# The CADEx experiment: progress on the technology demonstration of the superconducting Kinetic Inductance Detectors (KIDs)

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*on behalf of the CADEx colaboration*

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1. **Motivation**
2. **Superconducting Lumped Element Resonators (LERs)**
3. **Implementation**
4. **Results**
   1. ***Setting the operational frequency band***
   2. ***Dark cryogenic characterization***
   3. ***Radiation absorption characterization: responsivity to W-band***
5. **Summary**

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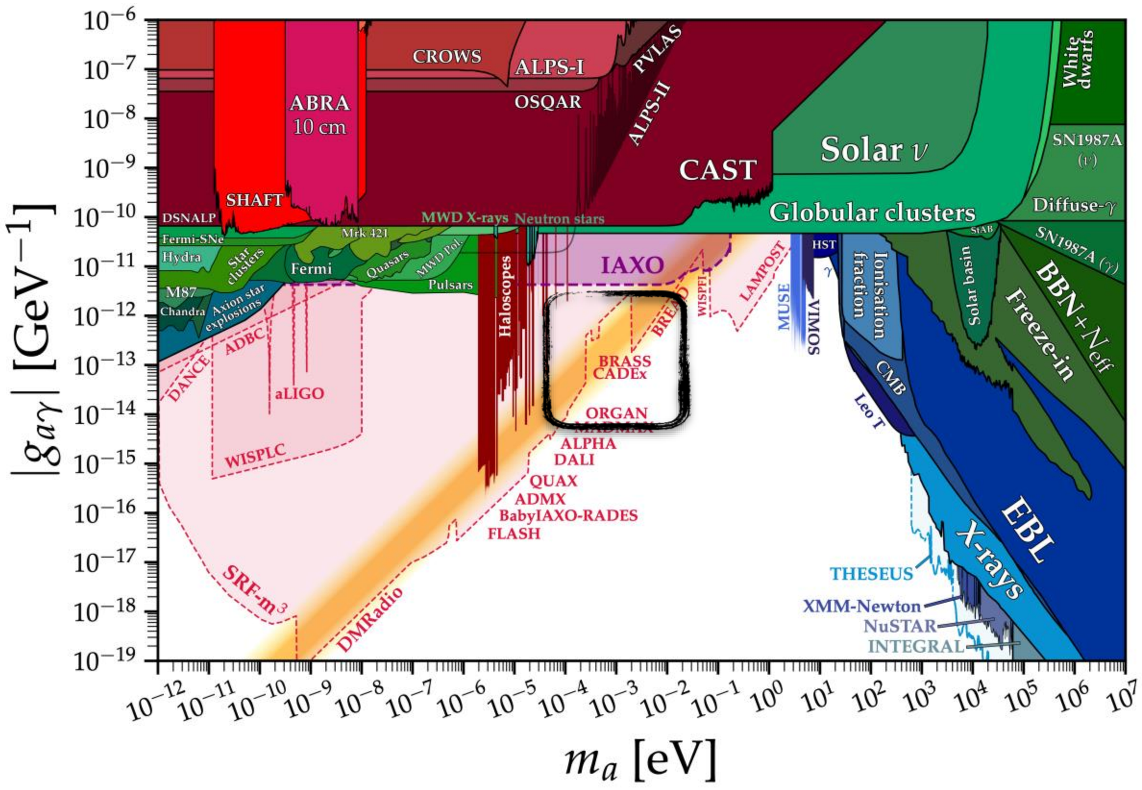
# Motivation

Novel detection system:
**Haloscope + KIDs**

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



CaDEx

CENTRO DE ASTROBIOLOGÍA
ASOCIADO AL NASA ASTROBIOLOGY INSTITUTE
GOBIERNO DE ESPAÑA CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS INTA Instituto Nacional de Técnica Aeroespacial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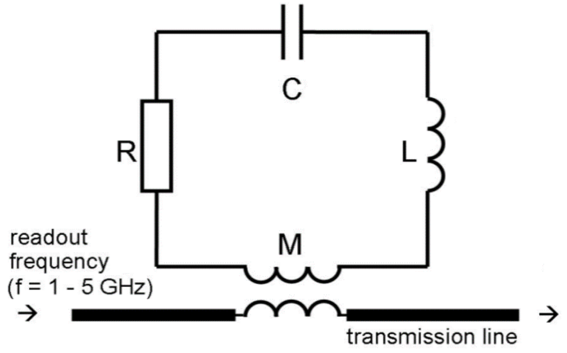
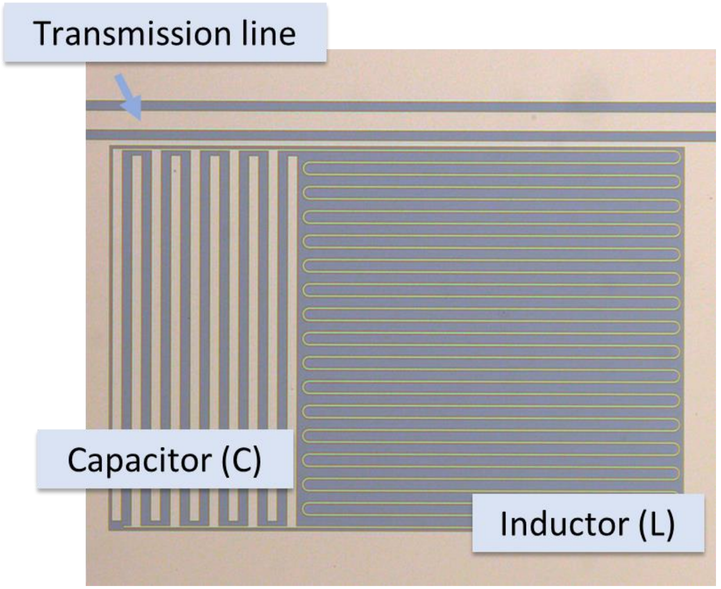
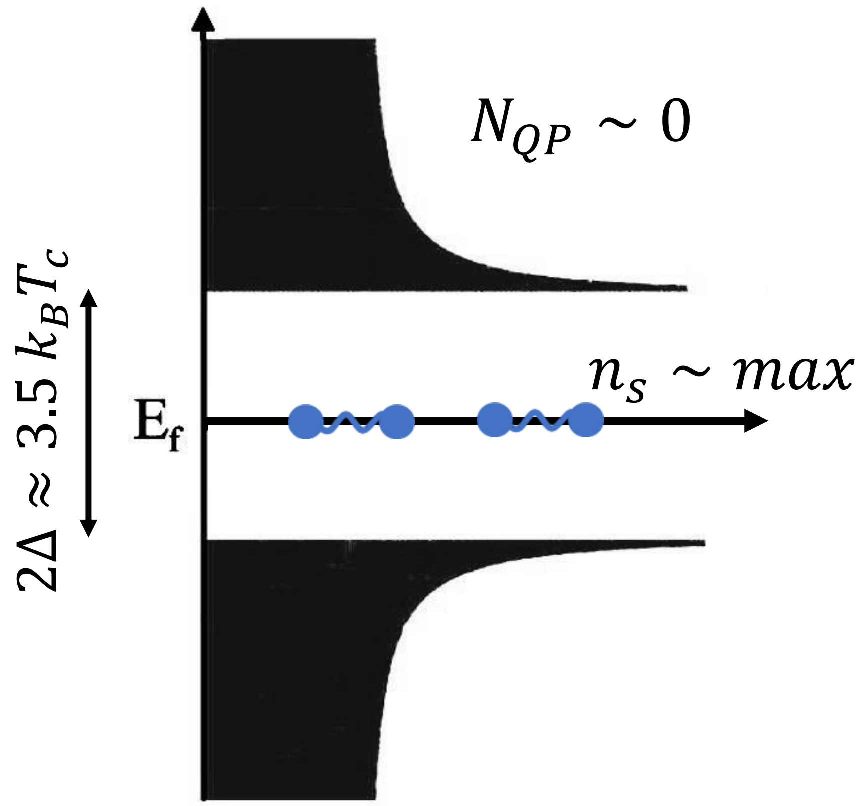
# Superconducting Lumped Element Resonators (LERs)

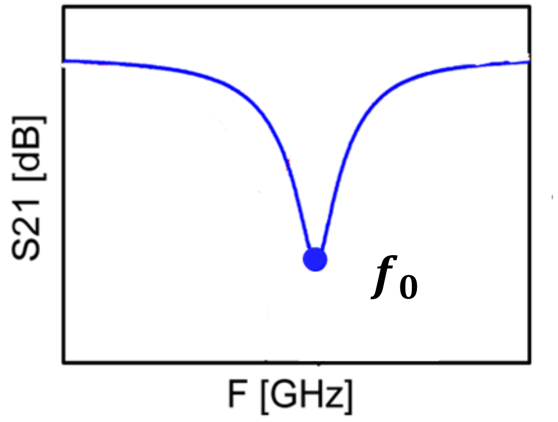
## LERs as Kinetic Inductance Detectors (KIDs)

