RED DE INFRAESTRUCTURAS DE ASTRONOMIA

Tec2SPACE CM

Superconducting resonators for space and quantum applications

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21th April 2022

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

We are a team

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Funding and support

S2018/NMT-4291 (TEC2SPACE-CM)

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PID2019-105552RB

State-of-the-art detectors for space applications

REQUIREMENTS

- High sensitivity.
- Large number of pixels.
- Low power dissipation.

→ **Superconducting detectors**

X-IFU, LiteBird, SAFARI, OST, LISTZ, FOSSIL,…

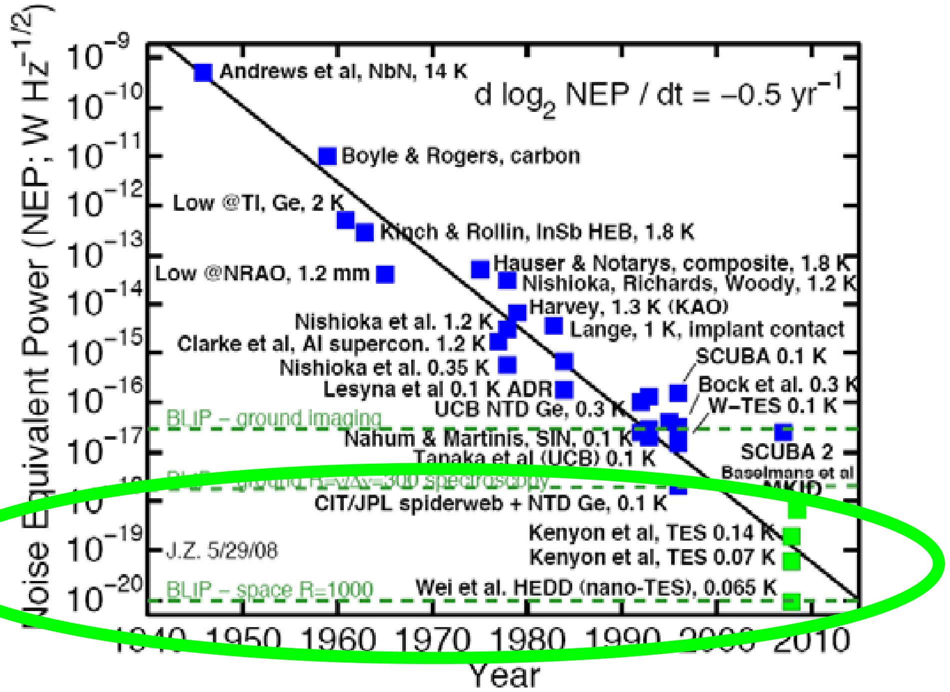


Image credit J. Zmuidzinas (2010)

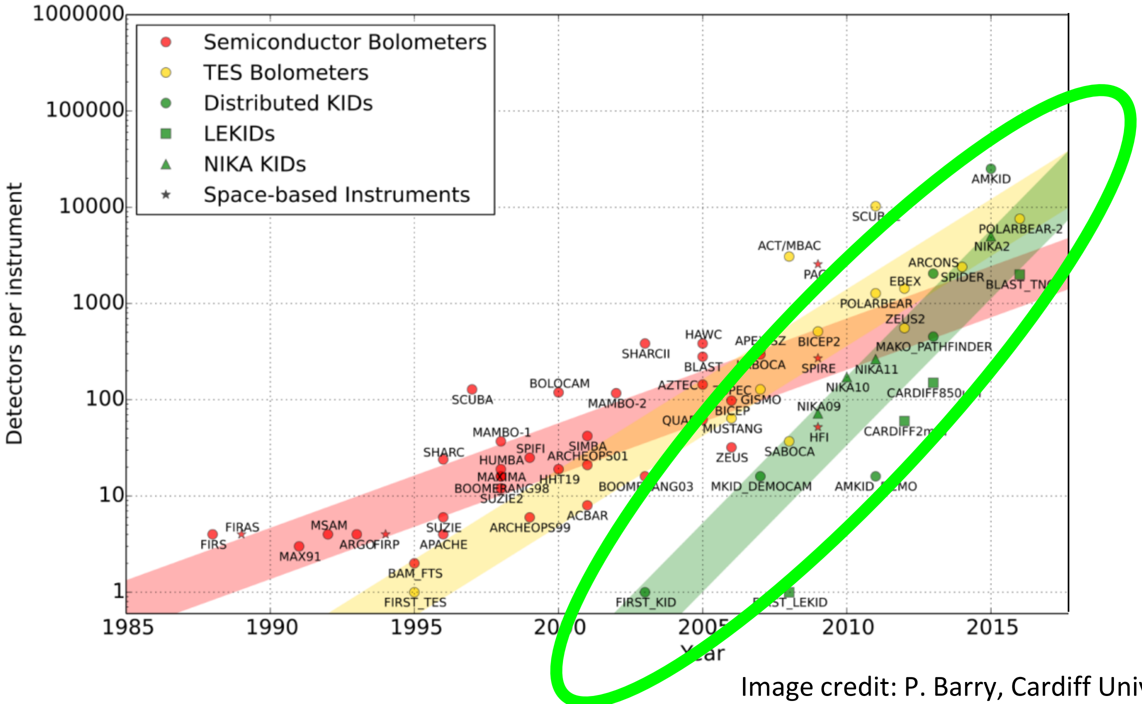


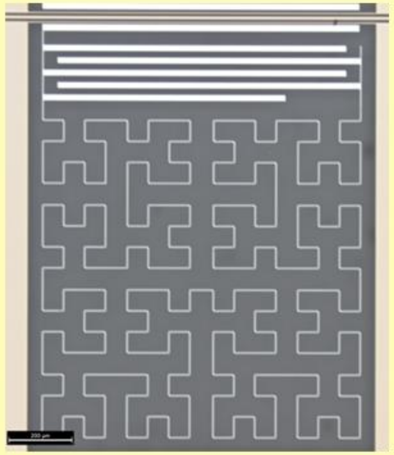
Image credit: P. Barry, Cardiff University (2015)

Superconducting detectors

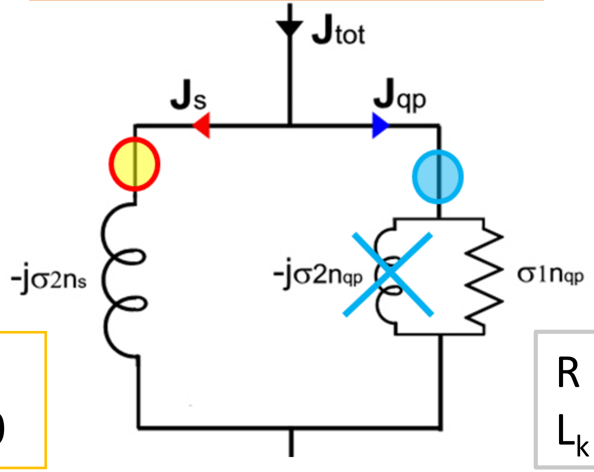
Which property is it going to be measured?

