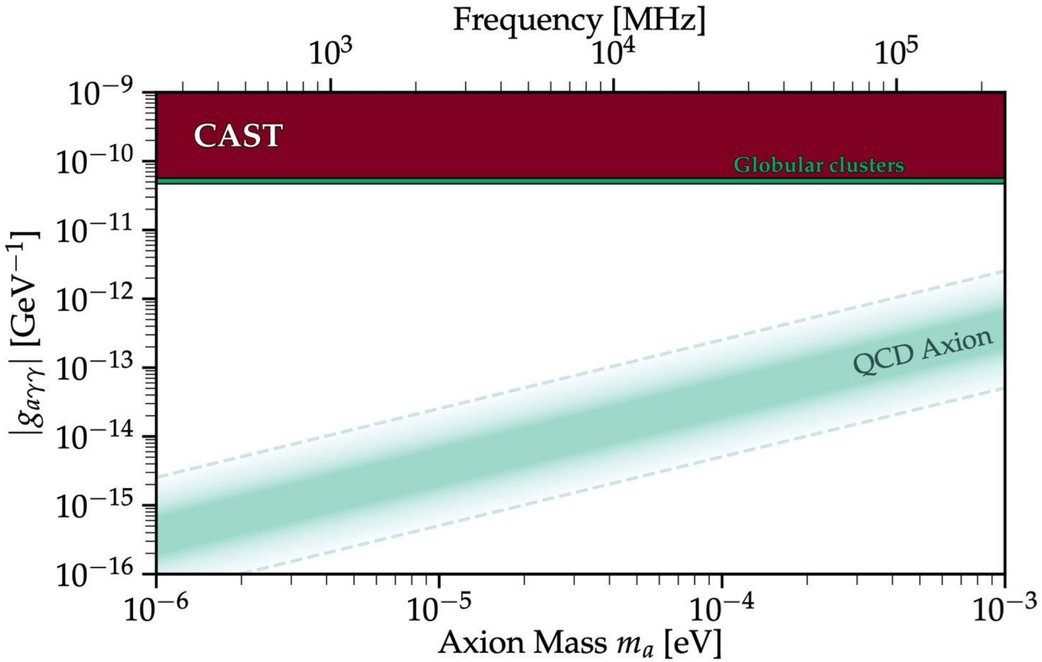
2nd Workshop of the CPAN Network on Instrumentation and Detectors

The challenging mm/submm/THz desert

- ***Axions :*** Solves the Charge-Parity (CP) problem.
- ***Axion mass → Free parameter***



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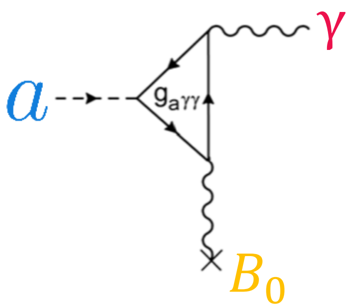

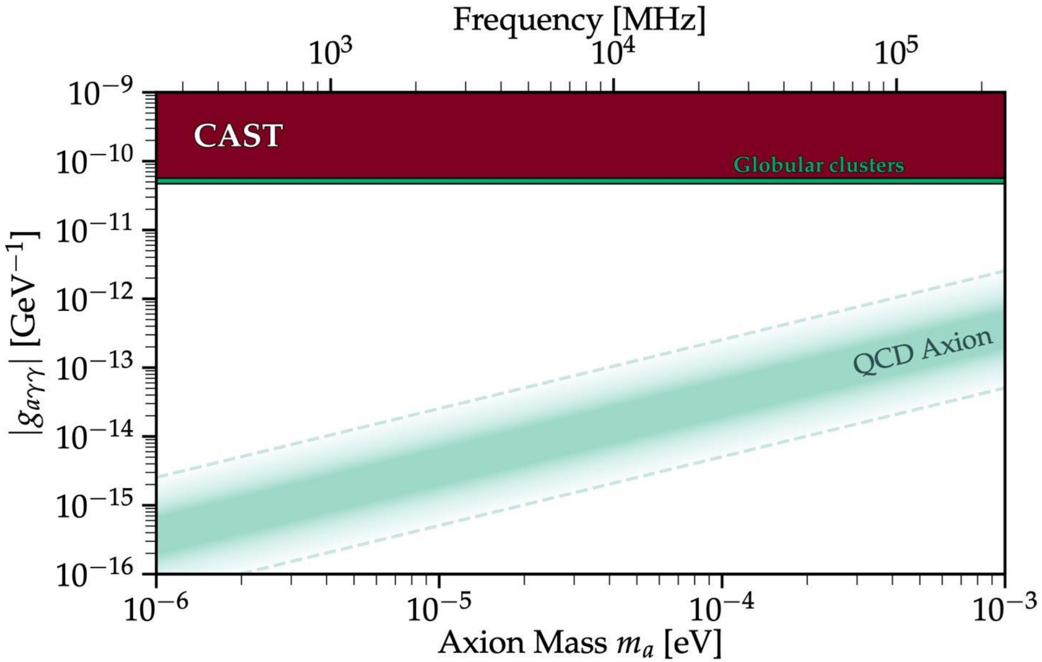

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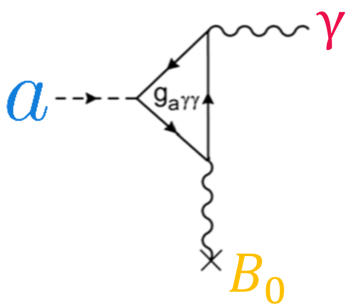

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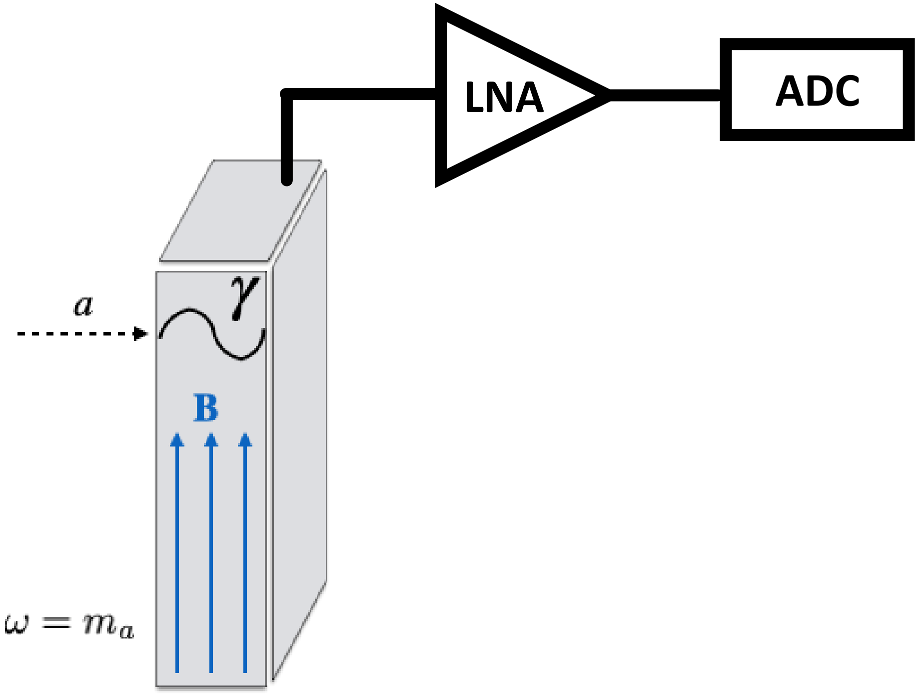

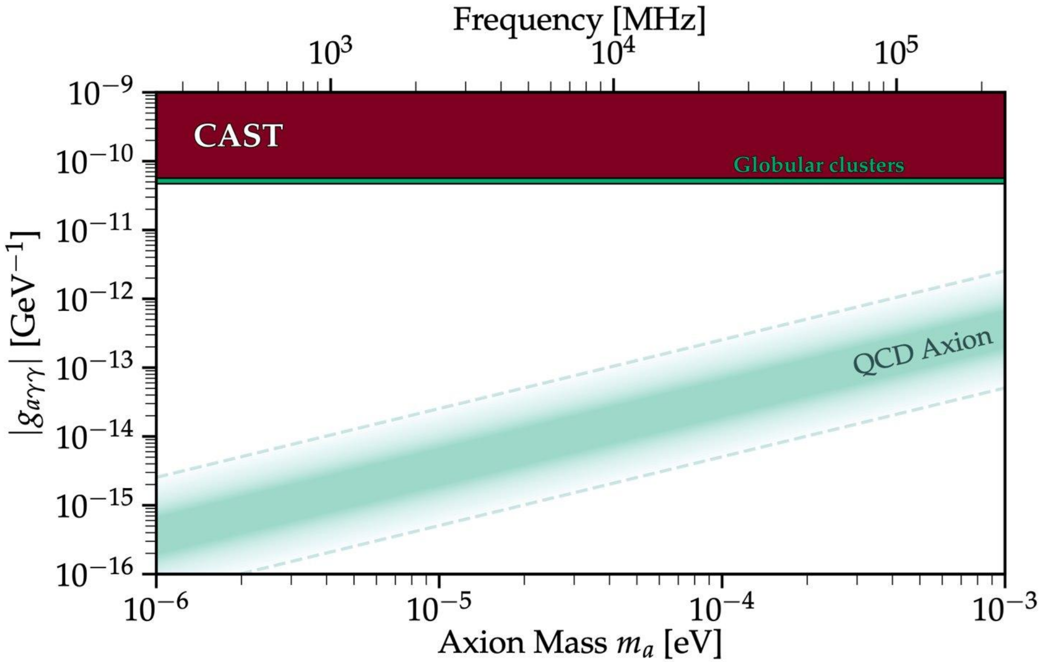

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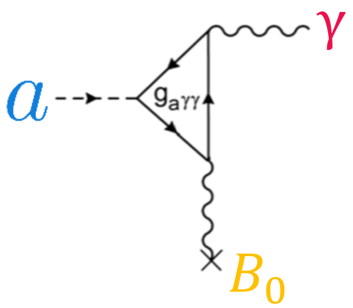