***Superconducting detectors for mm/submm astronomy***



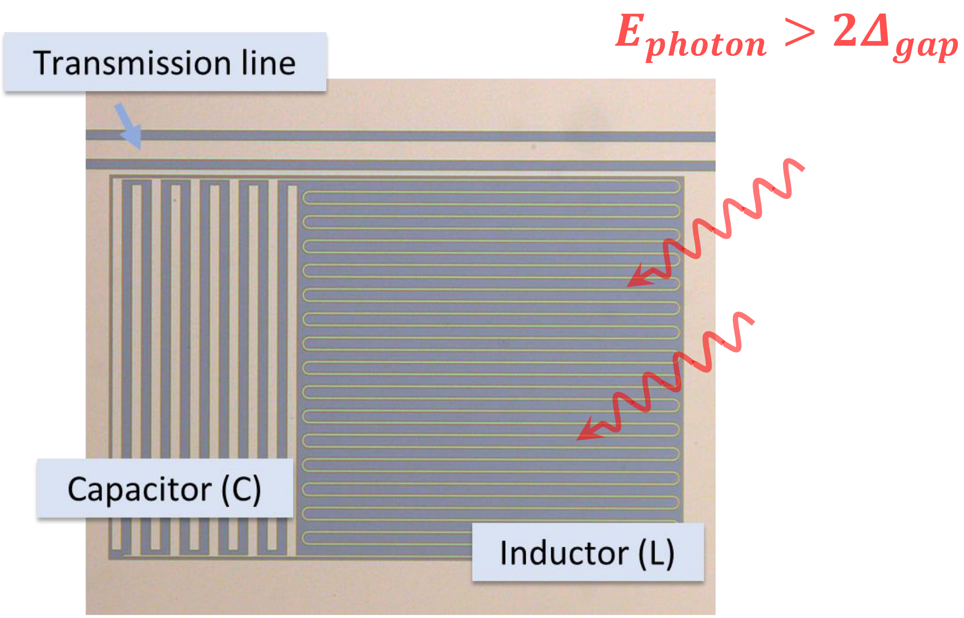

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

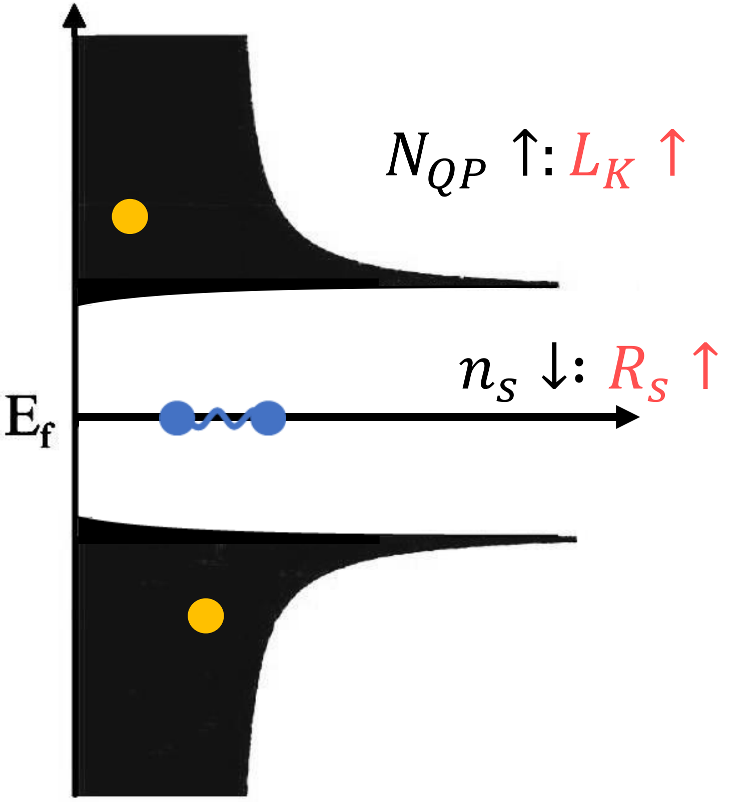
# Superconducting Lumped Element Resonators (LERs)

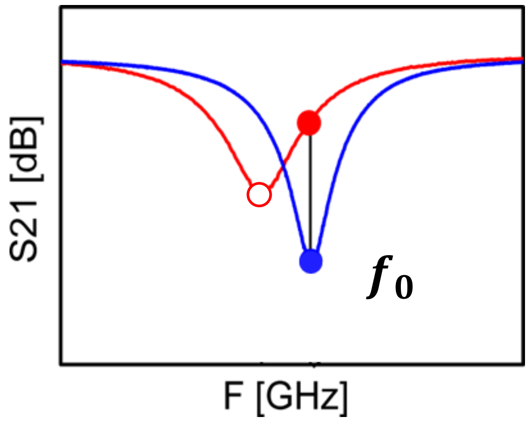


## LERs as Kinetic Inductance Detectors (KIDs)

*Superconducting detectors for mm/submm astronomy*




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

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

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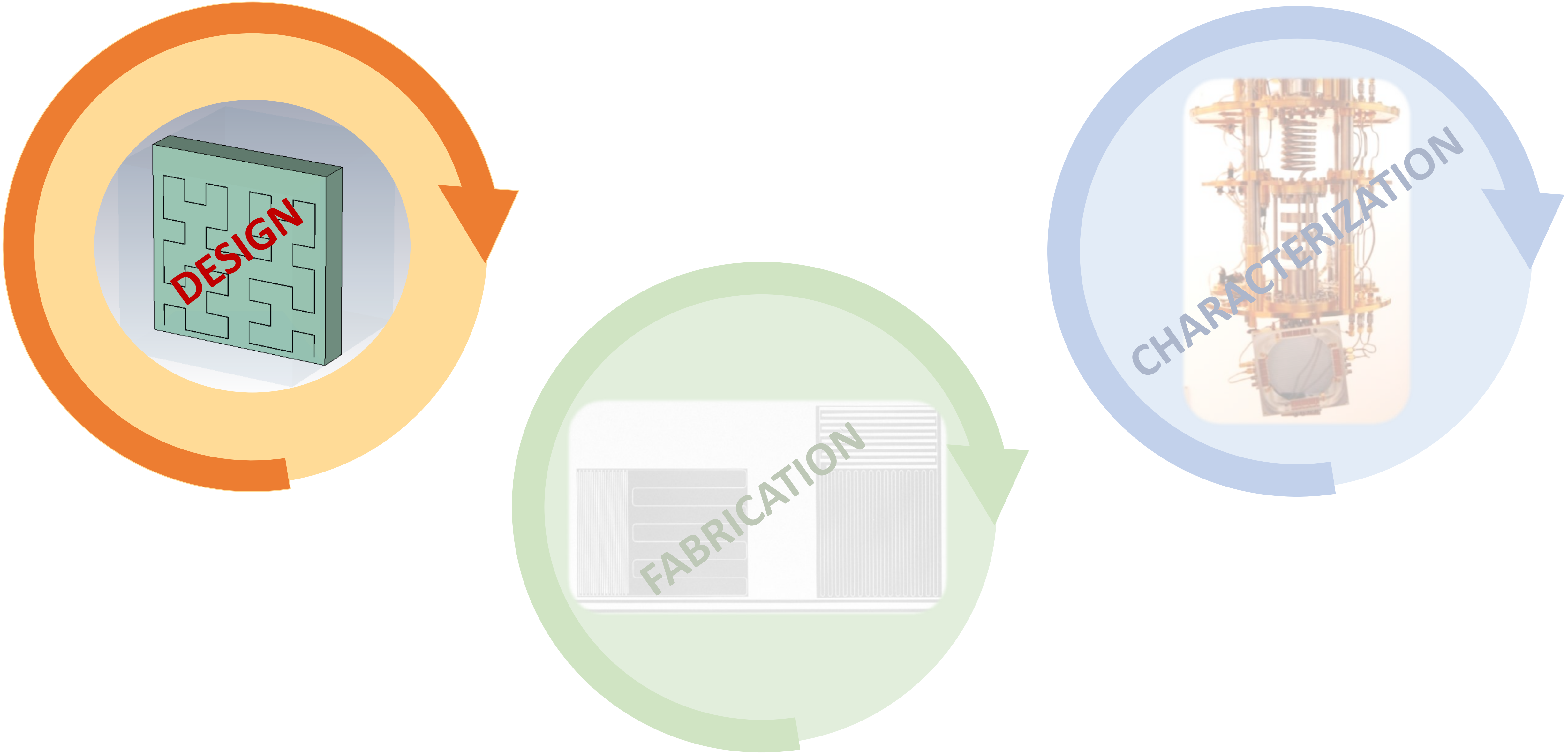
# Implementation

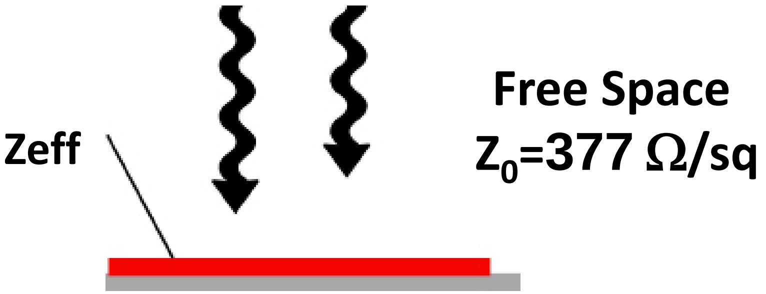


# Implementation

## *Tuning operational frequency band: Pixel Geometry*

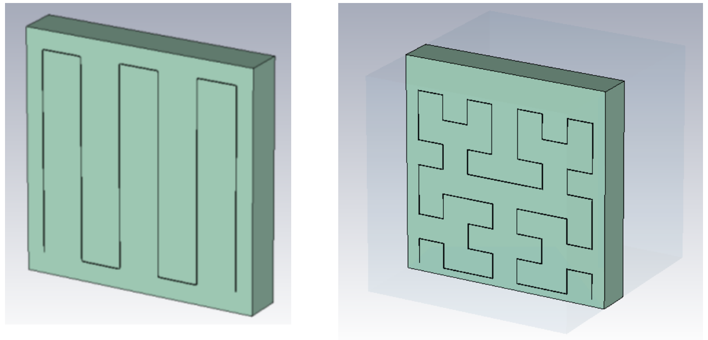
### *LEKID → Inductor = Absorber*

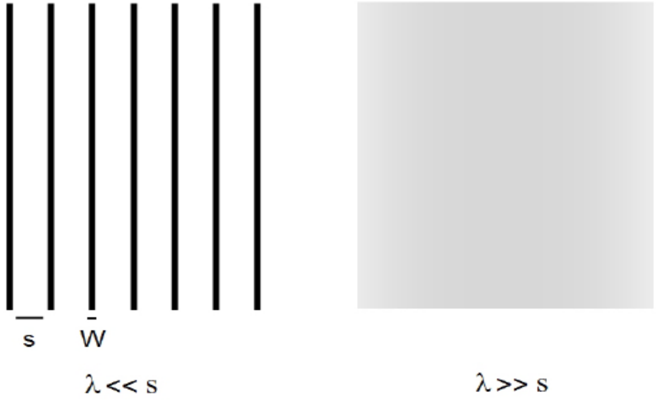
- **Matching impedance:** $Z_0 = Z_{eff}$