Change L_k

Kinectic Inductance Detector (KID)



TWO FLUID MODEL

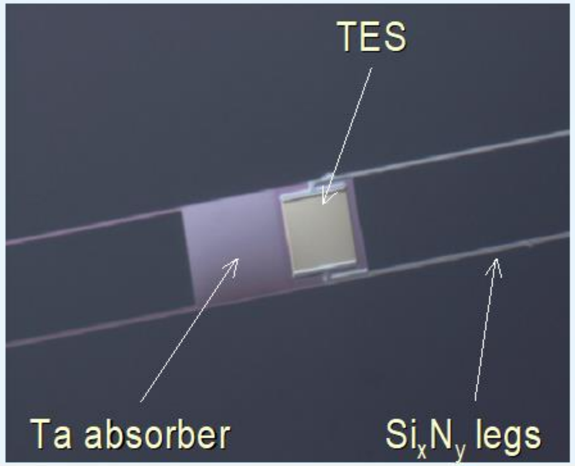


R= 0
$L_k \neq 0$

R ≠ 0
$L_k = 0$

Change in R

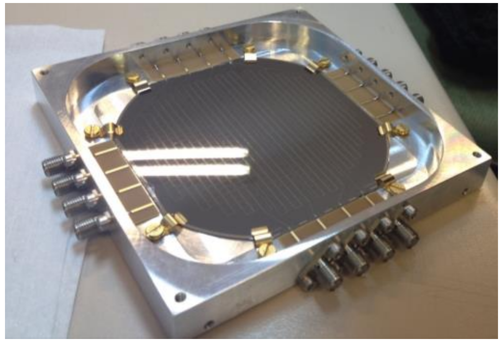
Transition Edge Sensor (TES)



Kinetic Inductance Detectors (KIDs)

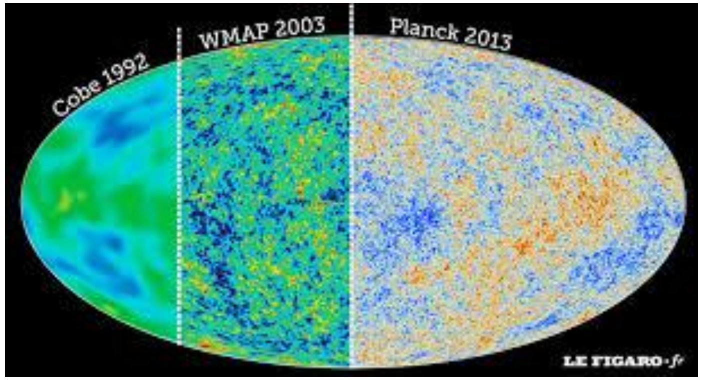
KIDs superconducting detectors for future space instrumentation

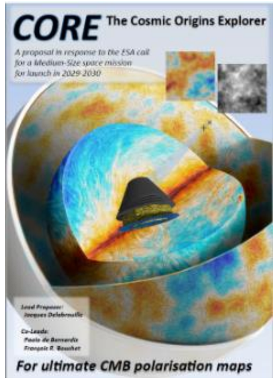
- State-of-the-art sensitivity
- Broad band detection
- Intrinsically multiplexable
  - Easy cryogenic harness



KIDs for W-band

Cosmic Microwave Background (CMB)



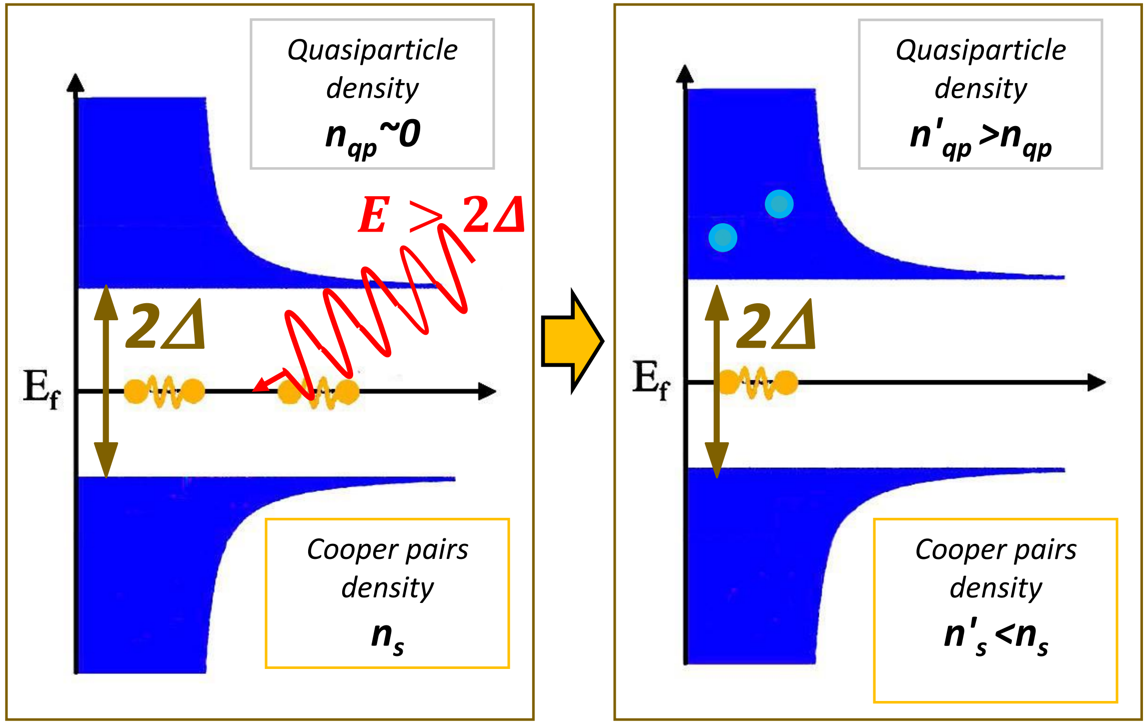


Dark Matter experiments: axions detection

CADEX Collaboration

Kinetic Inductance Detectors (KIDs)

PHOTON → $E_{photon} > 2\Delta_{gap}$



Change in...

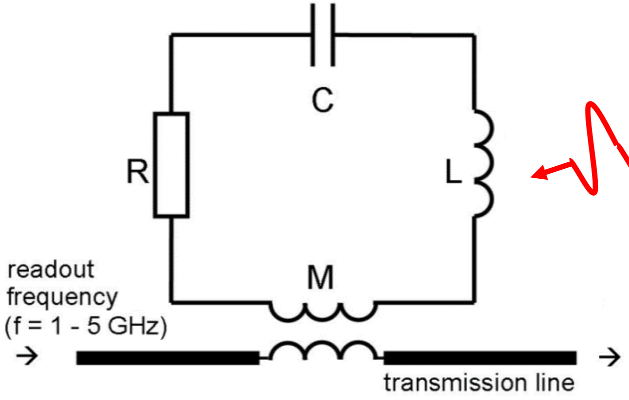
SUPERCONDUCTING PROPERTY

KINETIC INDUCTANCE

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

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

Kinetic Inductance Detectors (KIDs)