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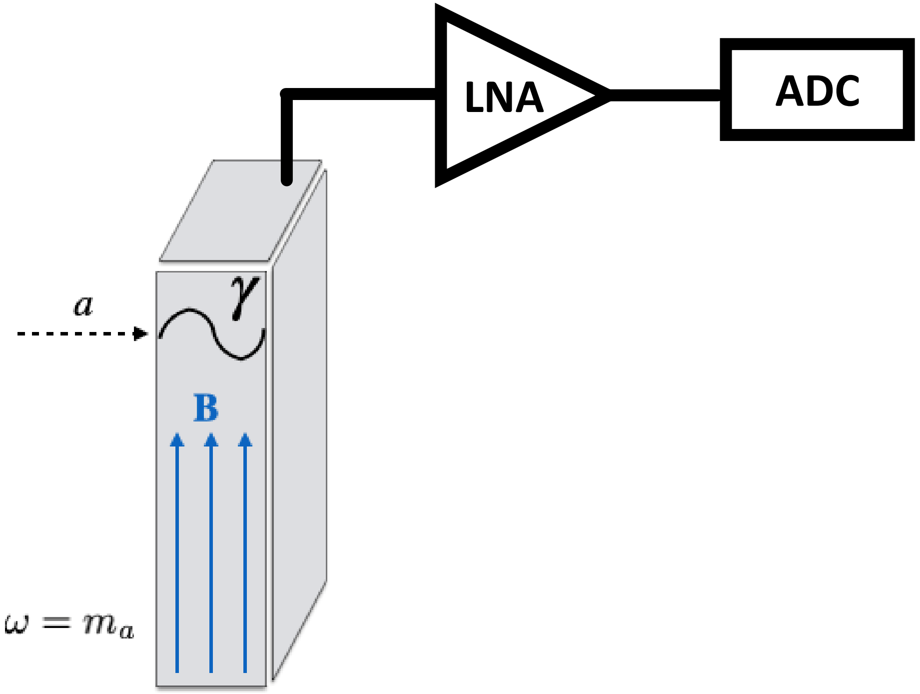

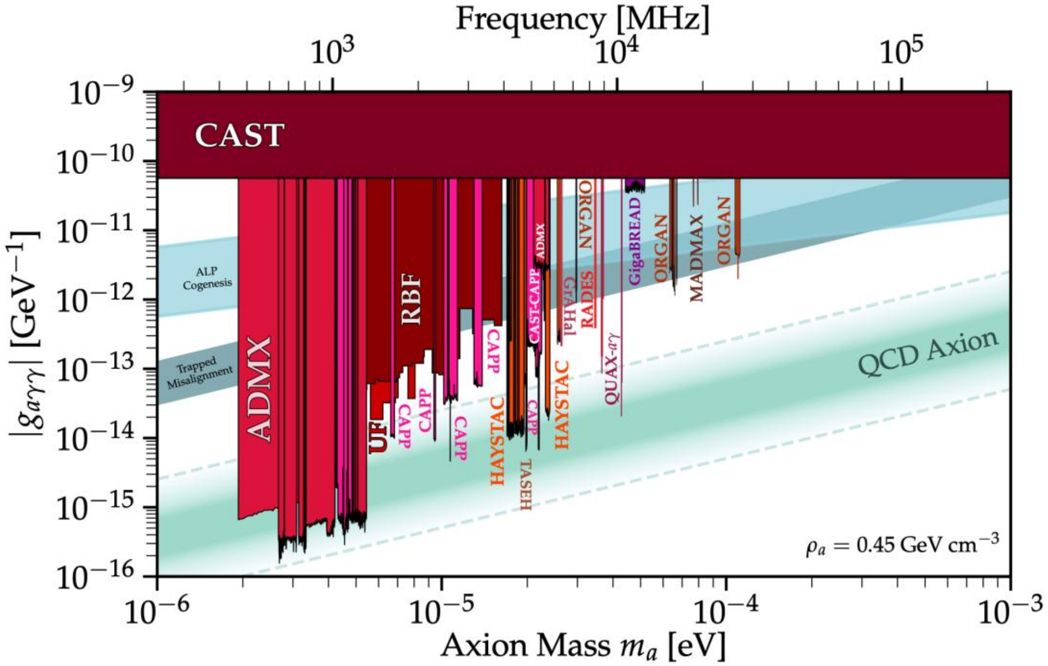

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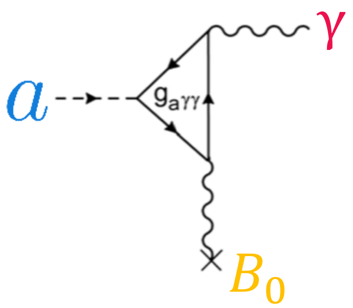

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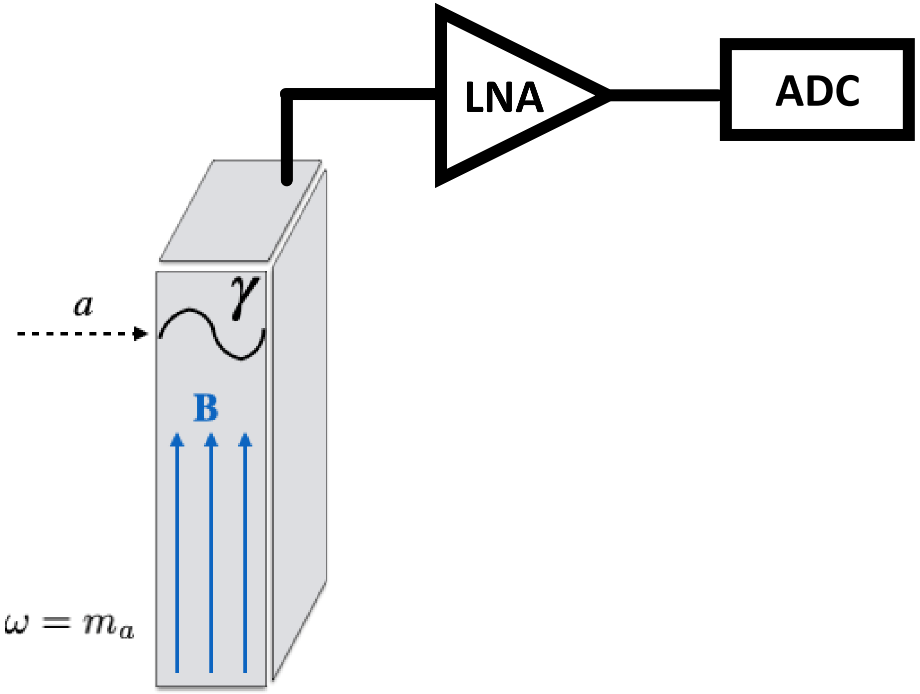

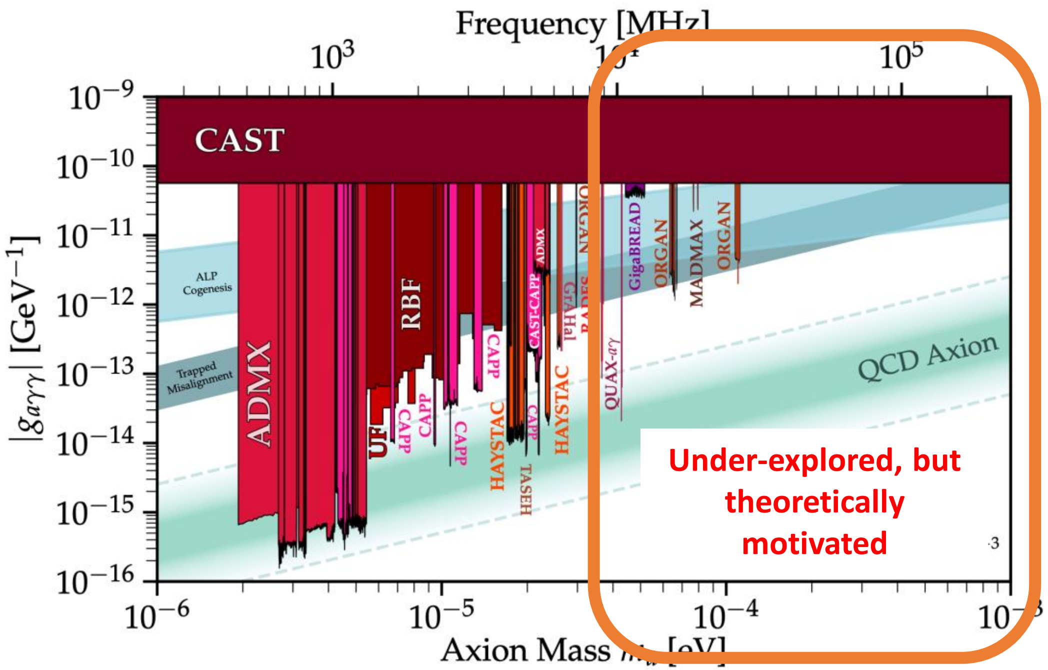

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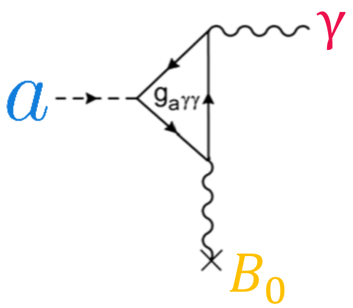