- **Solid absorber:** $\lambda/20 > s$

- **Geometry → Polarization sensitivity**





# Implementation

## LER Parameters

### Resonance frequency $f_0$

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

### Quality factor Q

$$Q = f_0 \frac{Average\ energy\ stored}{Energy\ loss/second} = \frac{f_0}{2\kappa}$$

$$\frac{1}{Q_T} = \frac{1}{Q_{int}} + \frac{1}{Q_{coupling}}$$

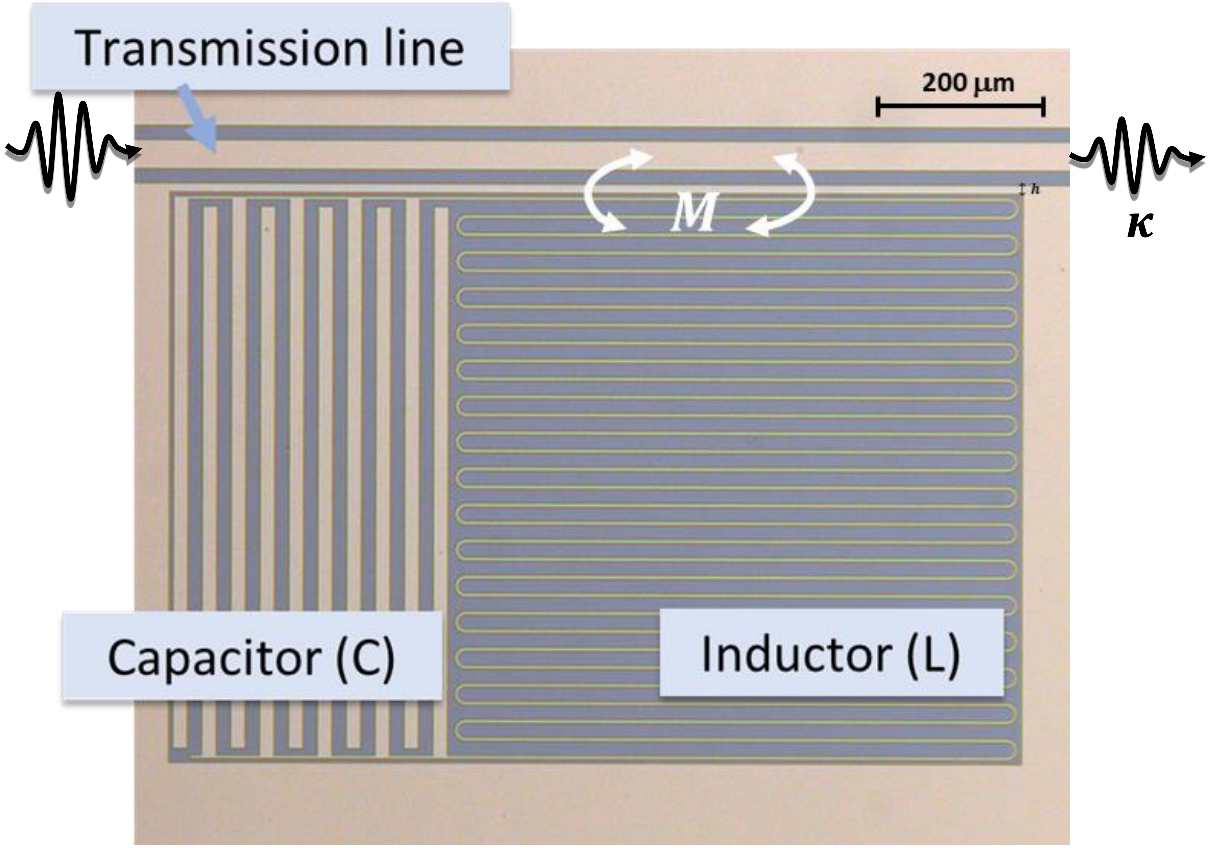
Internal quality factor

Coupling quality factor

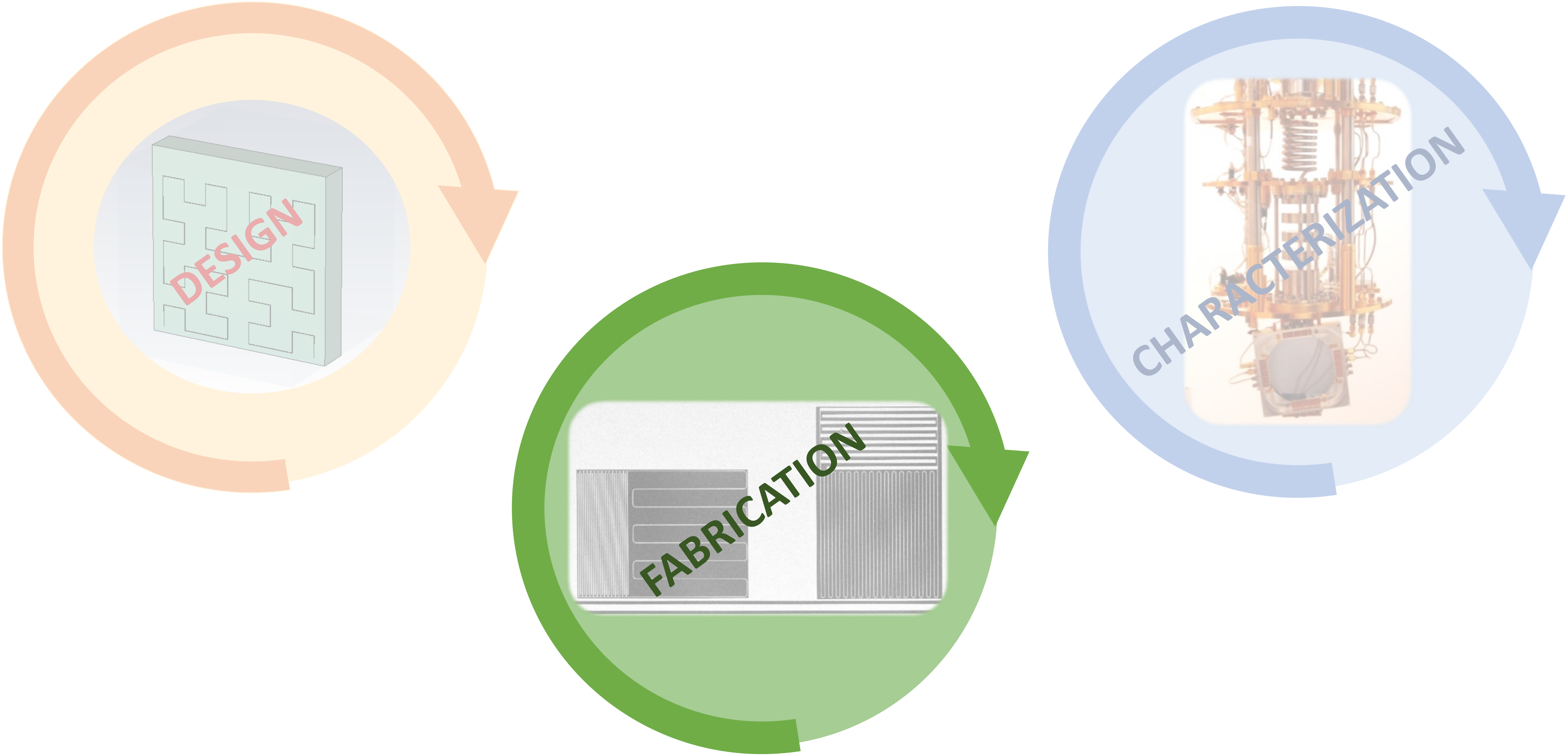
### Impedance Z

$$Z = \sqrt{\frac{L}{C}}$$

*Microwave Electromagnetic Simulations*



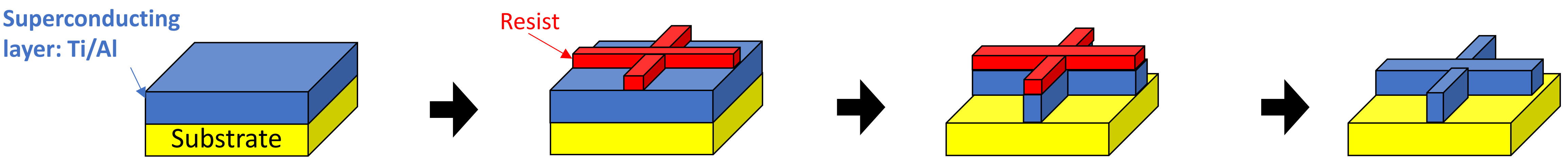
# Implementation



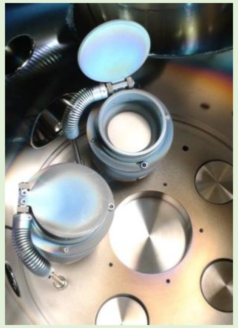
# Implementation

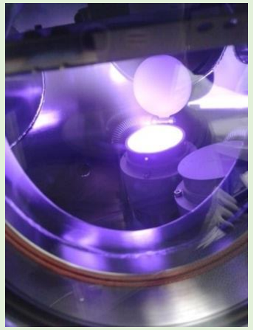


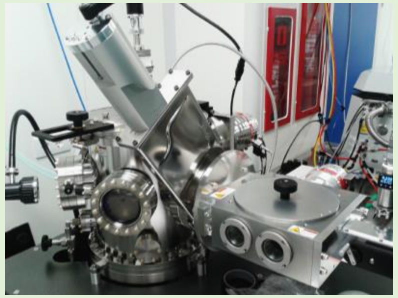