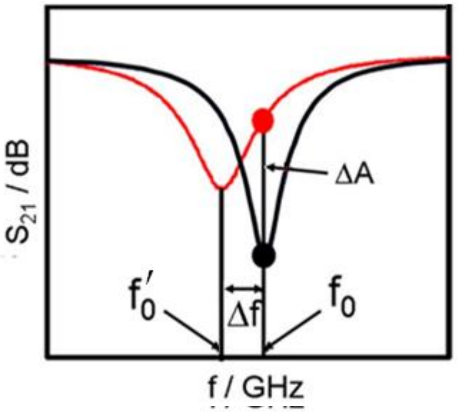


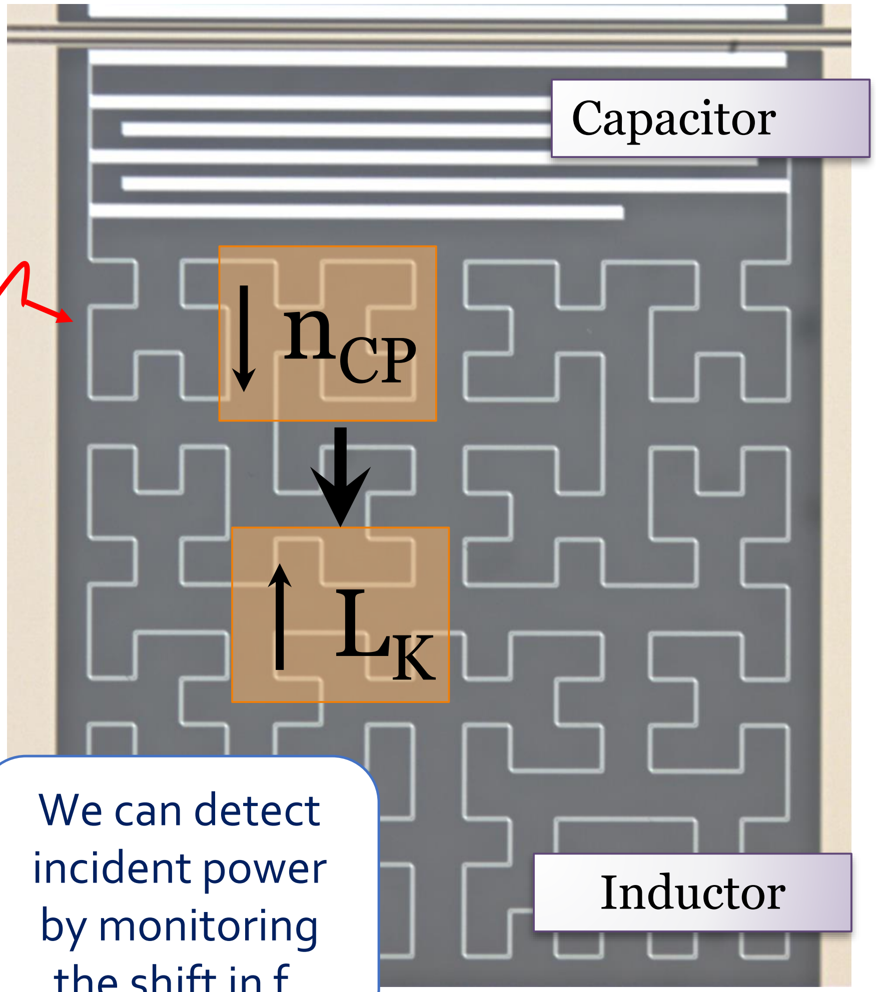
$$E > 2\Delta$$

$$L = L_g + L_k$$

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

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





We can detect incident power by monitoring the shift in f_o

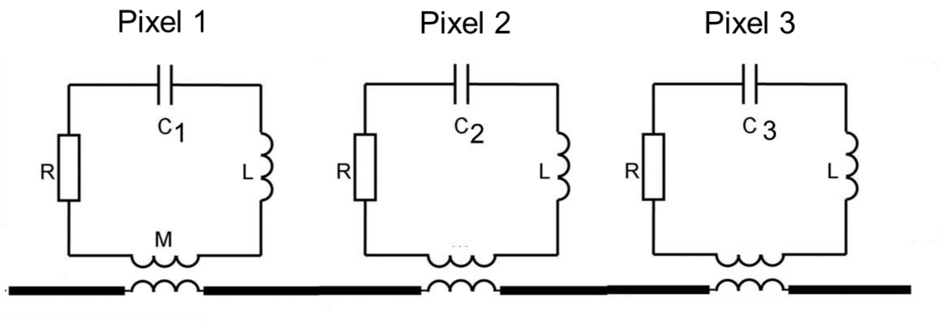
Day et al., Nature (2003)

Doyle et al., JLTP (2007)

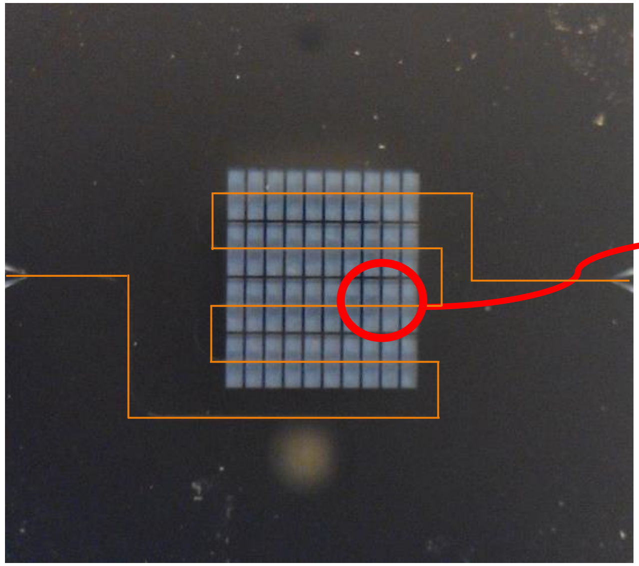
Kinetic Inductance Detectors (KIDs)