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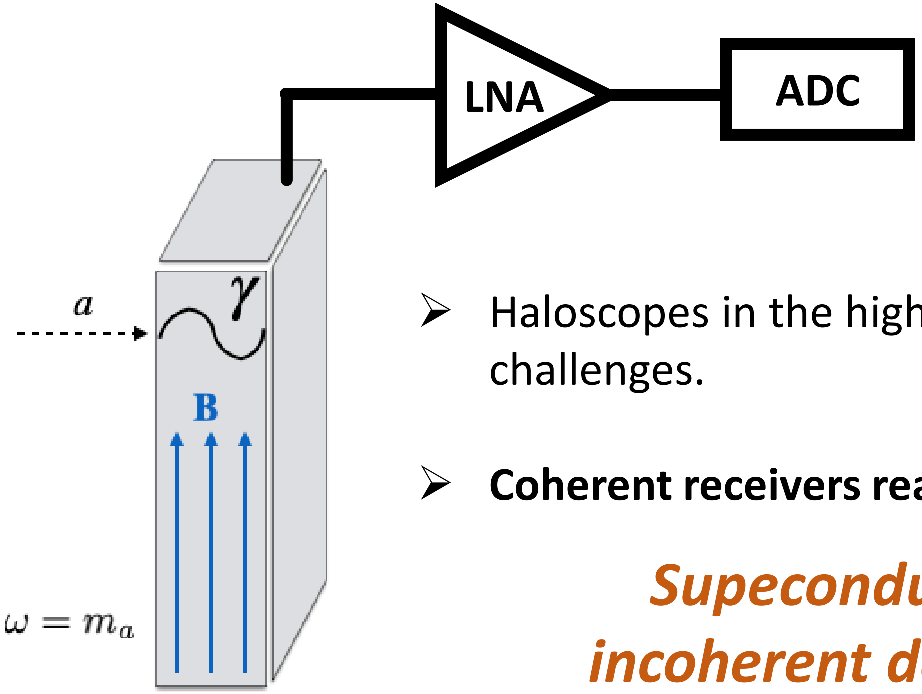
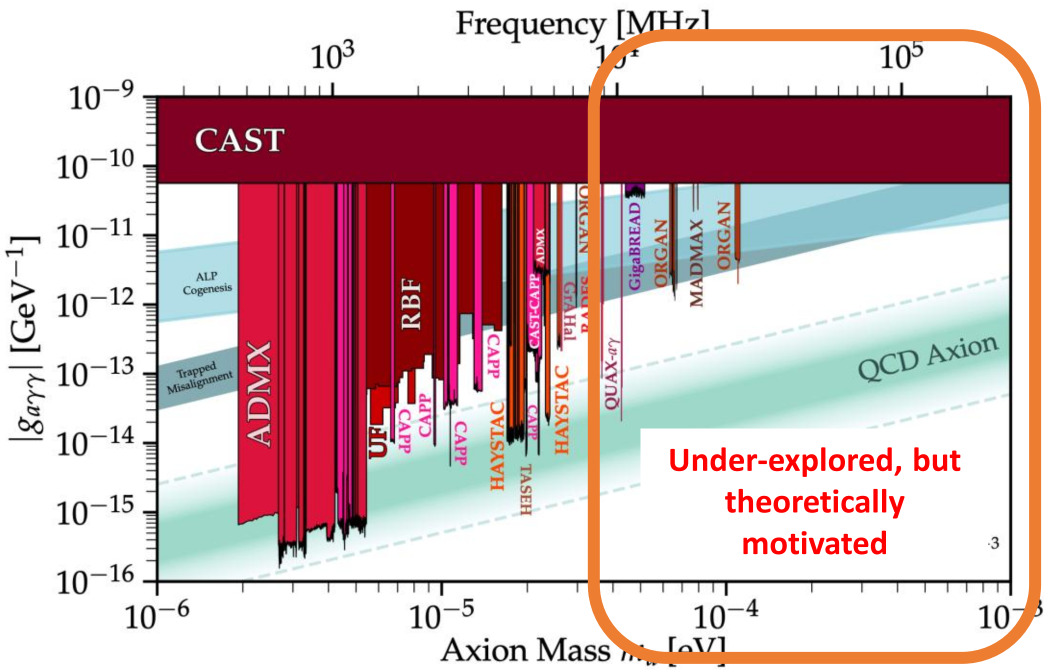


- Haloscopes in the high-freq regime are challenges.
- **Coherent receivers reach the SQL.**

Supeconducting incoherent detectors



The challenging mm/submm/THz desert

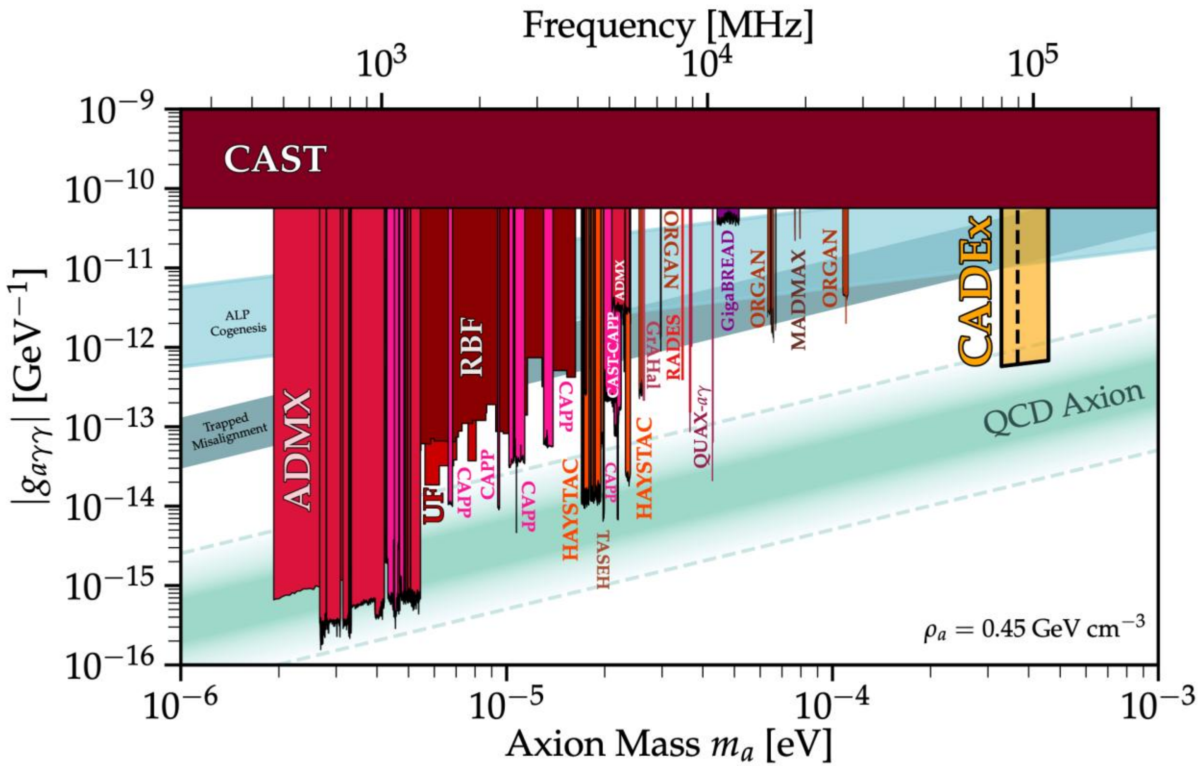
***CADEx**: a novel and challenging experiment to search for dark matter axions in the range m_a = 330–460 μeV (W-band: 86–110 GHz). Also sensitive to dark photons.*

Looking for axions in the mm/submm/Far- IR desert

Novel detection system:
Haloscope + KIDs

Estimate 5σ sensitivity assuming:

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



- - - - - 3 month exposure with NEP = 10^{-19} W/$\sqrt{\text{Hz}}$
——— 8 year scan with NEP = 3×10^{-20} W/$\sqrt{\text{Hz}}$

The CADEx team

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

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]