## LERs nanofabrication in Clean Room



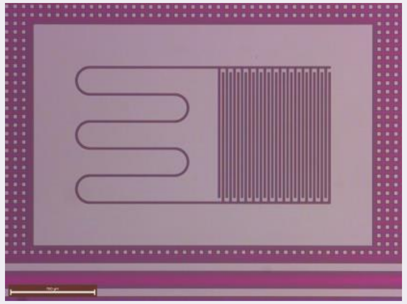

***Sputtering / Electron beam evaporator:***
*Deposition of superconducting films*



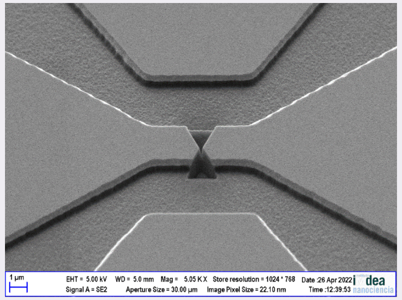




***Nano and micro lithography***

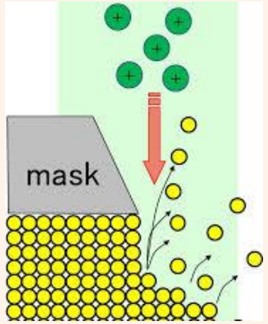


*Laser writer*

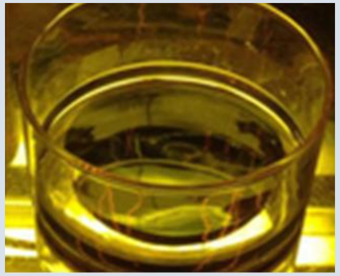


*Focus ion beam*

***Etching:***
*Wet etching, ion milling and RIE*



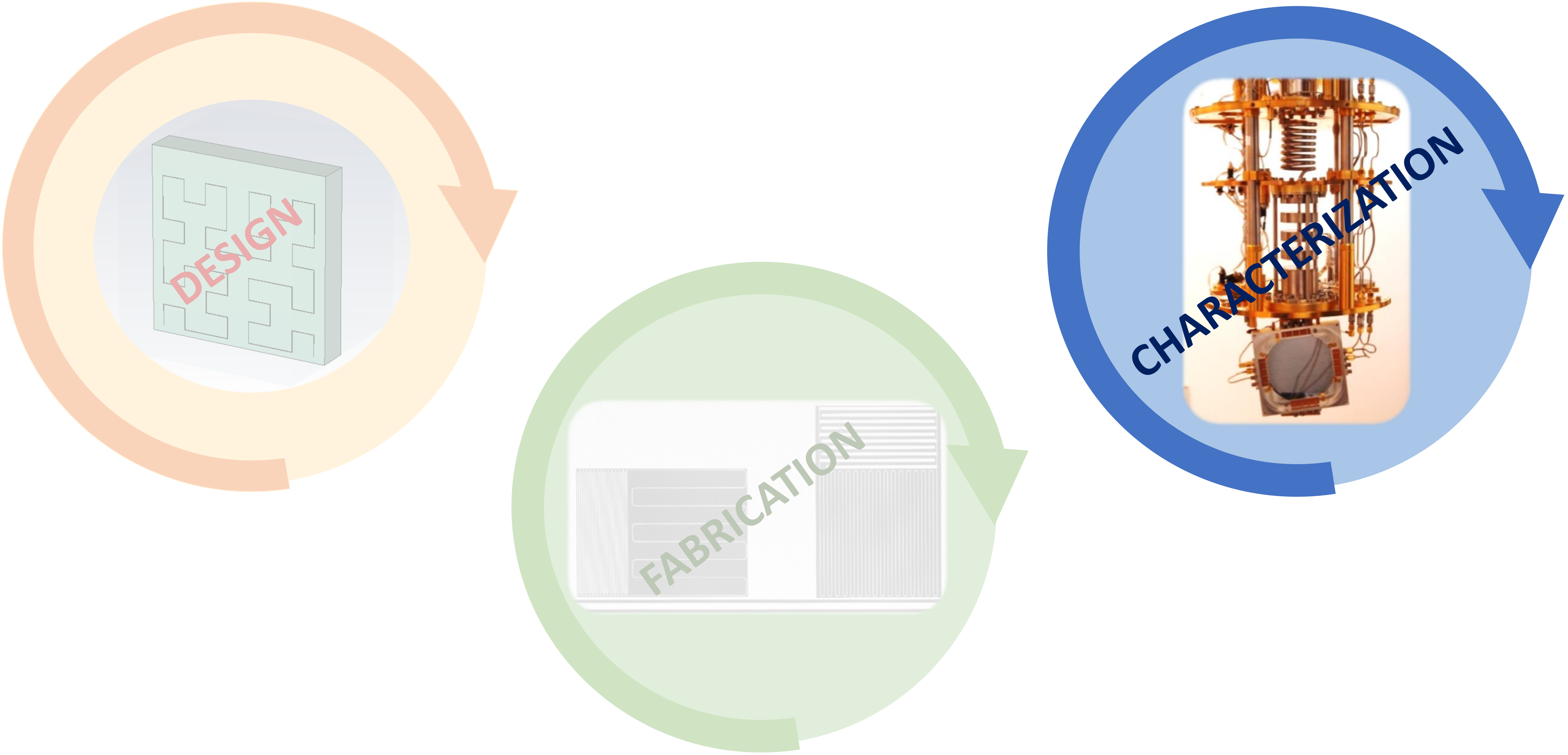

***Stripper:***
*Removing the resist*



*Acetone bath*

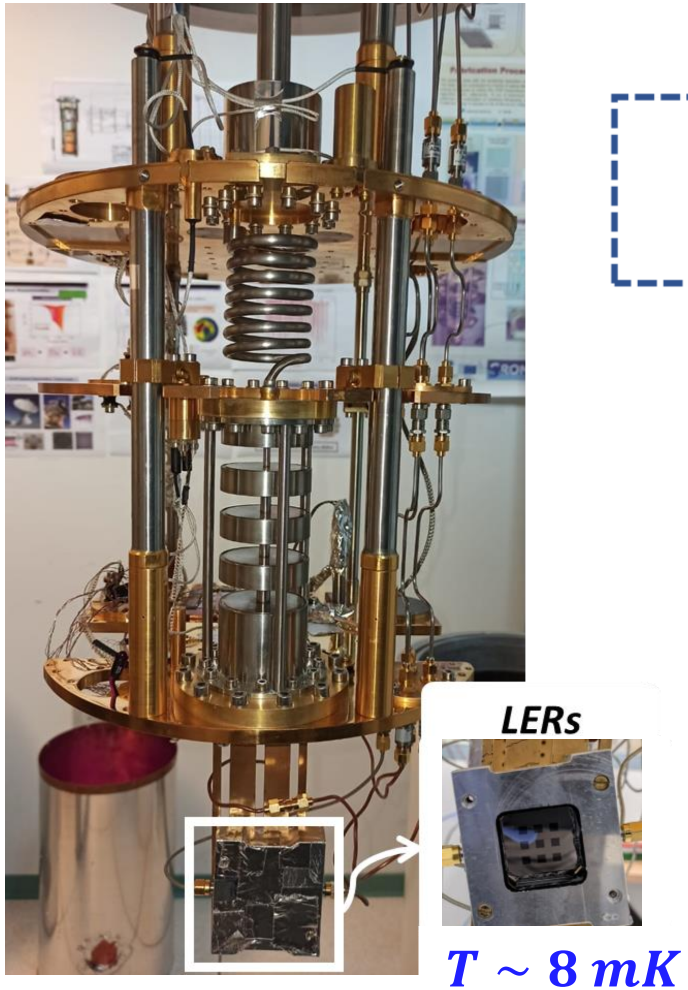
*Oxygen plasma*

# Implementation

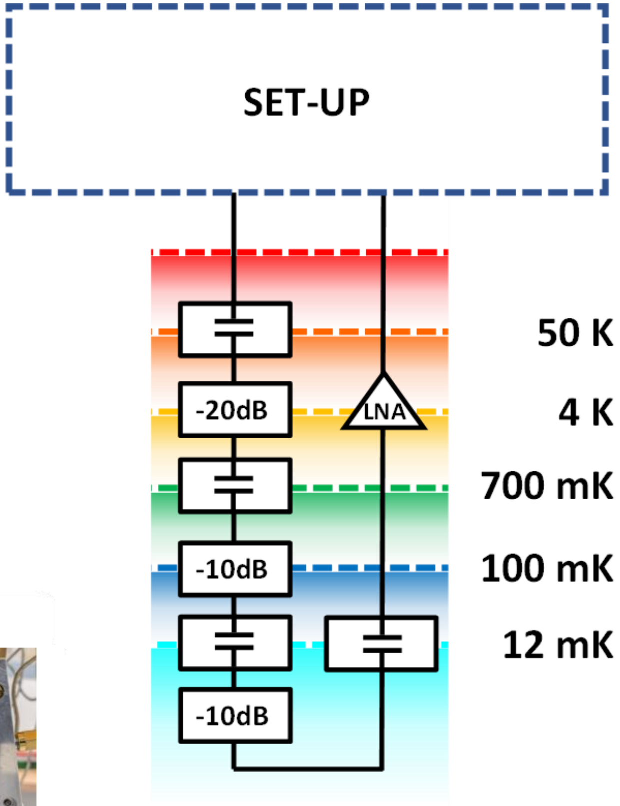


# Characterization

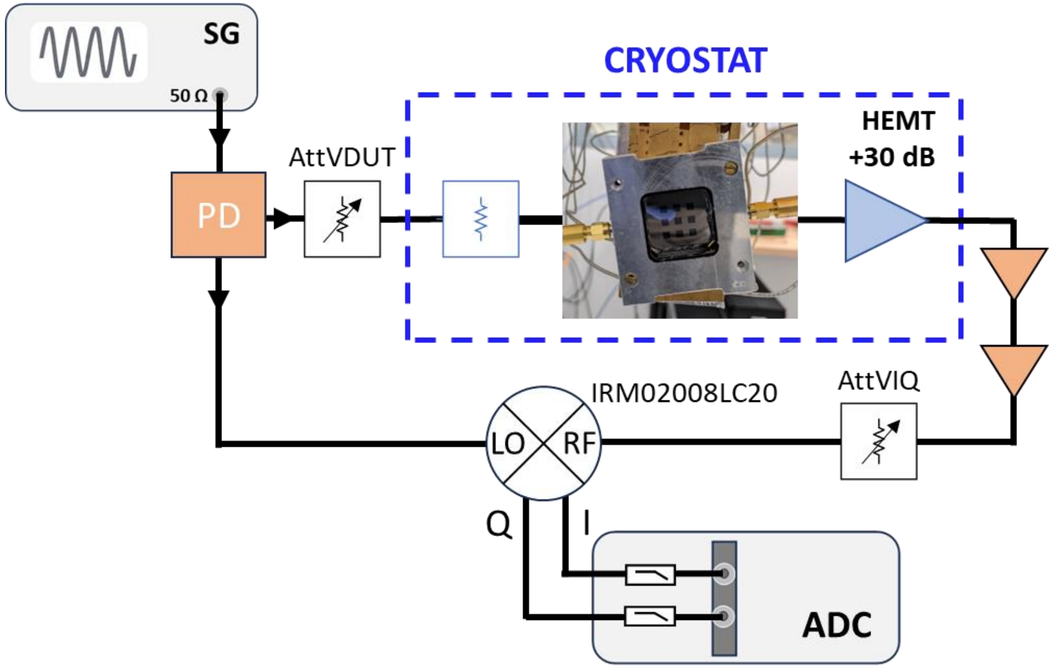
### *He³/He⁴ Dilution Refrigerator*




$T \sim 8\,mK$