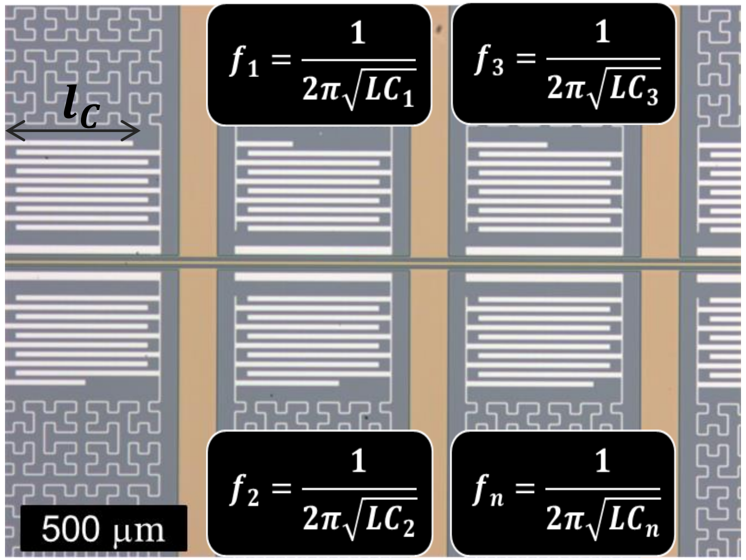
Multiplexing → 1 wire > 1000 LERs

Transmission line →



Multiples LERs coupled to a single transmission line

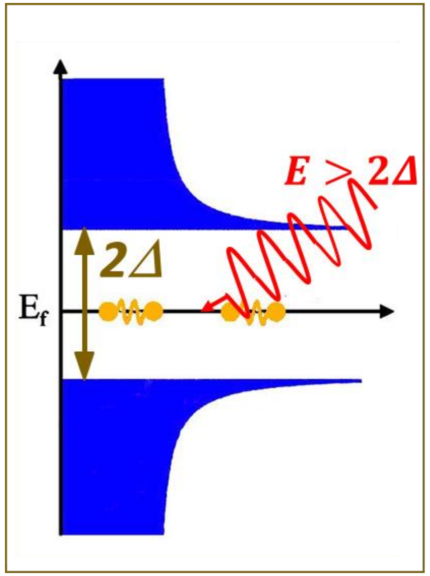




KIDs for W-band

1. Tuning operational frequency band: Superconducting Materials

KIDs:
Pair-breaking detectors

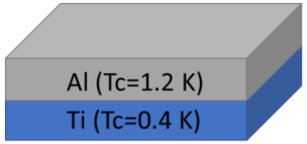


Al → $f_c \approx 100$ GHz

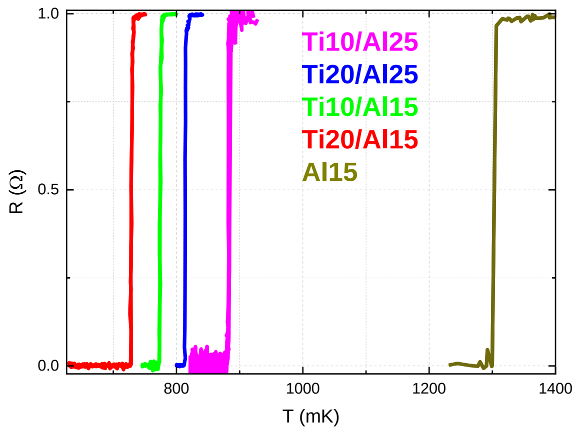
W-band : 75-110 GHz → Al not suitable

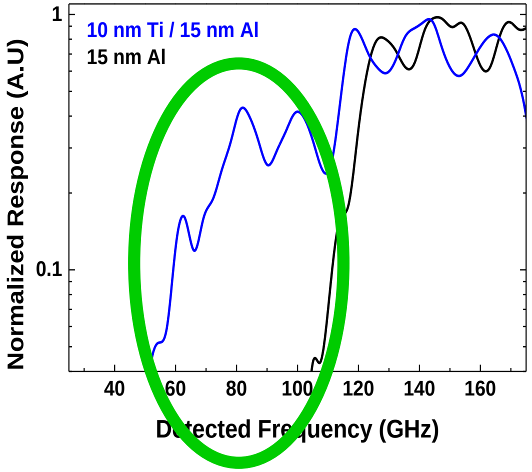
Proximity Effect $2\Delta_{gap} \sim 3.52 K_B T_c$

Titanium/Aluminum bilayers



W-band Sensitivity ✓





2. Impedance Matching: quasi-optical design

Lumped Element-KIDs (LEKIDs)

↓

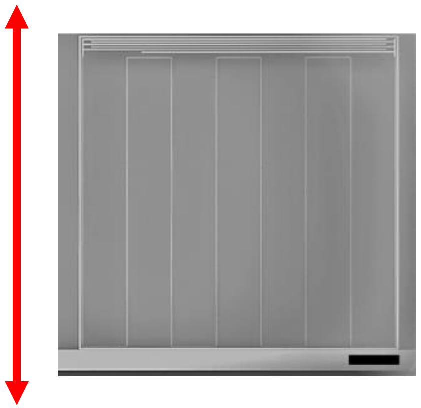
Current uniform distributed in the inductor

↓

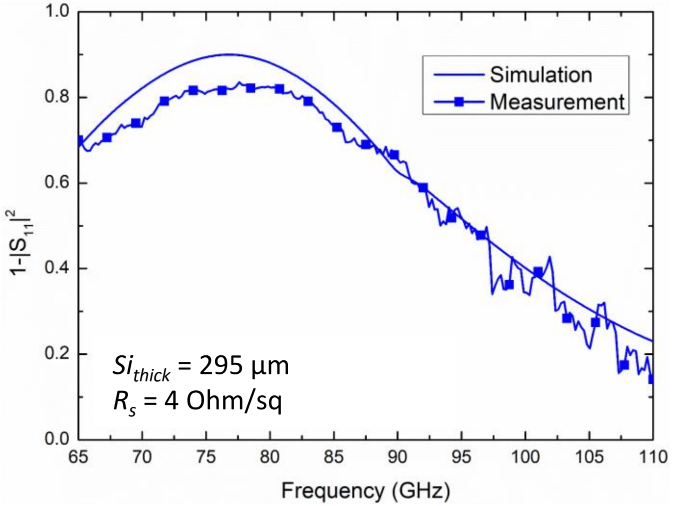
Effective optical absorbing area

Doyle et al., JLTP (2007)

- Inductor Impedance Matching → Geometric Constrains



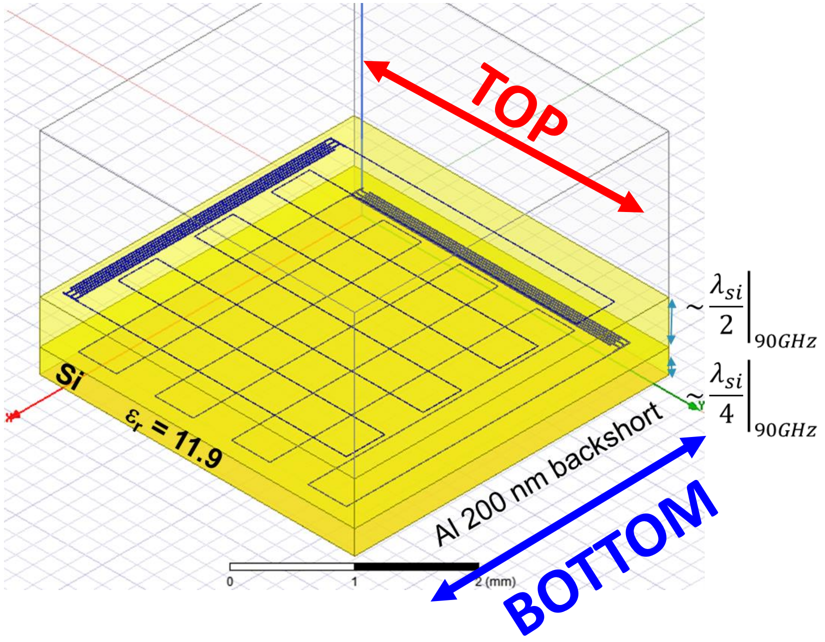
W-band Sensitivity
Single polarization ✓