More than 30 people from 11 institutions

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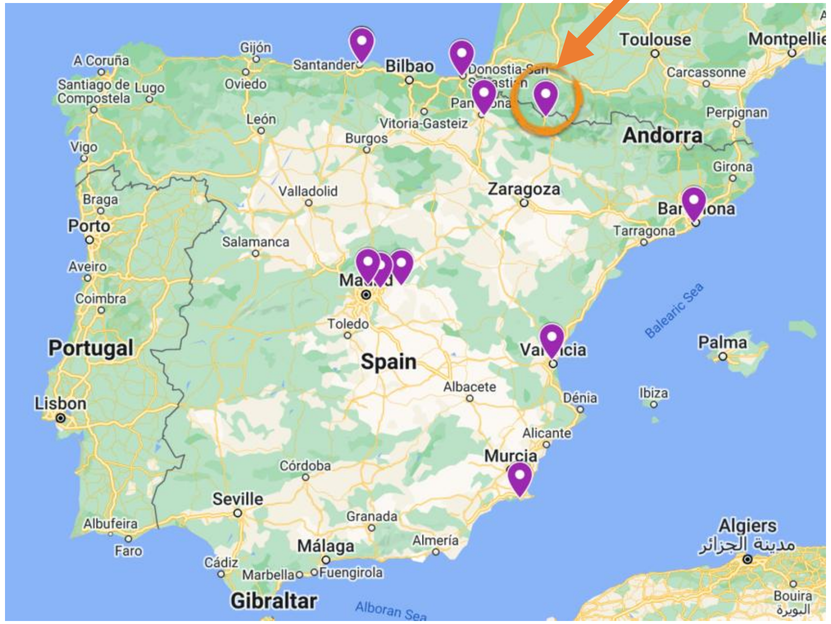
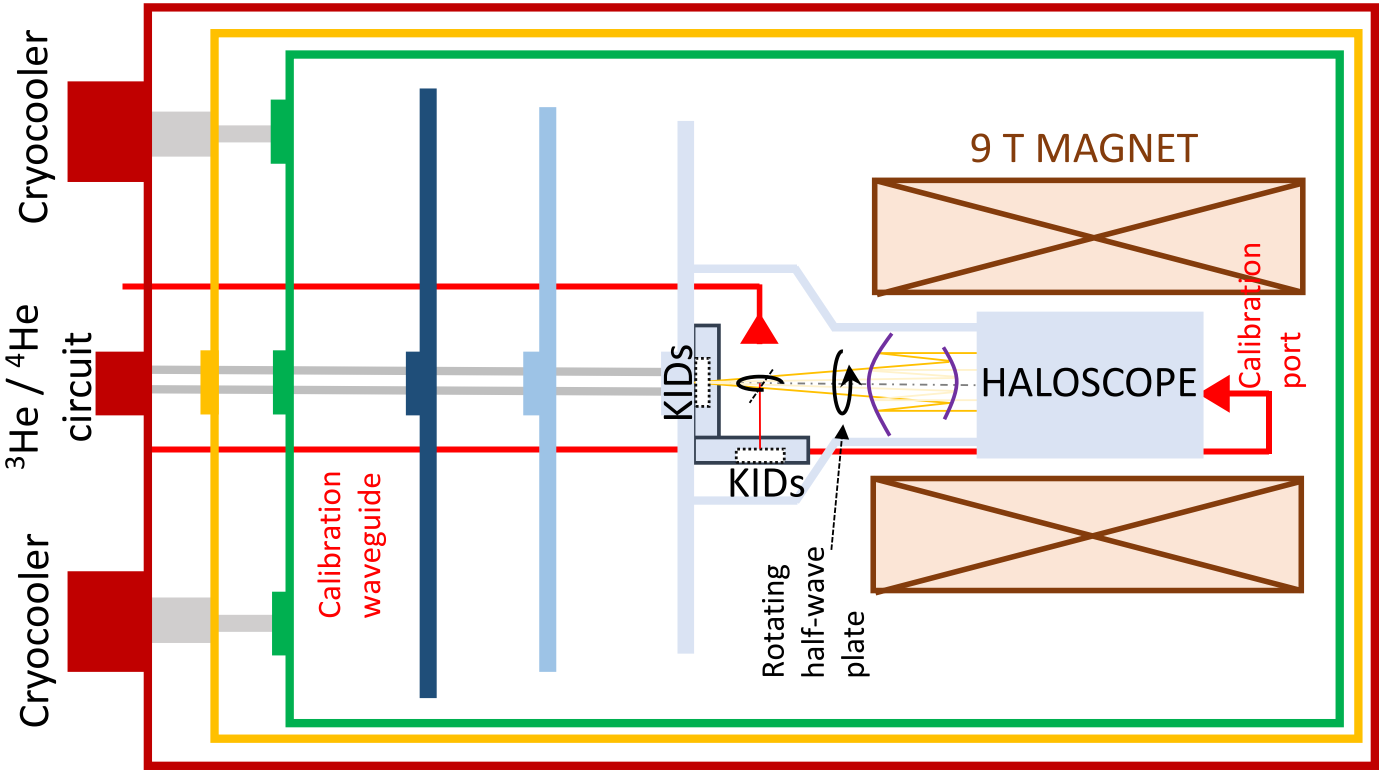
- Science
- Optics
- Haloscope
- Cryogenics
- Detectors
- Data Reduction



CADEx conceptual design

Technological challenges

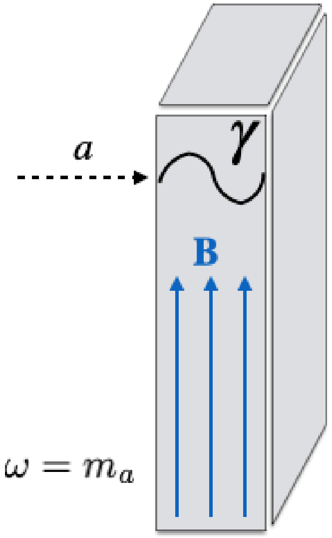
- Cryogenic background at **T = 100 mK**.
- Aim to discriminate the **polarized** axion-photon conversion signal from the unpolarized background.
- Immerse **haloscope** array in high static **B = 8-10 T**.
- Detection system based on **Kinetic Inductance Detectors**.



Generation: The haloscope

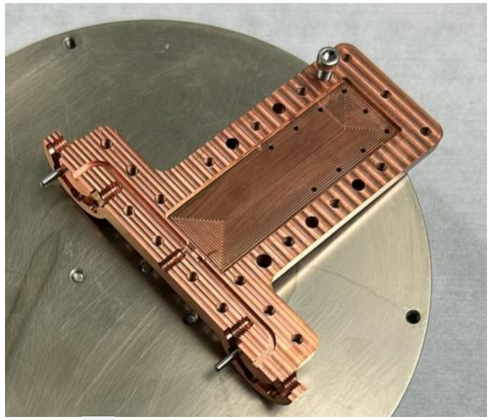
Inverse Primakoff effect Generated Signal:

$$P_{a\to\gamma} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} \boldsymbol{B}^2 C V \frac{\beta}{(1+\beta)^2} \boldsymbol{Q_0}$$

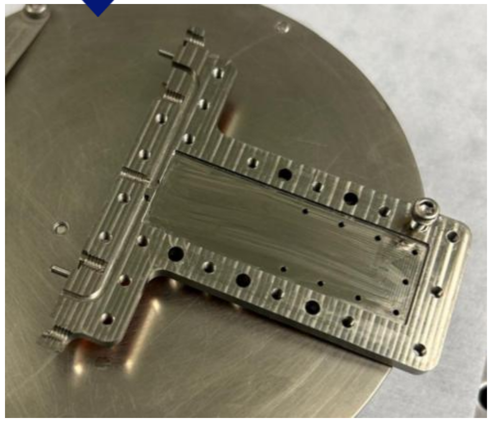


$\boldsymbol{B = 9T}$

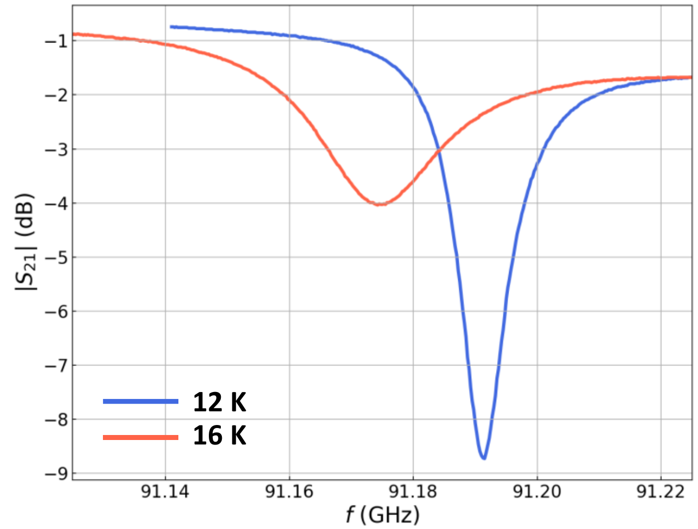
$\boldsymbol{Q_0}$ → **Quality factor (1/losses)**



NbTiN Sputtering



NbTiN Tc = 14.3 K



Q_0 (16 K) = 7.4 · 10^3
Q_0 (12 K) = 8.8 · 10^4

Temp → 10 mK → 5.0 · 10^5

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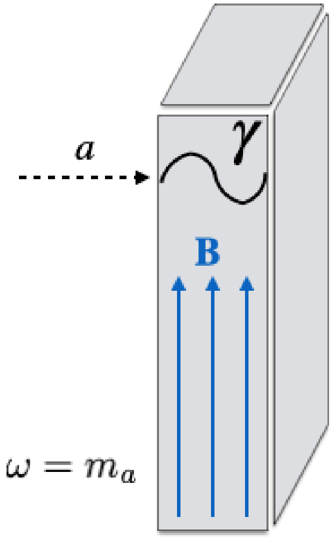
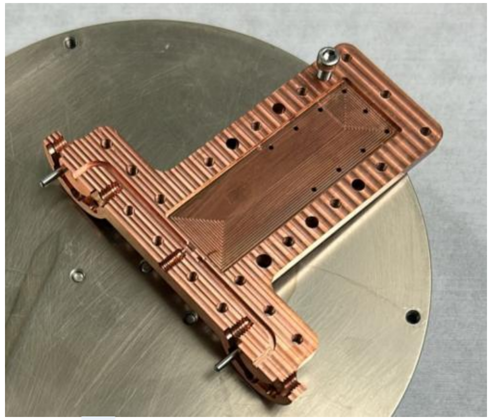


$\boldsymbol{B} = \boldsymbol{9T}$ ✓



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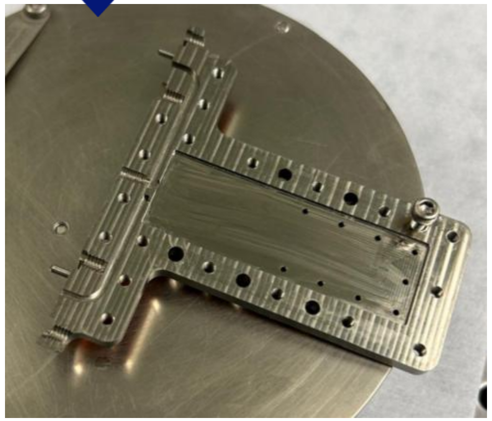

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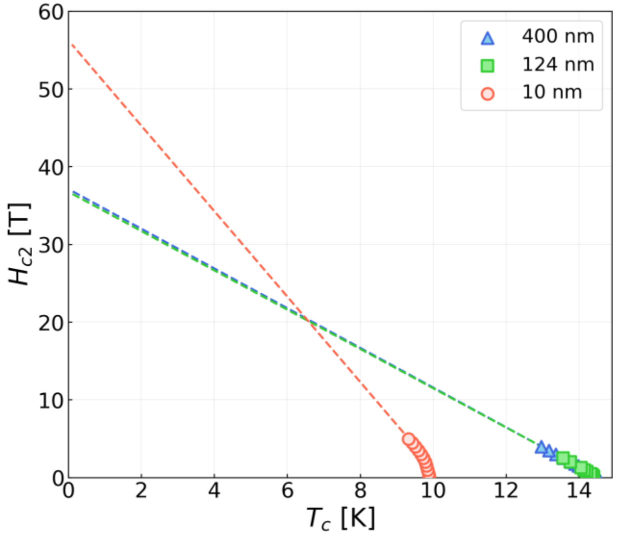