### *Radio-Frequency Characterization set-up*



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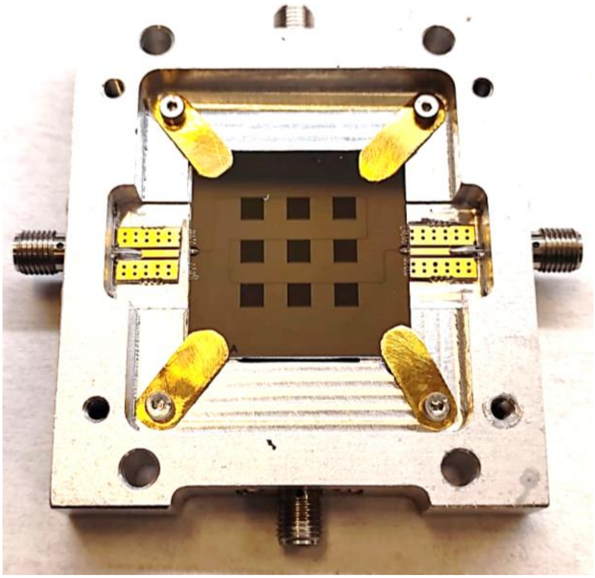
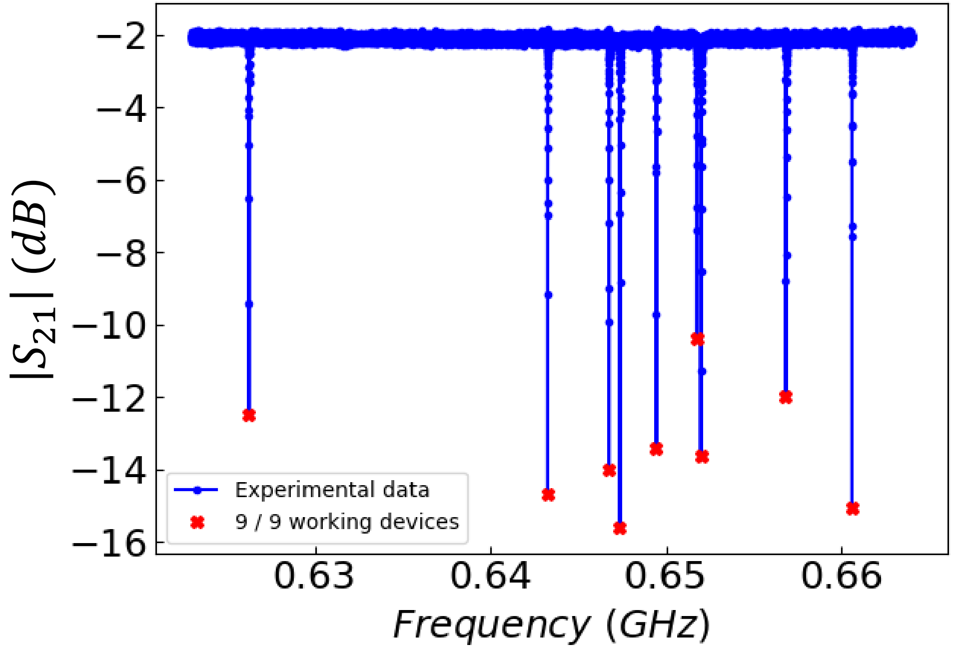
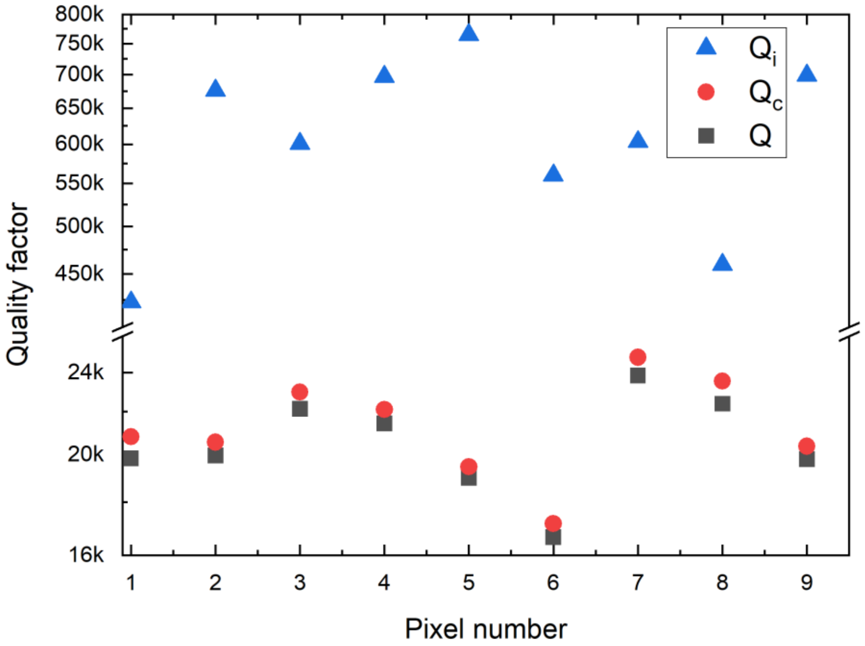
# Results

## Dark cryogenic characterization

*9 pixels demostrator*






**High internal quality factor:** $Q_i \sim 7 \cdot 10^5$

**Kinetic fraction:** $\alpha \equiv \frac{L_k}{L_{total}} = 1 - \left(\frac{f_{exp}}{f_{simLk=0}}\right)^2 \approx 0.57$

✓ High superconducting film quality

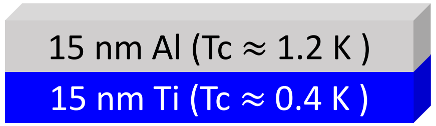
✓ High nanofabrication yield

*M. C. de Ory et al. , IEEE TMTT (2024)*

# Results

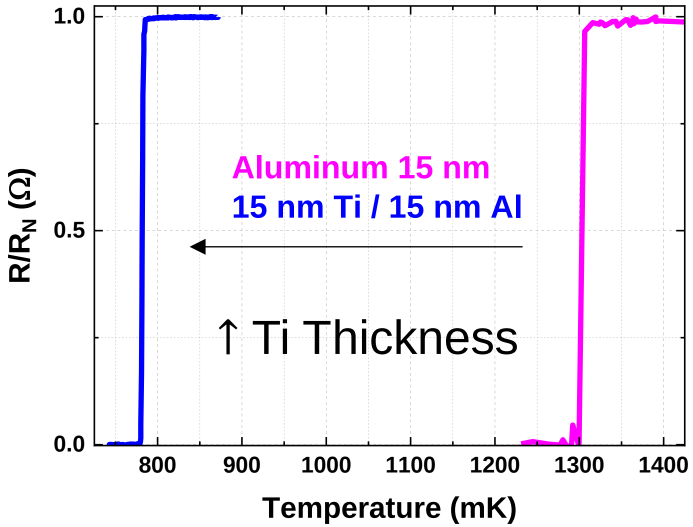
## Setting the operational frequency band to the W-band

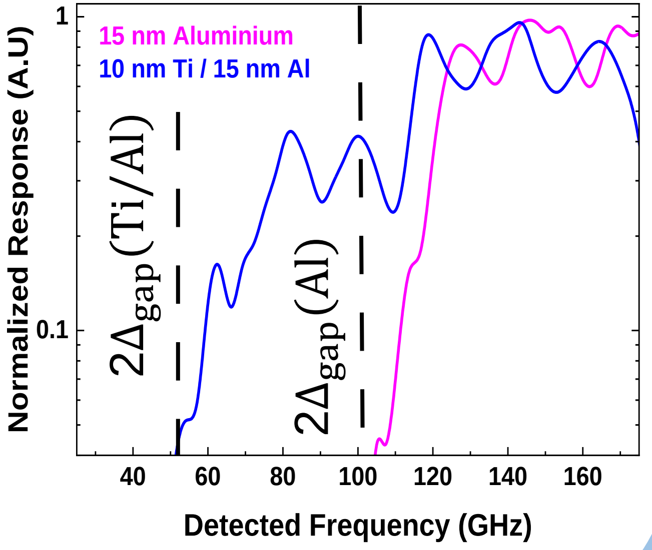
### *Proximity Effect: Titanium/Aluminum bilayers*