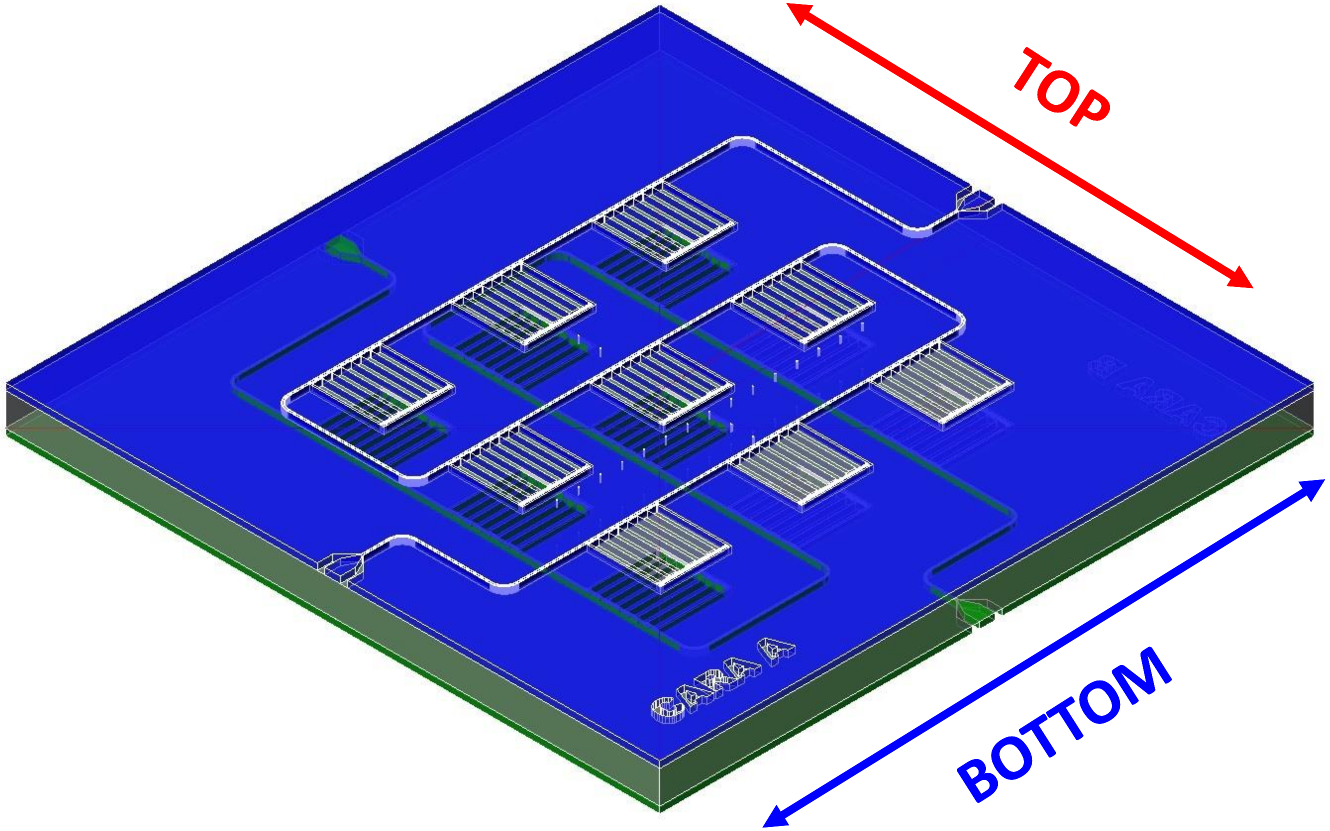
Aja et al., IEEE TMTT (2021)

2. Impedance Matching: quasi-optical design

On chip polarimetry for W-band → BiKID structure



Aja et al., IEEE TMTT (2021)



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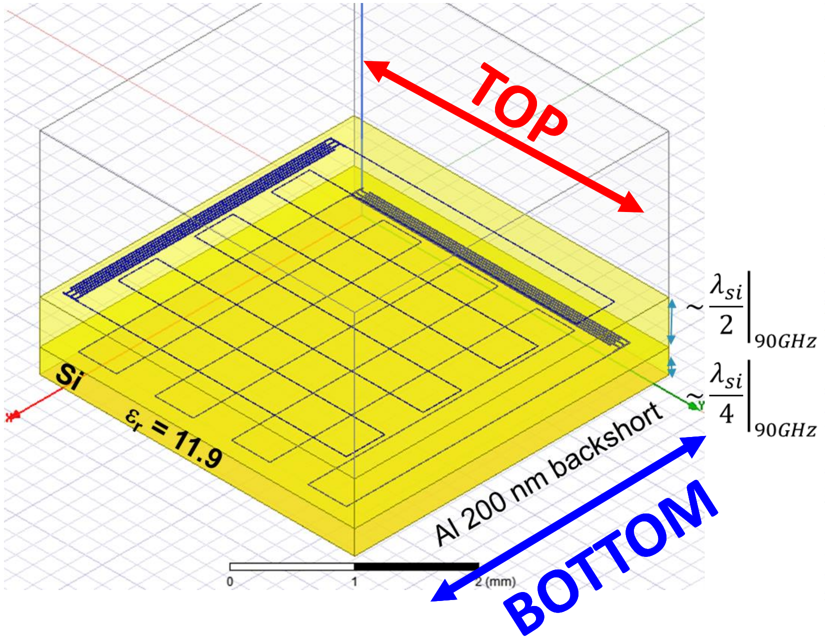
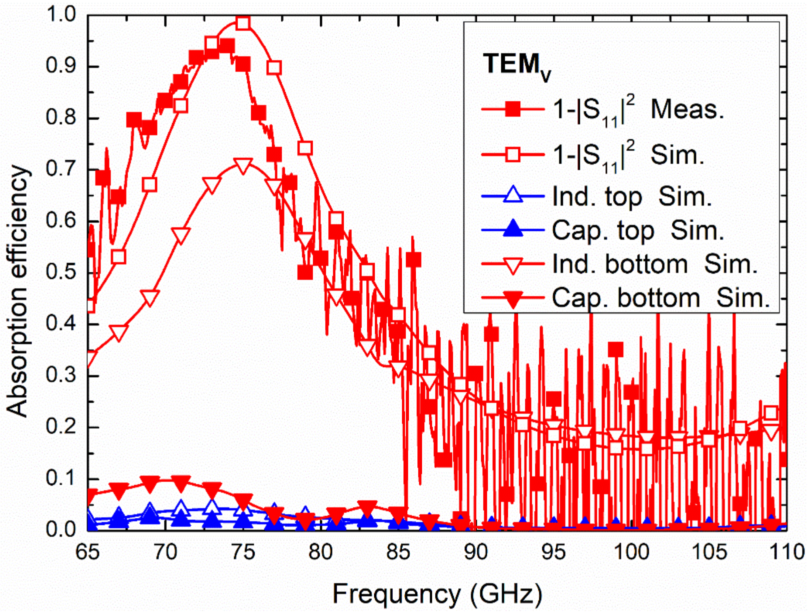
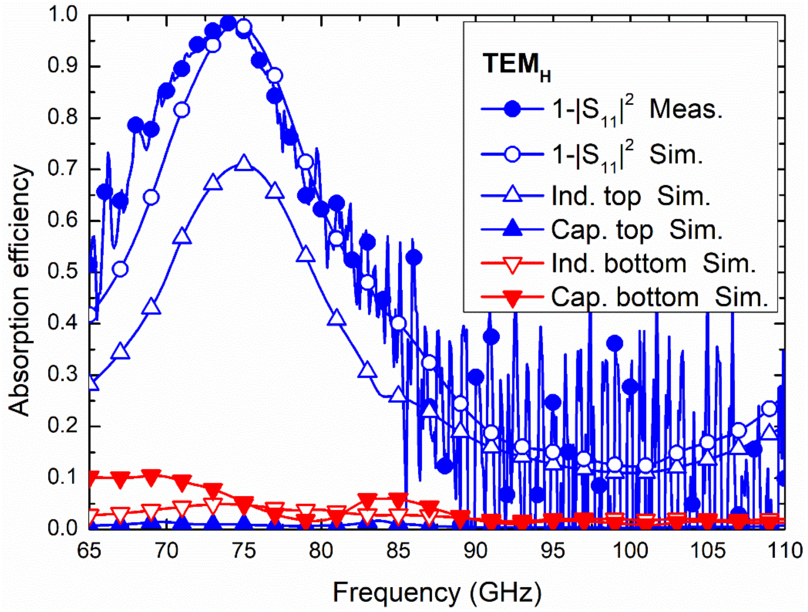
On chip polarimetry for W-band → BiKID structure