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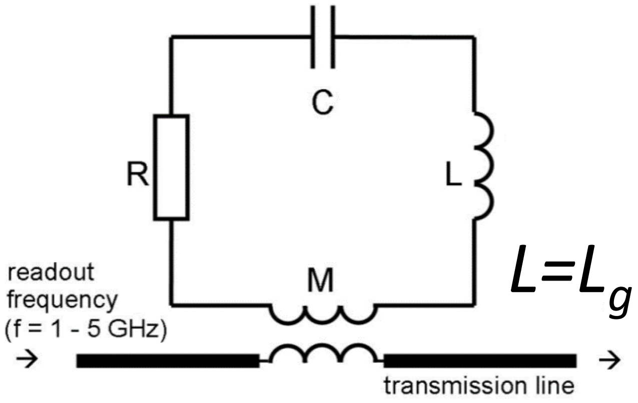
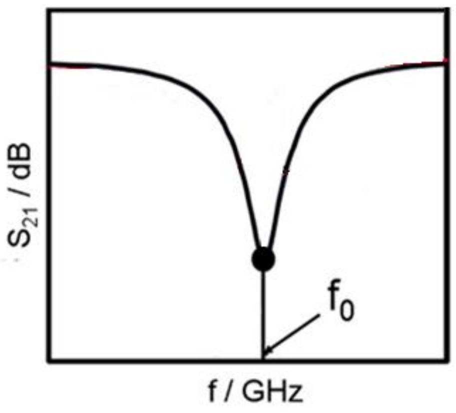
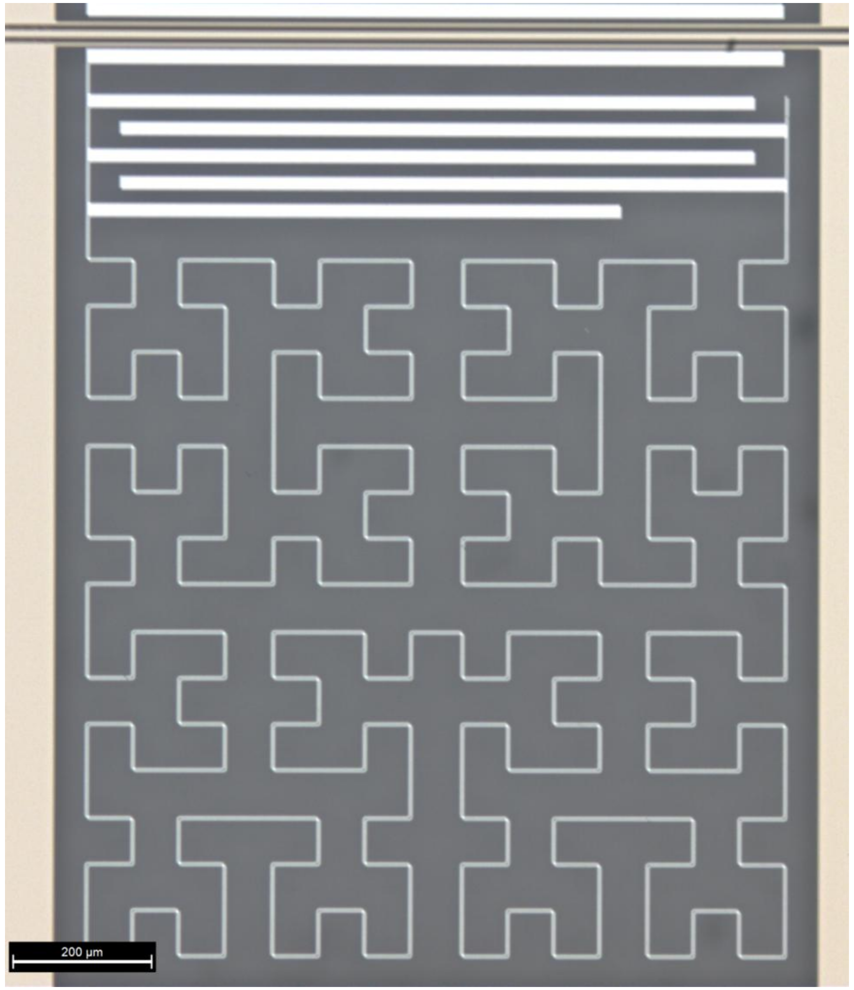
- Detection system based on superconducting **Kinetic Inductance Detectors**.



$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$



Day et al., Nature (2003)



Doyle et al., JLTP (2007)

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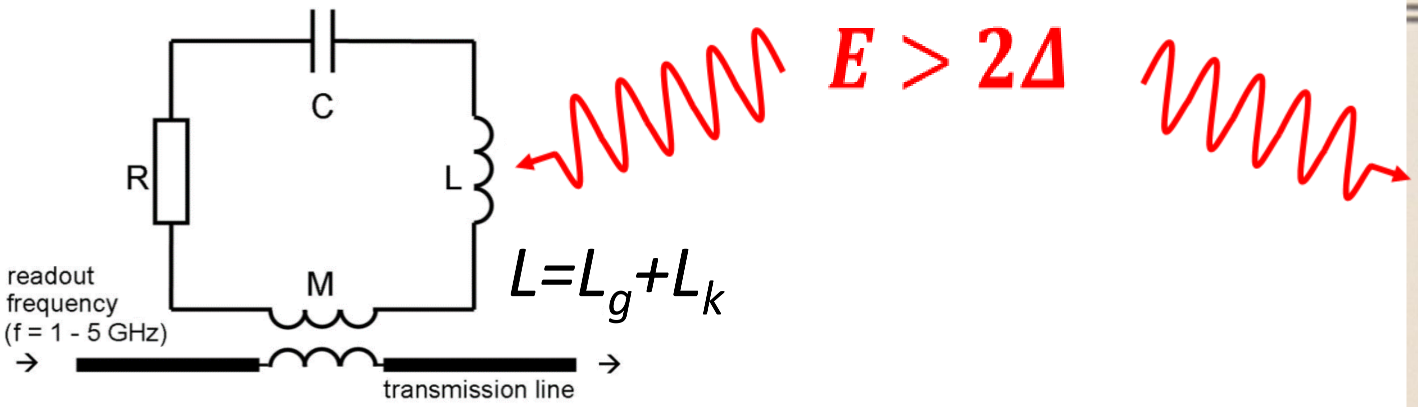

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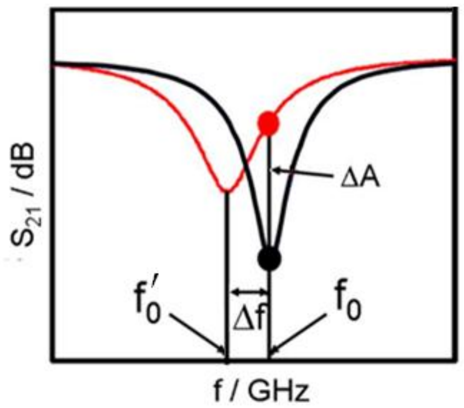
$$f'_0 = \frac{1}{2\pi\sqrt{L'C}}$$



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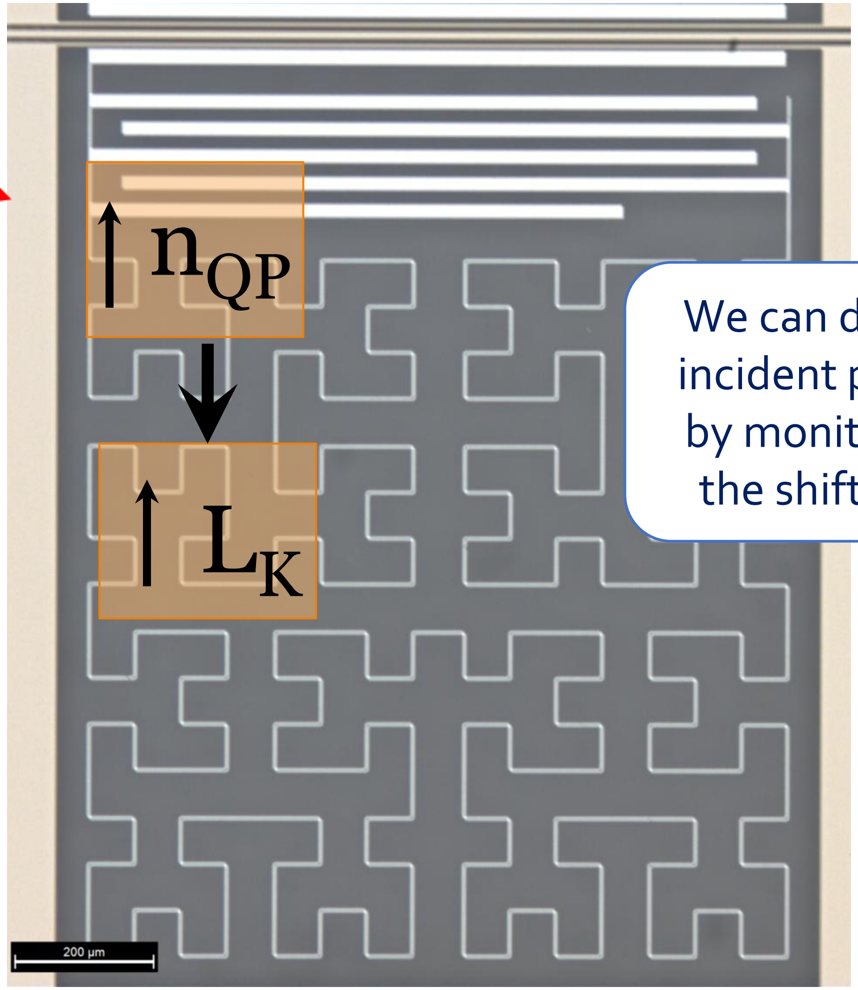