Ti/Al: $T_c \approx 780\,mK\ fcut\ @\ 60\,GHz$

***W-band : 75-110 GHz → Ti/Al suitable***

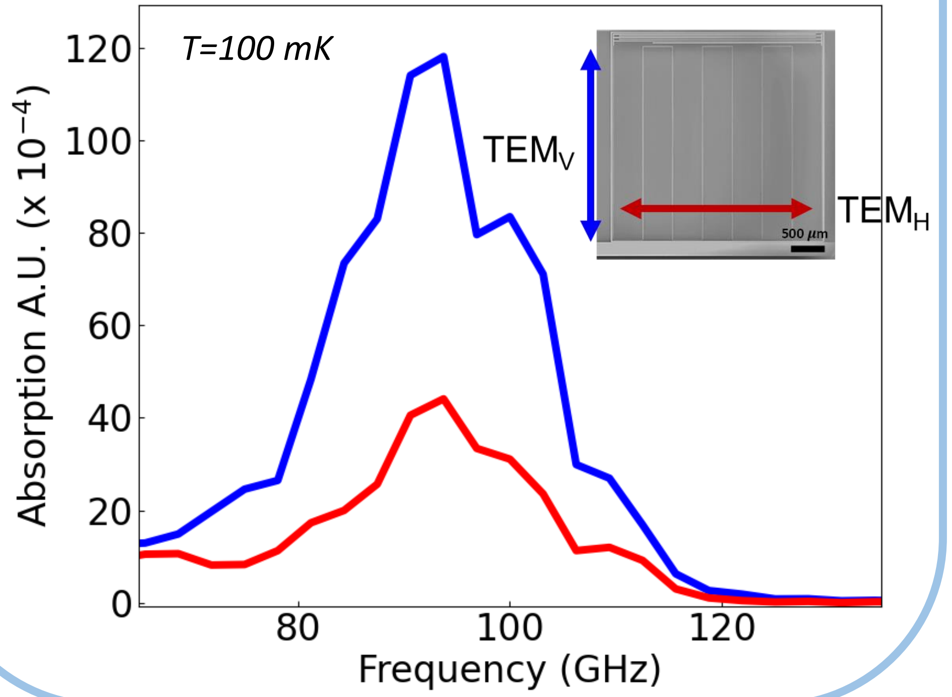



*A. Catalano et al., A&A (2015)*

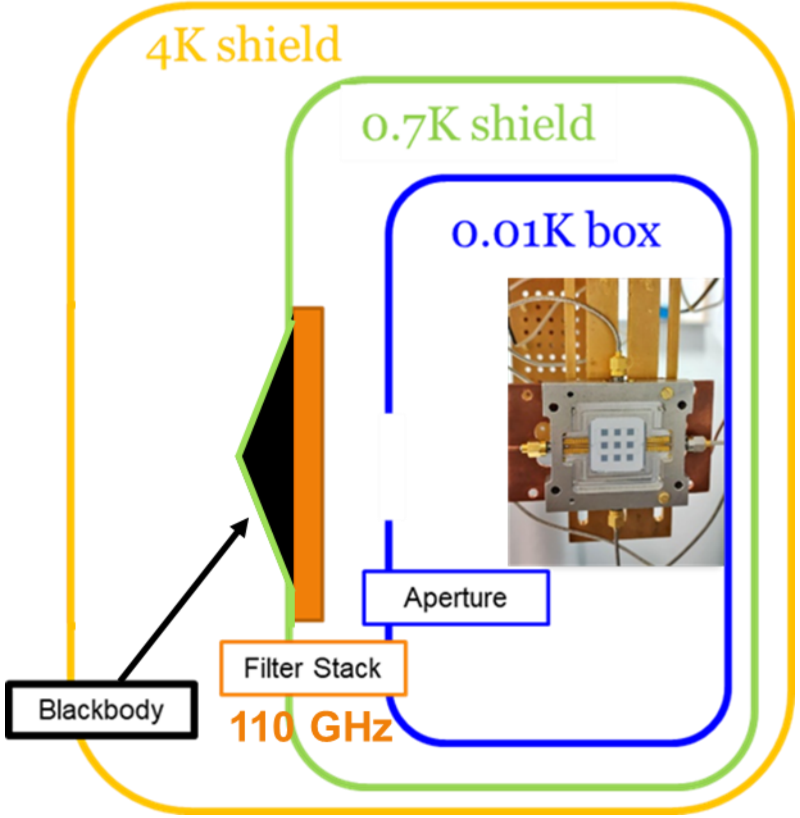
### *Impedance Matching*

*LEKID → Inductor is the effective optical absorbing área → Geometry constrains*



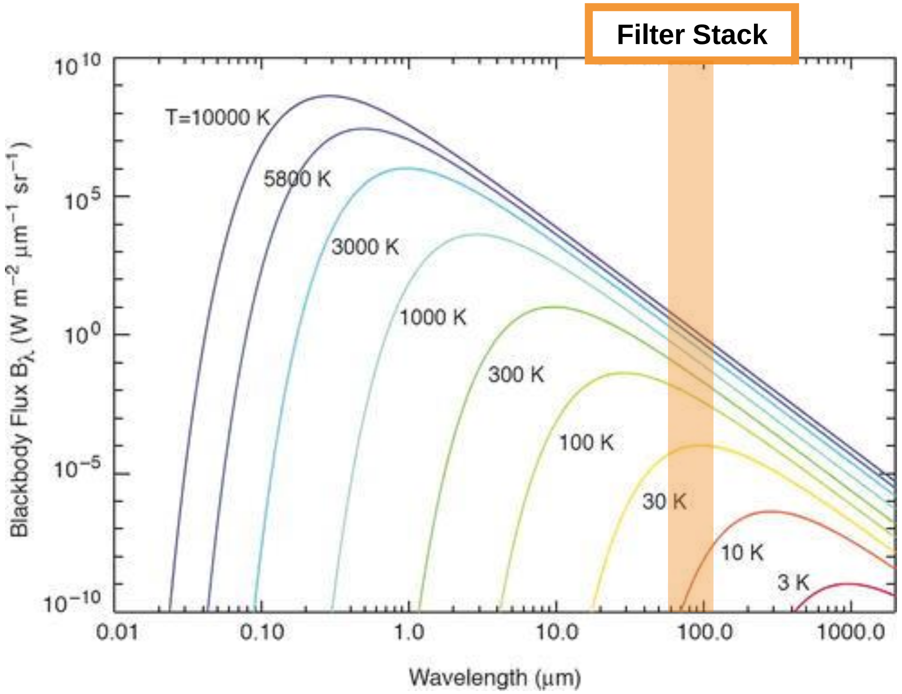
# Results

## Radiation absorption characterization
## responsivity to W-band



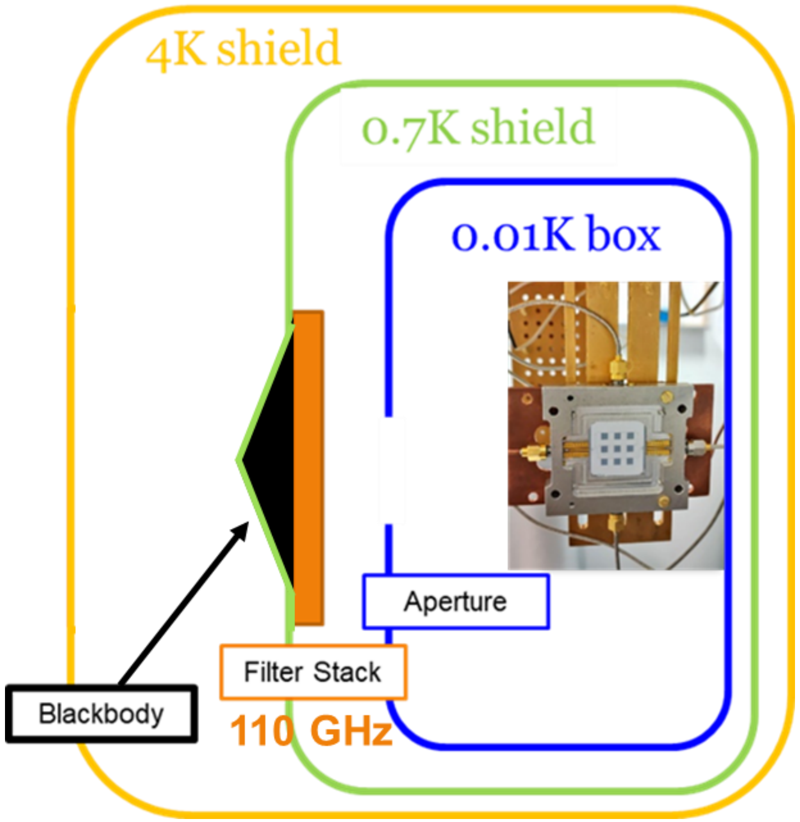

*Blackbody temperature controls optical loading*

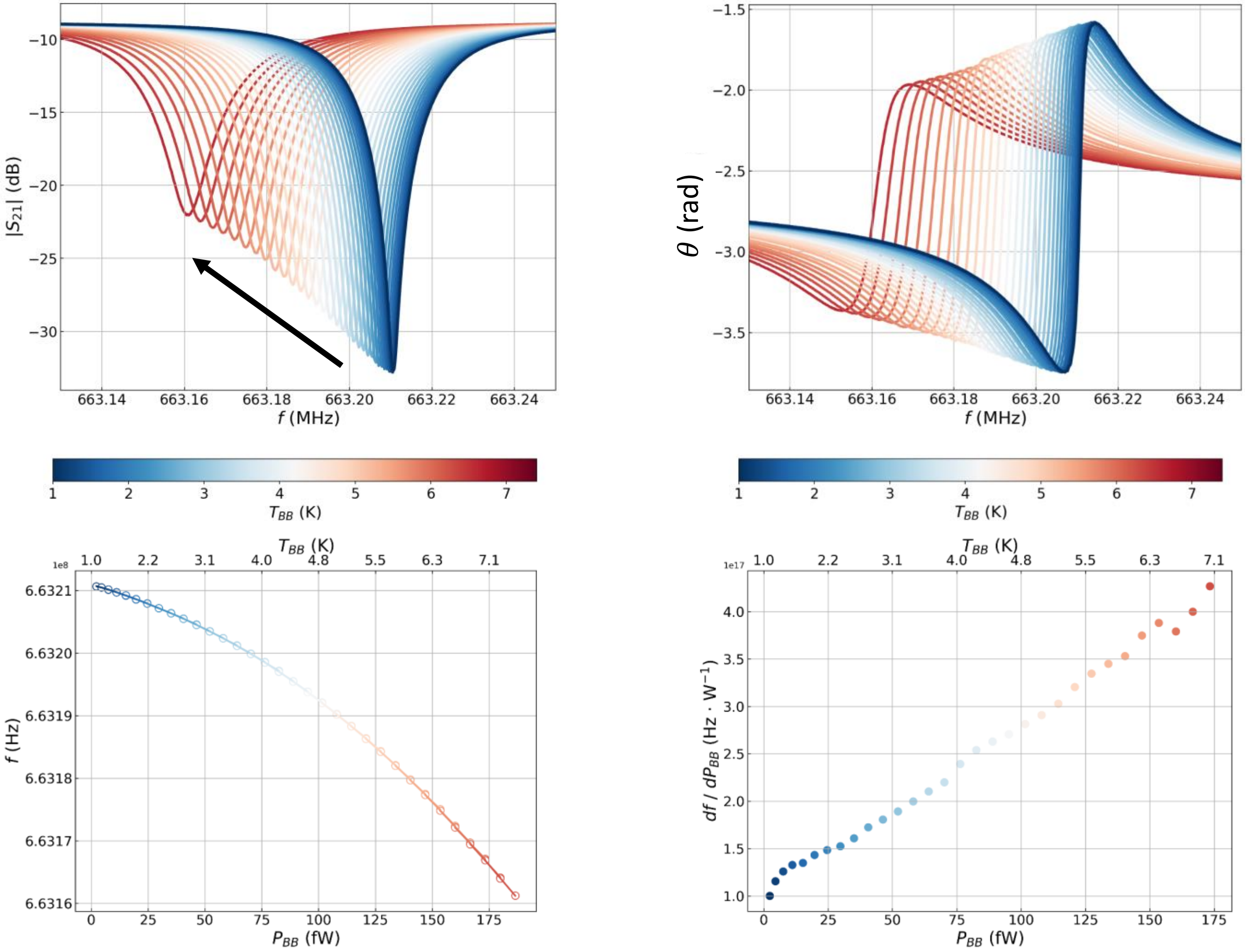
$T_{BB}$ (1 K– 7K) : Optical Power Load



# Results

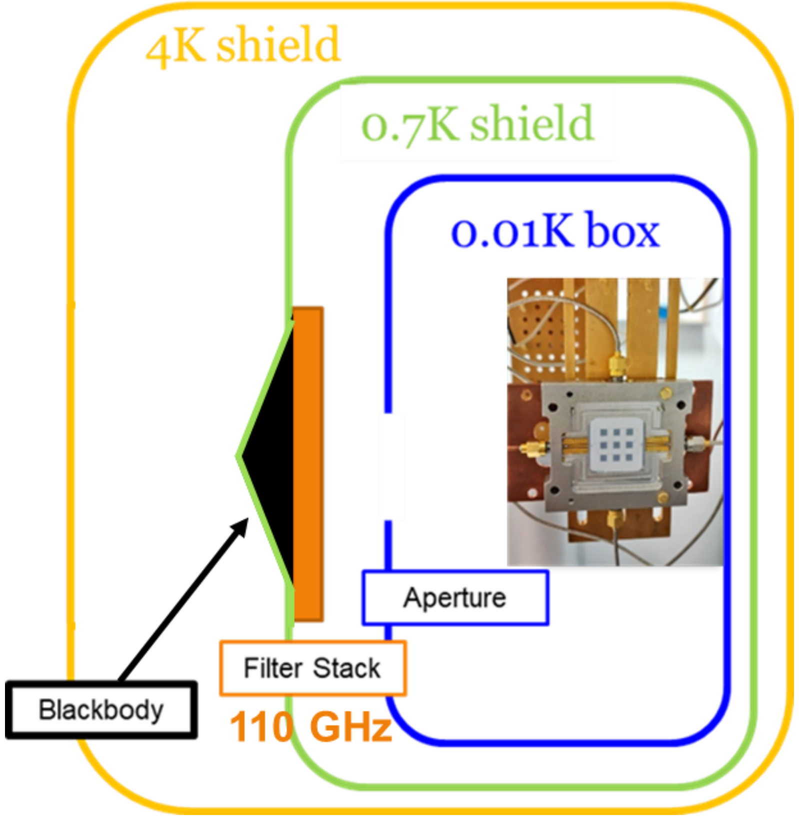
## Radiation absorption characterization
## responsivity to W-band