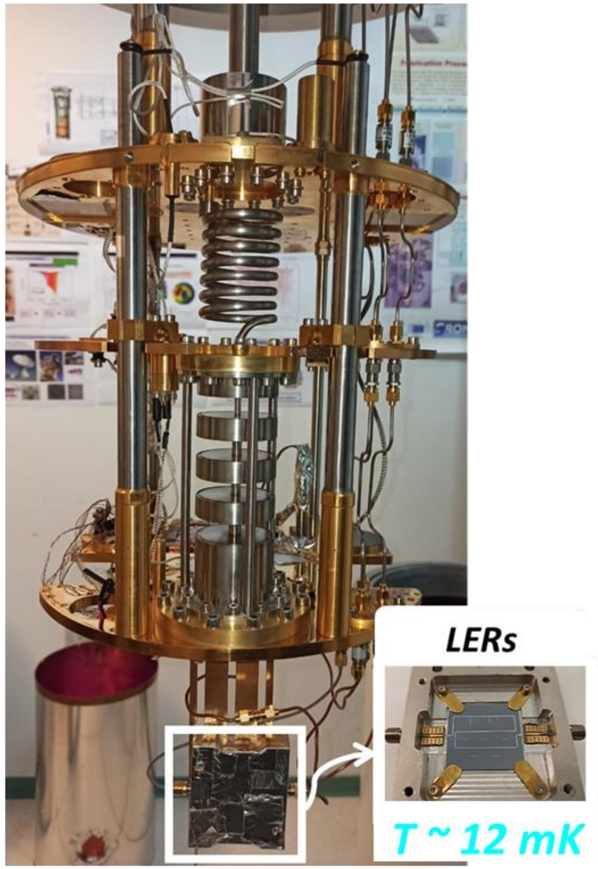
Aja et al., IEEE TMTT (2021)