We can detect incident power by monitoring the shift in f_o

Doyle et al., JLTP (2007)

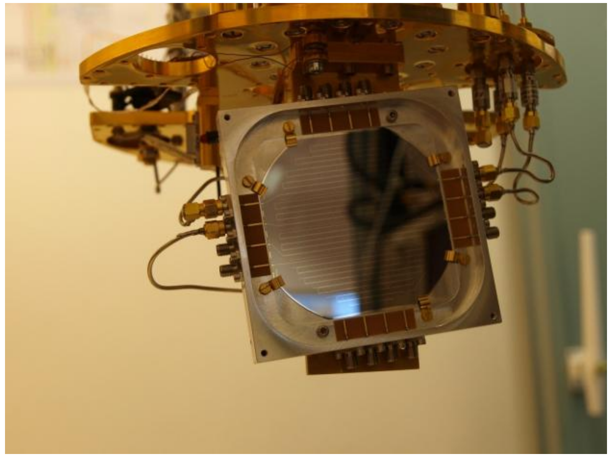
Detection: Kinetic Inductance Detectors

CaDEx

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

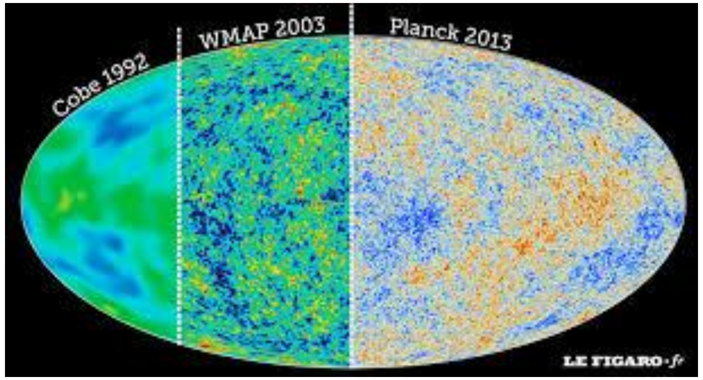
KIDs superconducting detectors for future instrumentation

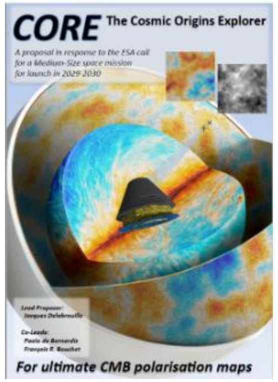
- ➢ State-of-the-art sensitivity
- ➢ Broad band detection
- ➢ Intrinsically multiplexable
  - Easy cryogenic harness



KIDs for W-band

Cosmic Microwave Background (CMB)



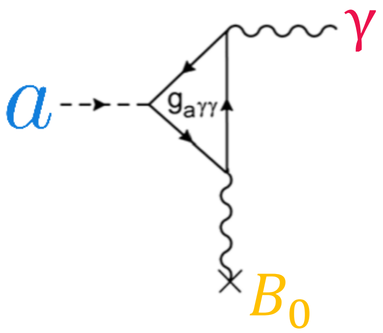


Dark Matter experiments: axions detection

CADEX Collaboration

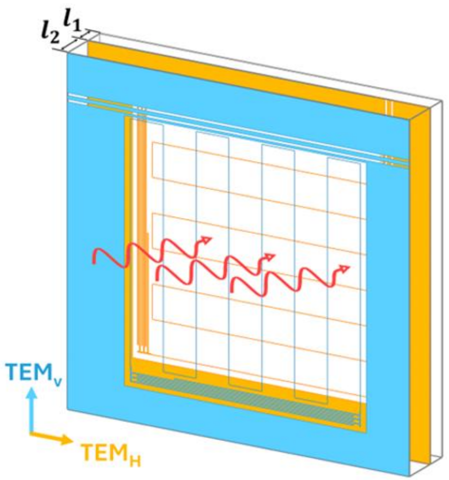
CADEx status: Kinetic Inductance Detectors

- Detection system based on superconducting **Kinetic Inductance Detectors**.
- Axion signature is linearly polarized → **Development of on-chip polarimeter for W-band**.



Photons are generated polarized along the DC magnetic field

KID
On-chip polarimetric camera



M. Calero et al. (2024)
10.1109/IMS40360.2025.11103839

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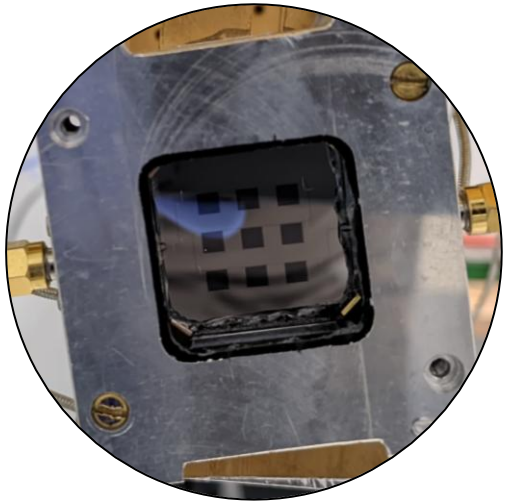
9 x 9 Ti/Al pixels on chip polarimeter demonstrator

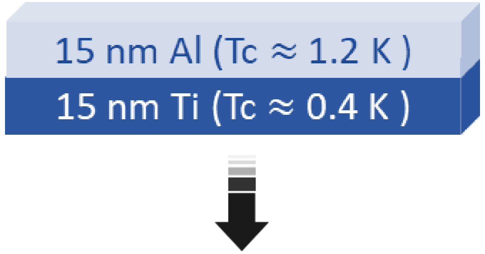
KID → Pair-breaking detectors

$E_{photon} > 2\Delta_{gap}$ *and* $2\Delta_{gap} \sim 3.52 K_B T_c$

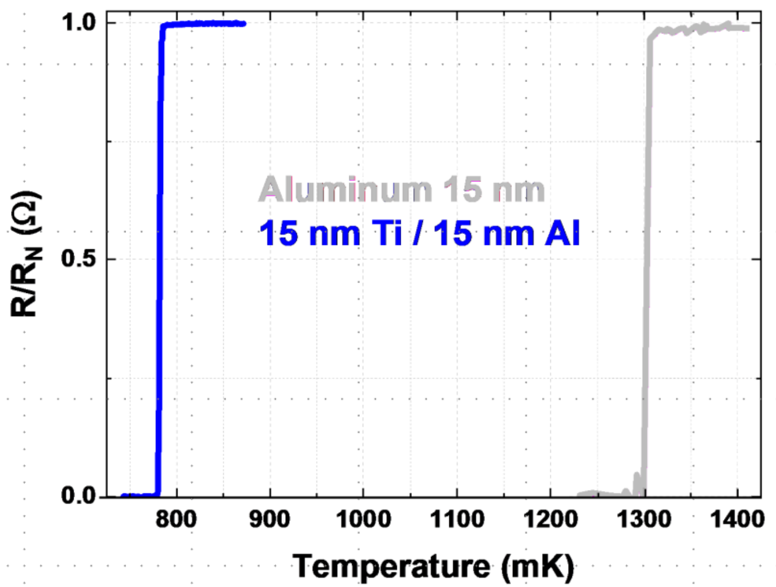


Reaching absorption in the W-band

Titanium / Aluminum
bilayer



T_c = 780 mK
70 GHz low cut off



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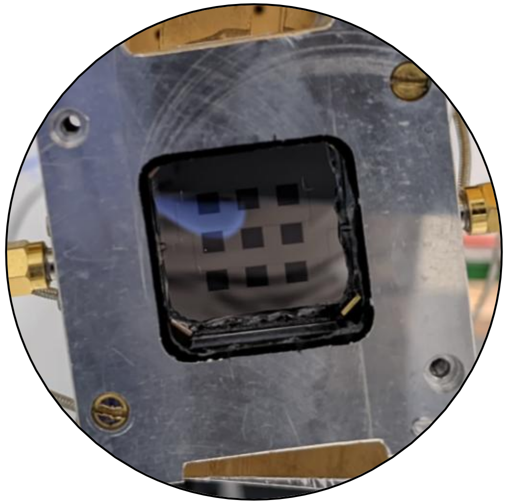

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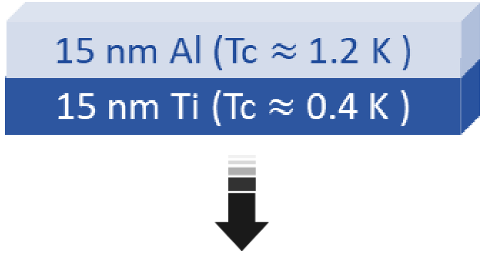

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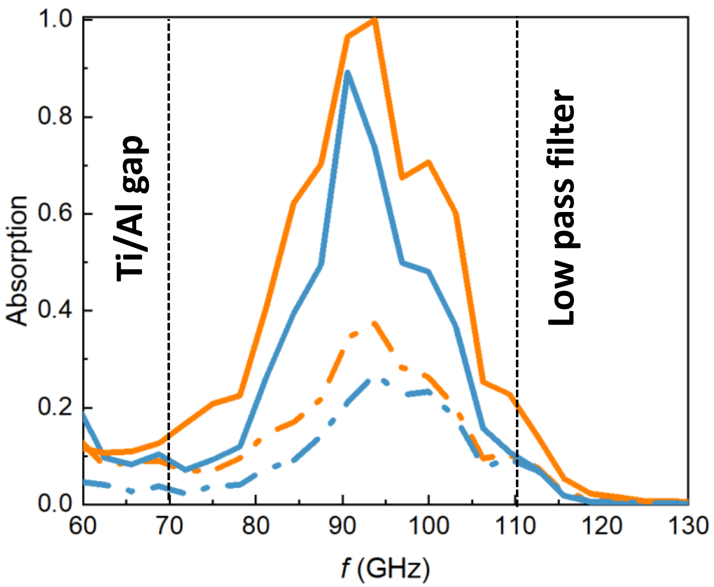