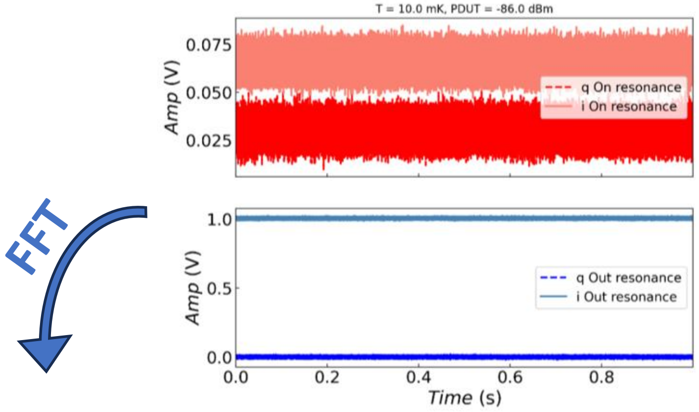


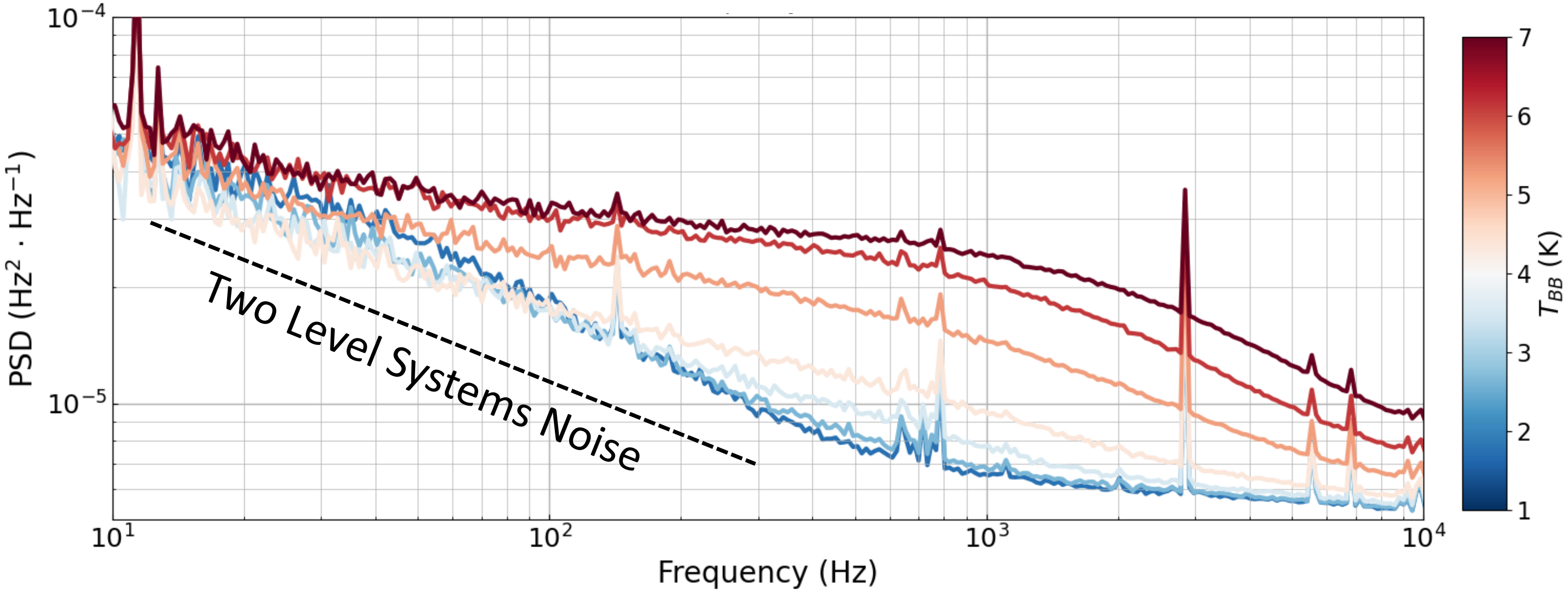
# Results

## Radiation absorption characterization responsivity to W-band



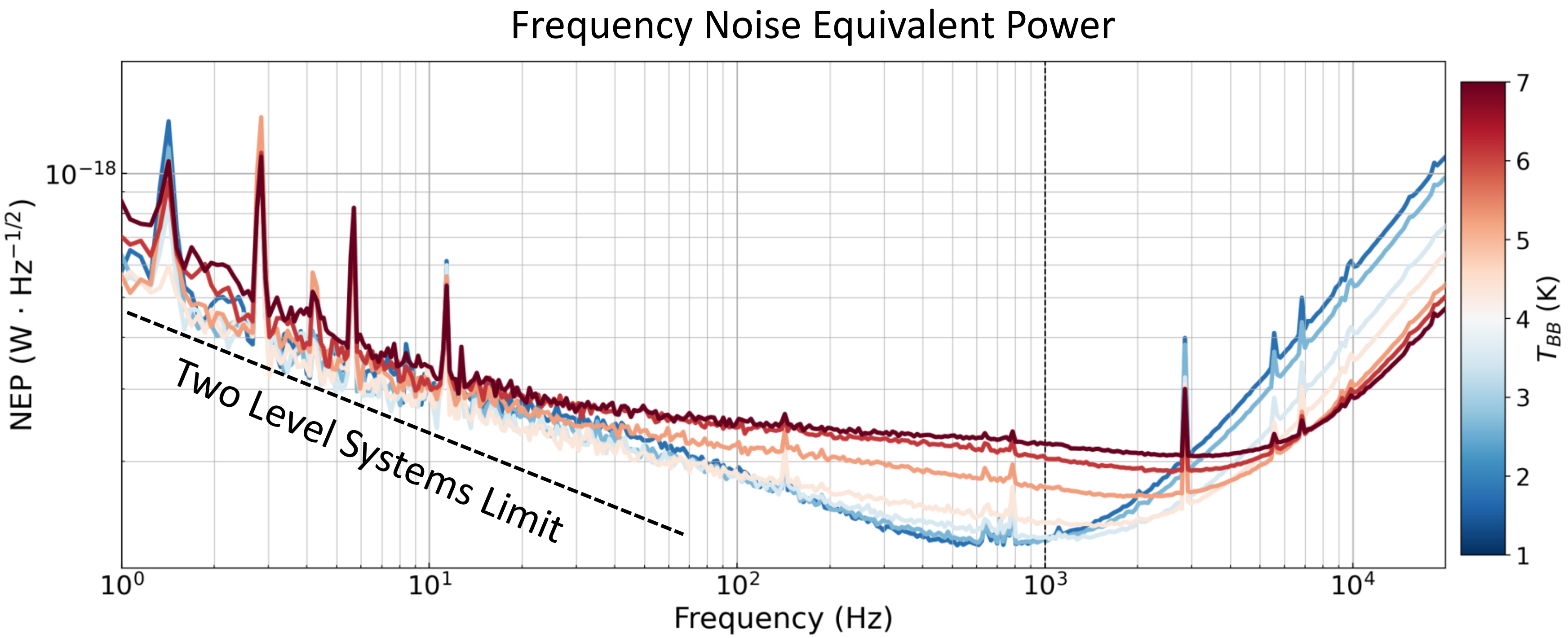



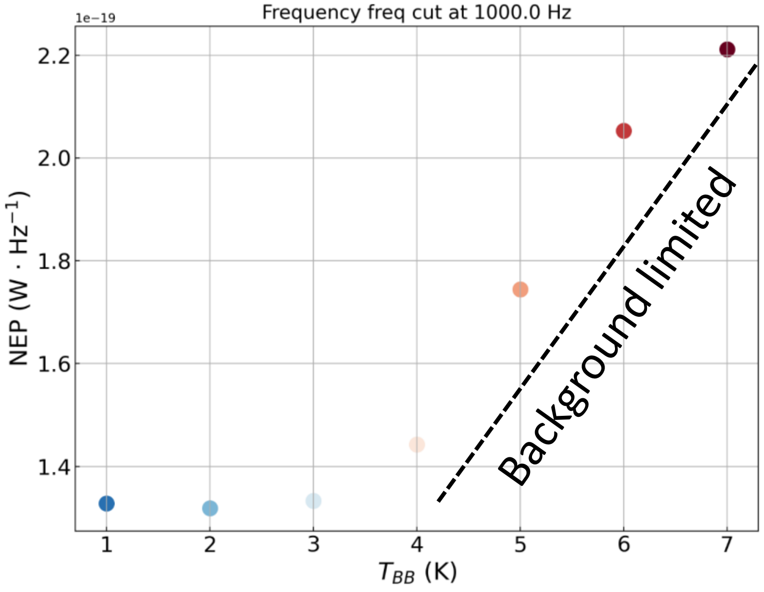

Frequency noise response



# Results

## Radiation absorption characterization responsivity to W-band




$$NEP_{\delta f}(1.0\ K, 1\ kHz) \sim 1.3 \cdot 10^{-19}\ W/\sqrt{Hz}$$

# Summary

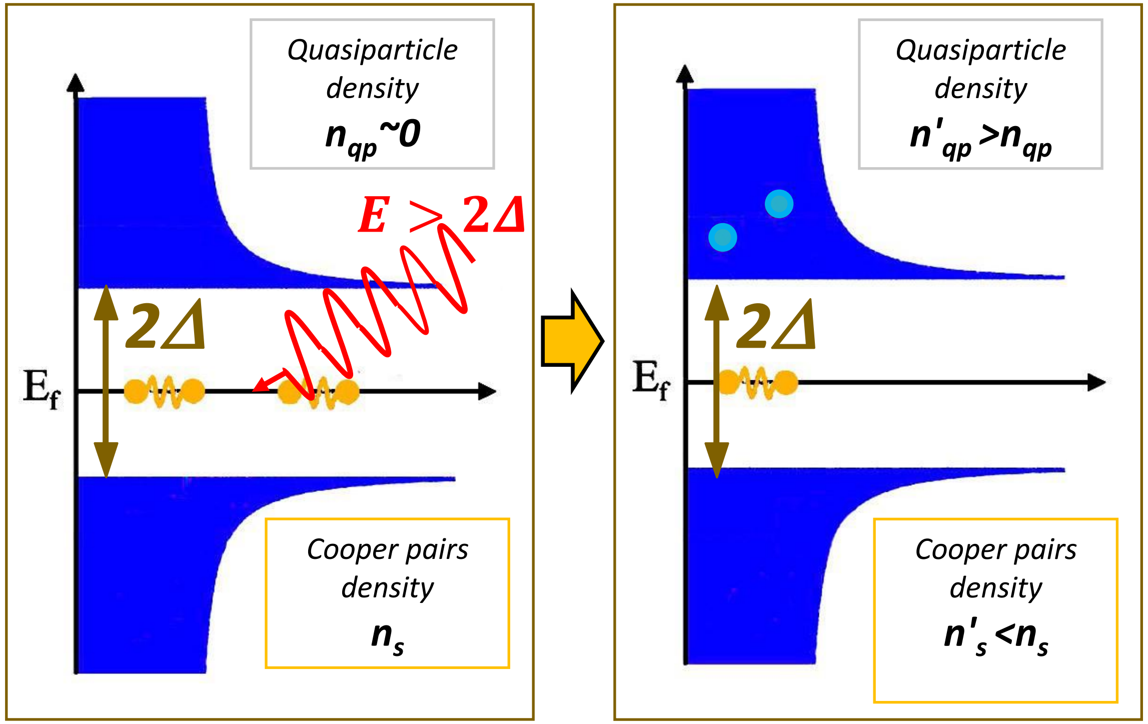
- **Characterized LEKIDs noise response sweeping the Black Body temperature.**
- **Best NEP is about $\mathbf{1.3 \cdot 10^{-19}}\ \boldsymbol{W/\sqrt{Hz}}$. We are still background limited.**
- **Sensitivity is close to the baseline of CADEx**