Polarization Sensitivity in W-band ✓

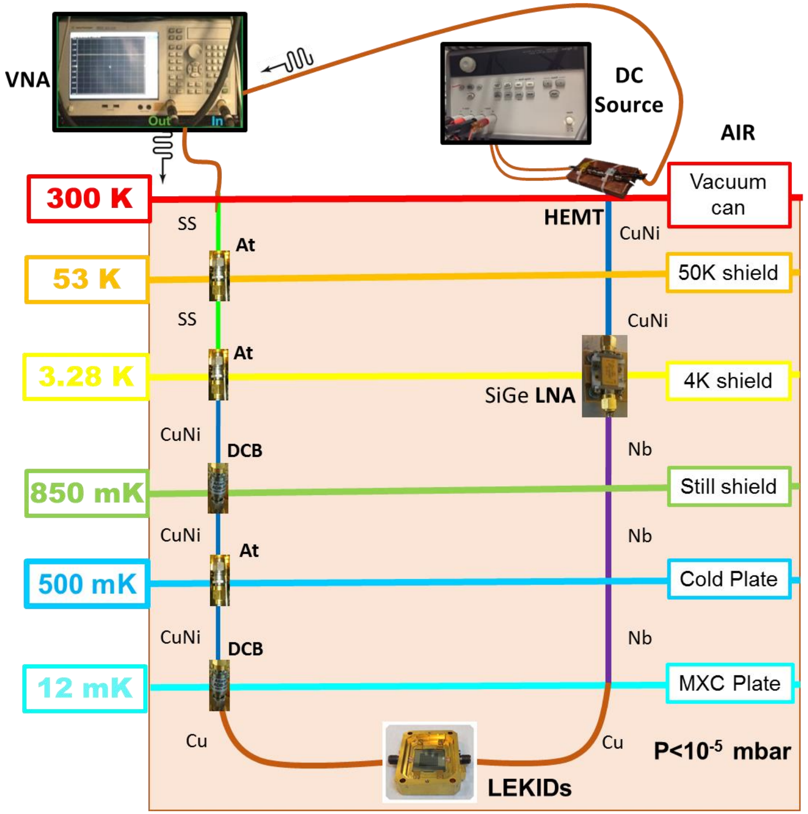
KIDs for W-band

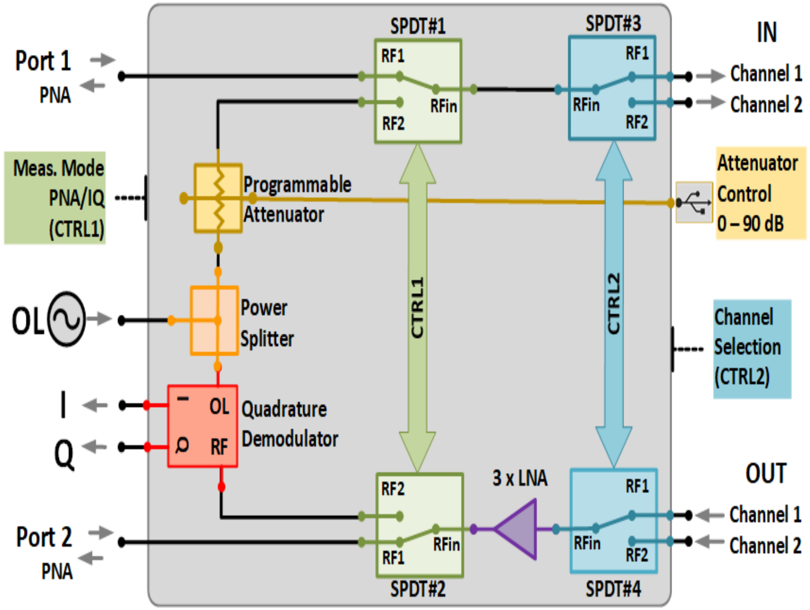
3. Cryogenic Characterization

He^3/He^4 Dilution Refrigerator



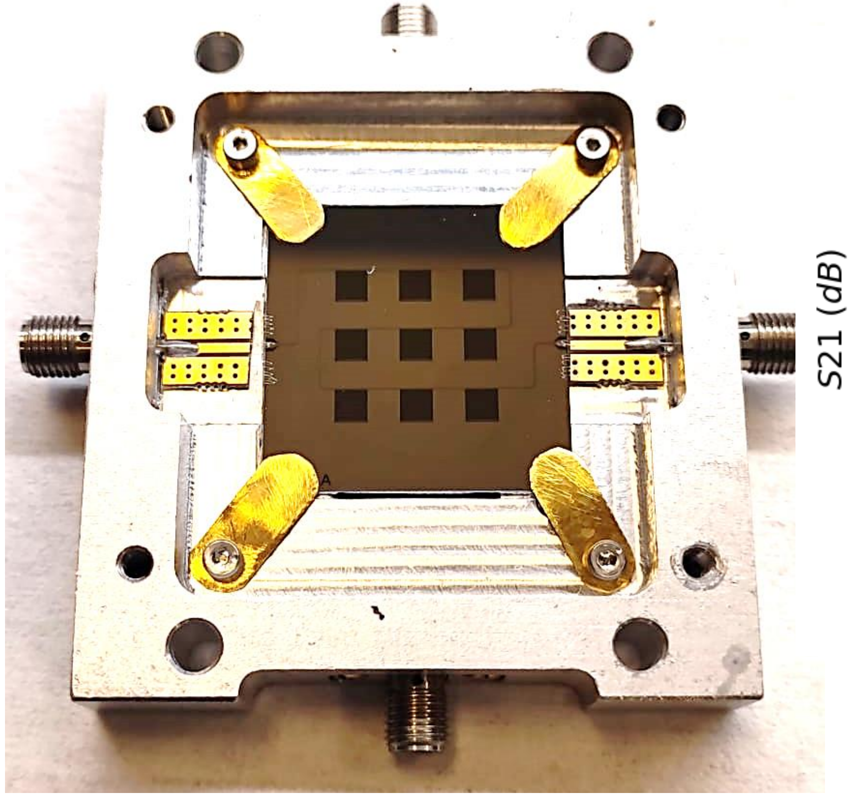
Microwave harness set-up

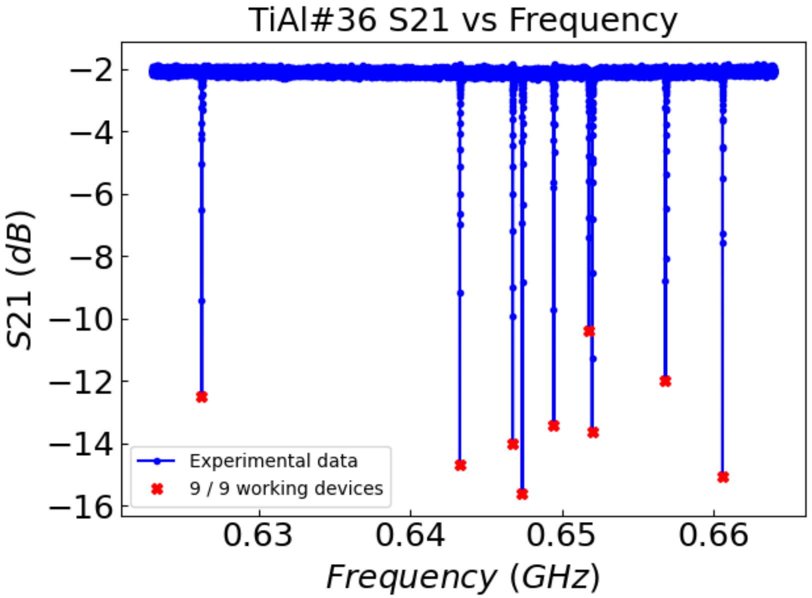


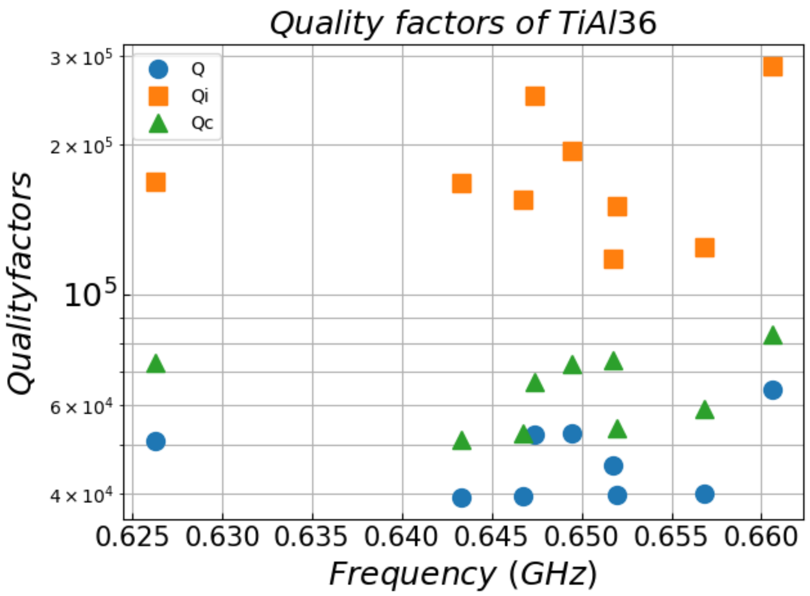


3. Cryogenic Characterization

Dark characterization





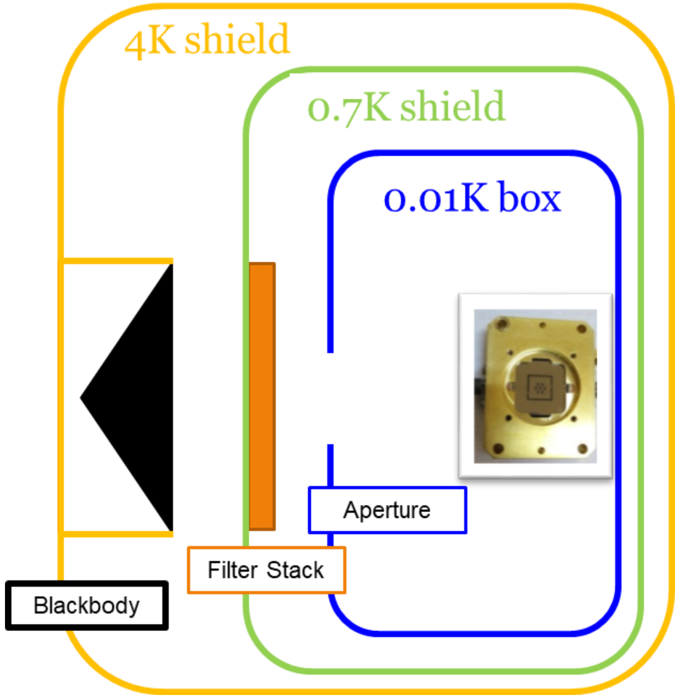


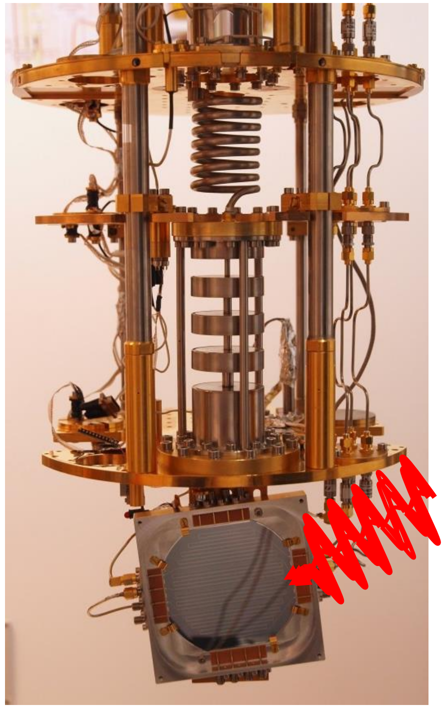
- ✓ High superconducting film quality
- ✓ High nanofabrication yield