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9 x 9 Ti/Al pixels on chip polarimeter demonstrator

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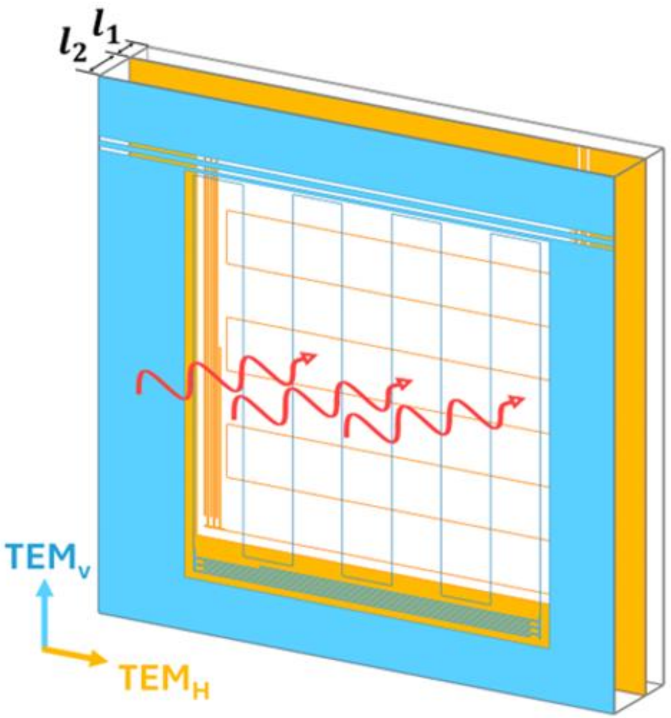
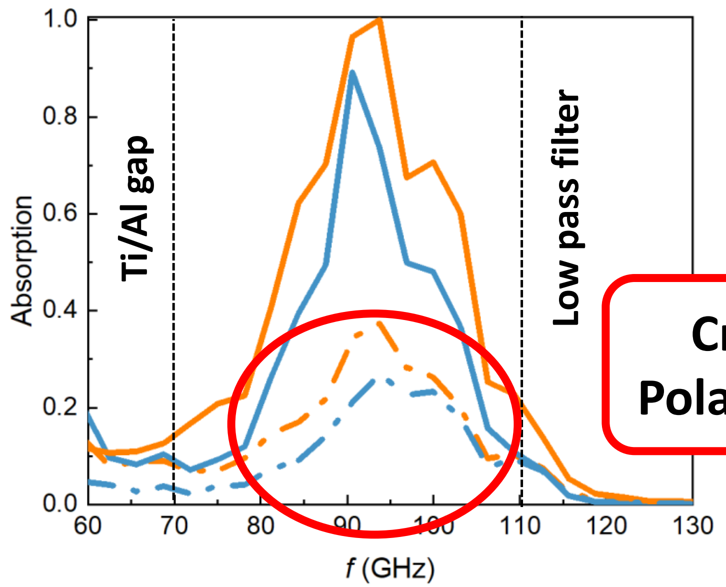


Titanium / Aluminum bilayer

15 nm Al (Tc ≈ 1.2 K)
15 nm Ti (Tc ≈ 0.4 K)

T_c = 780 mK
70 GHz low cut off



Cross – Polarization

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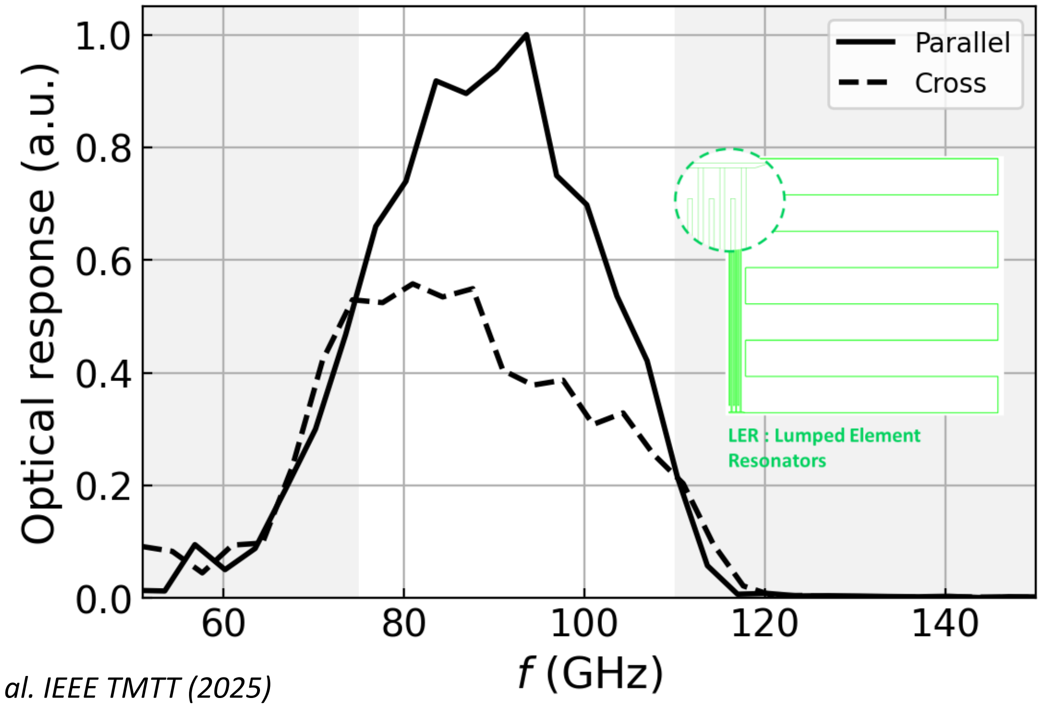
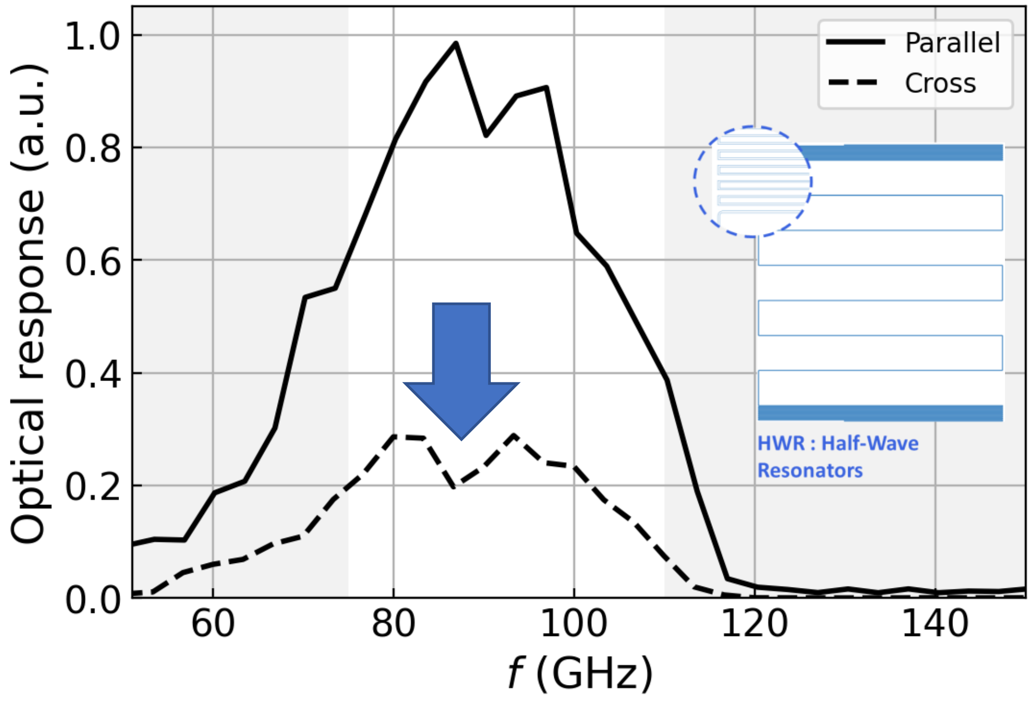
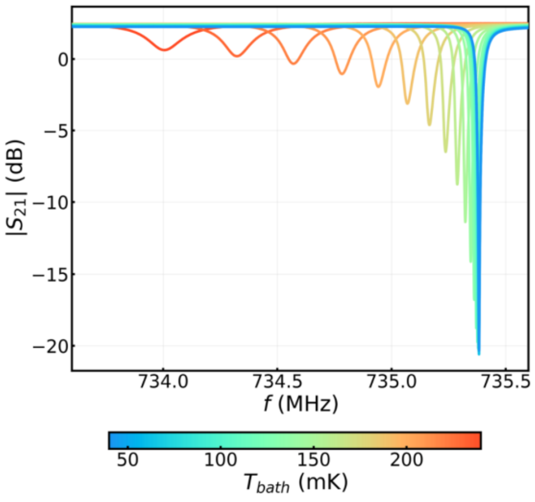