## Forward to achieve the CADEx goal

- **TLSs reduction and 1/f noise mitigation**
- **Responsivity measurement improvements in a controlled low background environment.**

# Kinetic Inductance Detectors (KIDs)

**PHOTON →** $E_{photon} > 2\Delta_{gap}$




Change in…

**SUPERCONDUCTING PROPERTY**

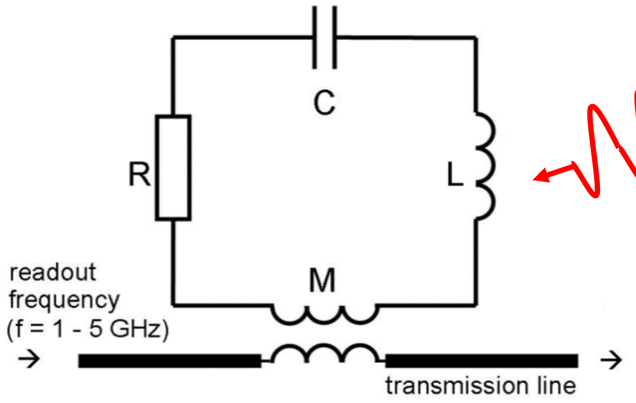
**KINETIC INDUCTANCE**

$$L_k = \frac{m_e}{n_s t e^2}$$

Absorbed photon → $\downarrow n_s$ → $\uparrow L_K$

# Kinetic Inductance Detectors (KIDs)

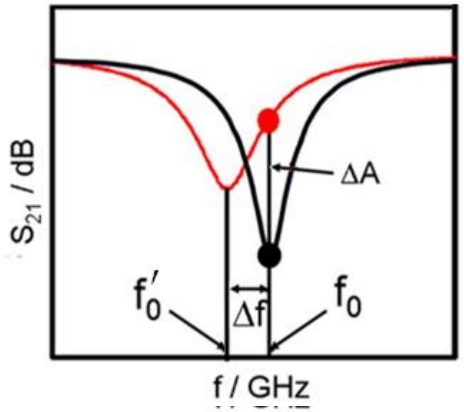
$E > 2\Delta$

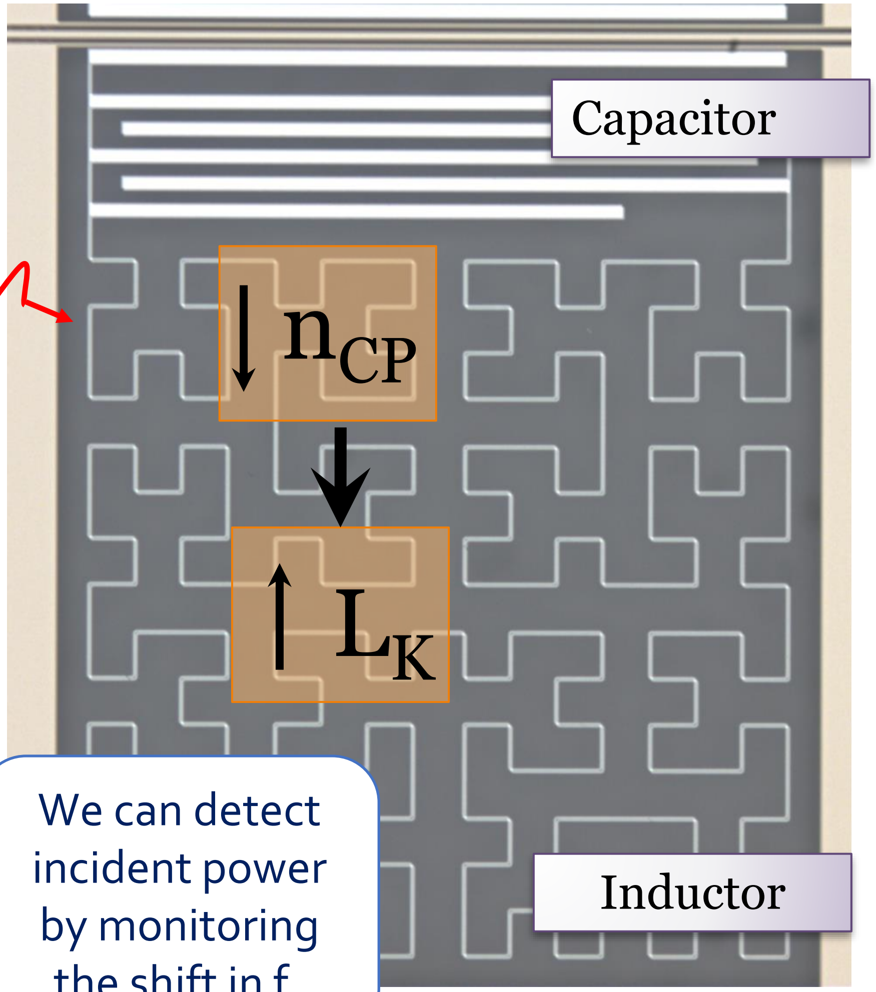



$L = L_g + L_k$

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

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



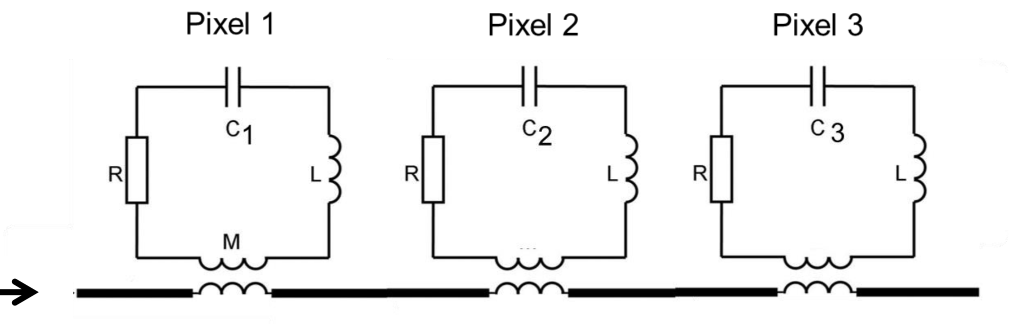




We can detect incident power by monitoring the shift in $f_0$

*Day et al., Nature (2003)*

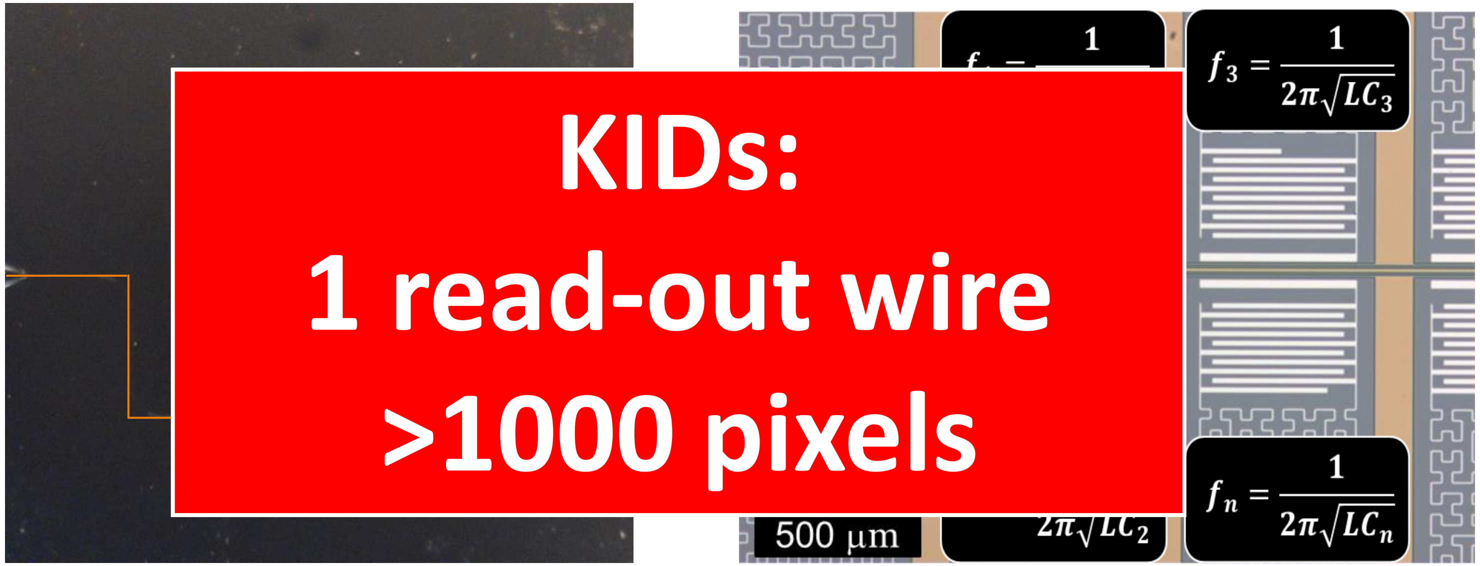
# Kinetic Inductance Detectors (KIDs)

## Multiplexing → 1 wire > 1000 LERs




Transmission line →

*Multiples LERs coupled to a single transmission line*




**KIDs:**

**1 read-out wire**

**>1000 pixels**