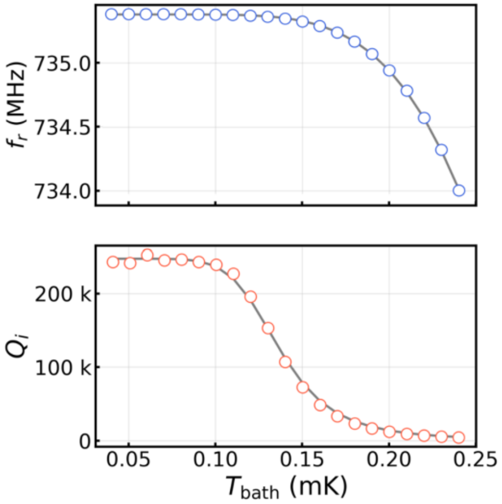


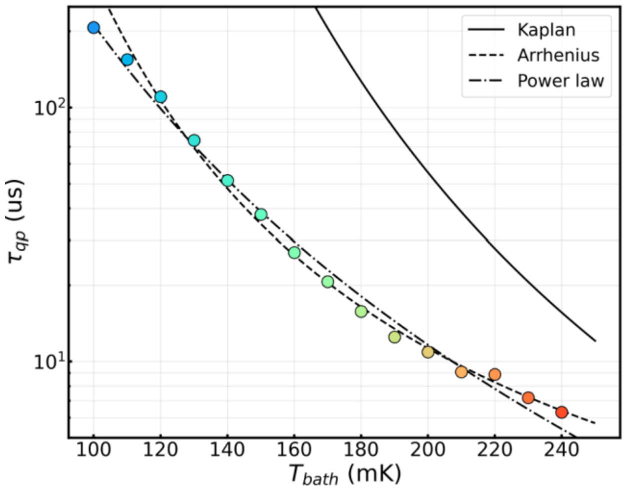
V. Rollano et al. IEEE TMTT (2025)

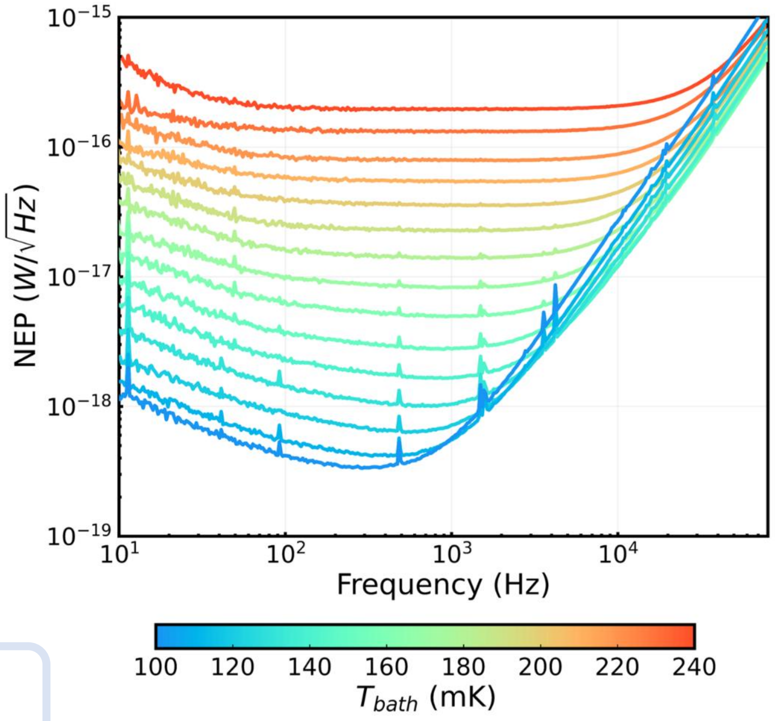
CADEx status: Kinetic Inductance Detectors

- ➢ Detection system based on superconducting **Kinetic Inductance Detectors**.
- ➢ Axion signature is linearly polarized → **Development of on-chip polarimeter for W-band**.
- ➢ Competitive sensitivity with NEP under no illumination of **3×10^{-19} W/Hz$^{0.5}$**









$$NEP_{dark} \approx 3 \times 10^{-19}\ W/Hz^{0.5}$$

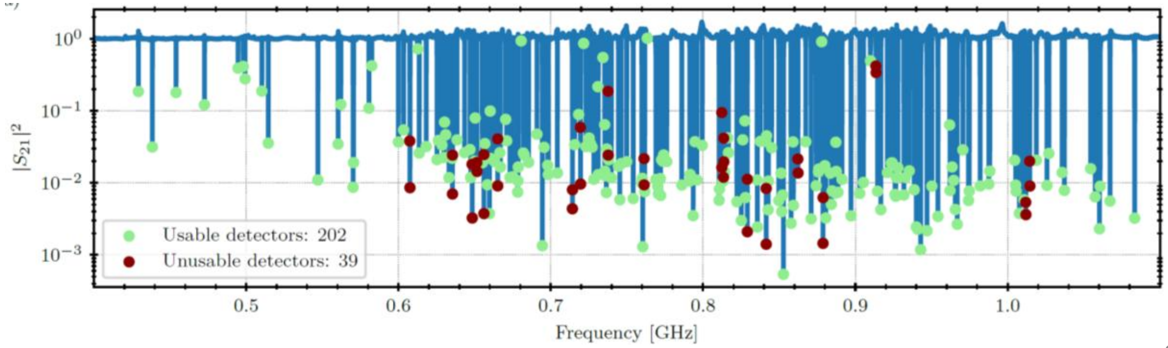
V. Rollano et al. IEEE TAS (2026)

CADEx status: Kinetic Inductance Detectors

- Detection system based on superconducting **Kinetic Inductance Detectors**.
- Axion signature is linearly polarized → **Development of on-chip polarimeter for W-band**.
- Competitive sensitivity with NEP under no illumination of **3×10^{-19} W/Hz$^{0.5}$**
- Read-out system from t0.technology under tests.

Multipixel characterization set-up:

- Eight DAC / ADC channels each capable of analysing 1023 tones simultaneously. **Noise correlation.**
- Fully portable system.

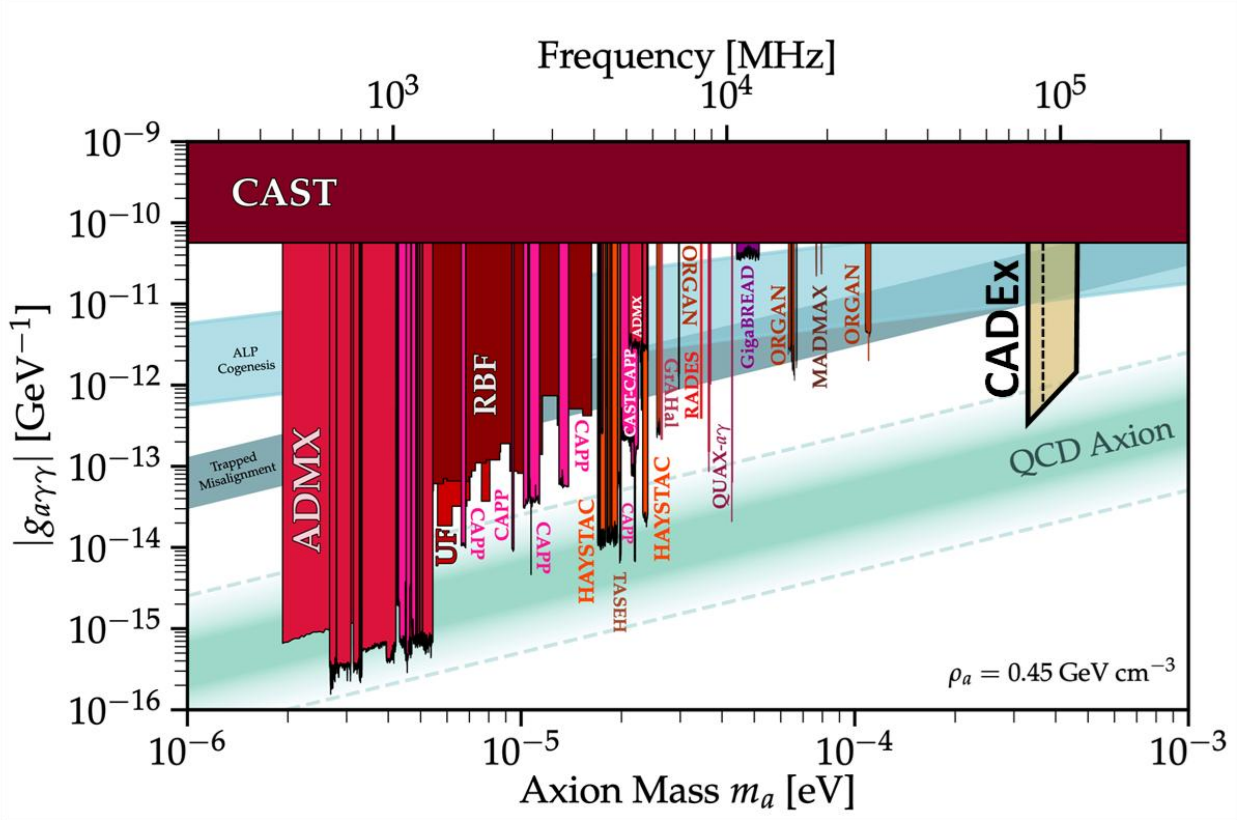


Summay

- **CADEx:** a novel search for Dark Matter axions (and more?) in a well-motivated but under-explored part of parameter space:
  - **The mm/submm/THz range.**
  - **Polarization discrimination.**

- Substantial **technological challenge.**
  - **Pushing KIDs sensitivity.**
  - **Pushing Haloscopes to the W-band.**

- **Complementary** to proposed non-haloscope high-frequency axion searches



The Canfranc Axion Detection Experiment

CaDEx

Alicia Gómez, on behalf of the CADEx Collaboration

Centro de Astrobiología (CSIC-INTA)

agomez@cab.inta-csic.es

CENTRO DE ASTROBIOLOGÍA · CAB
ASOCIADO AL NASA ASTROBIOLOGY PROGRAM
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EXCELENCIA MARÍA DE MAEZTU

Thank you!

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