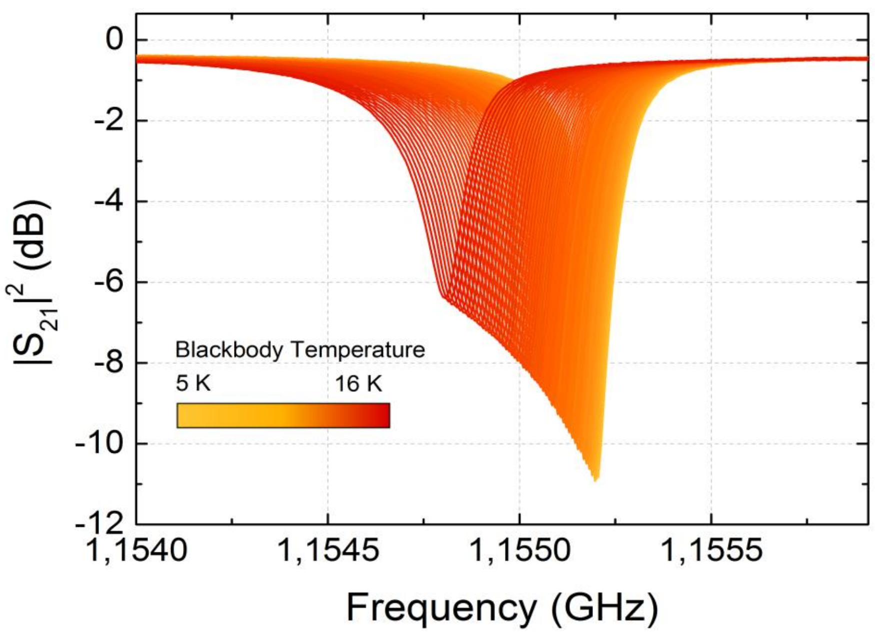
3. Cryogenic Characterization

Low background optical characterization

Sensitive to 90 GHz radiation ✓







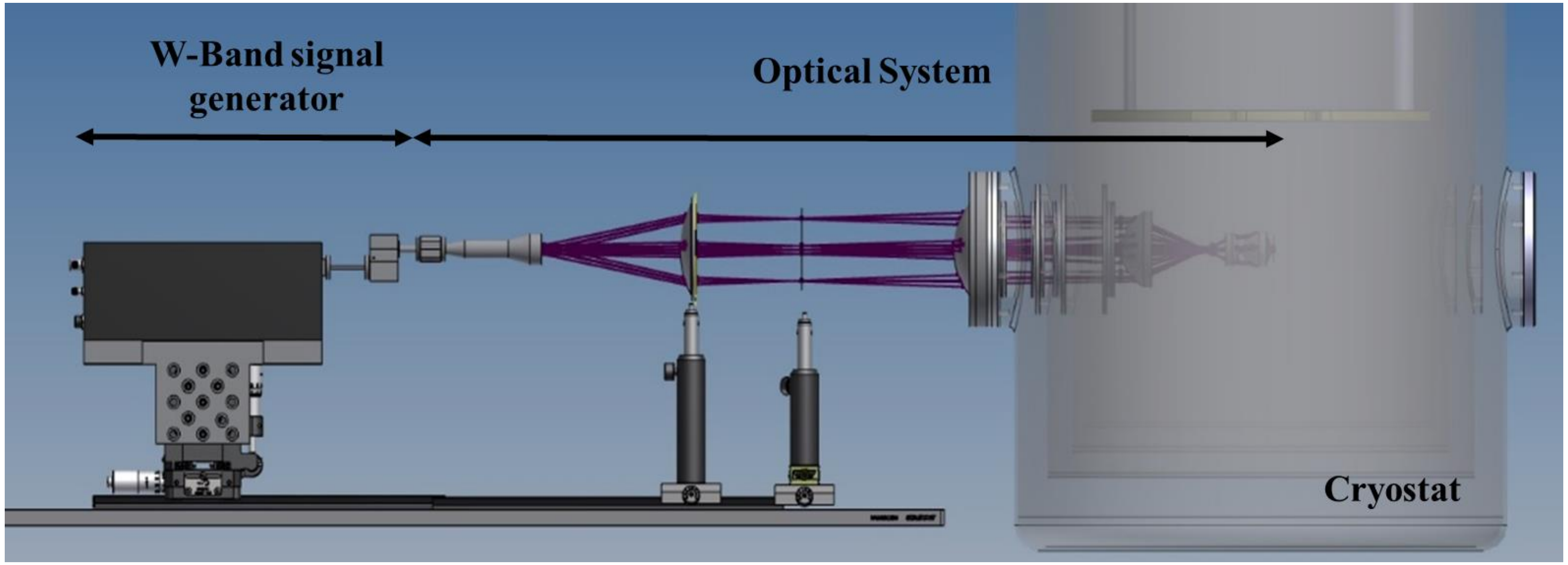
1 pixel ➡ $f_0 = \frac{1}{2\pi\sqrt{LC}}$

$\uparrow L_K$ ➡ $\downarrow f_0$

3. Cryogenic Characterization

High background optical characterization → In progress

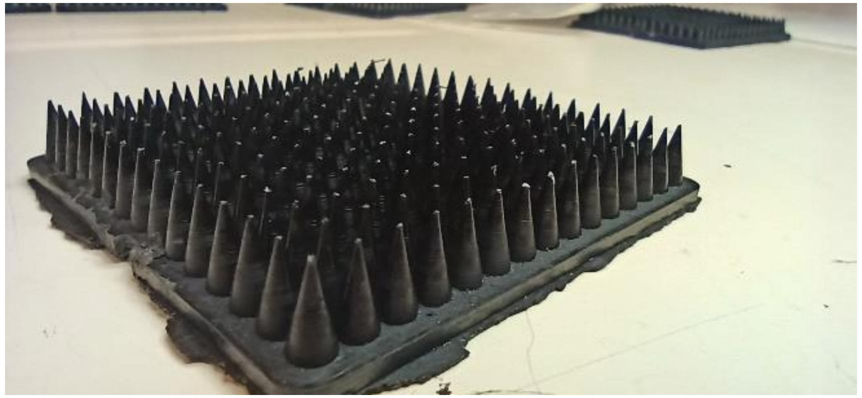
- Cryogenic Optical set-up development

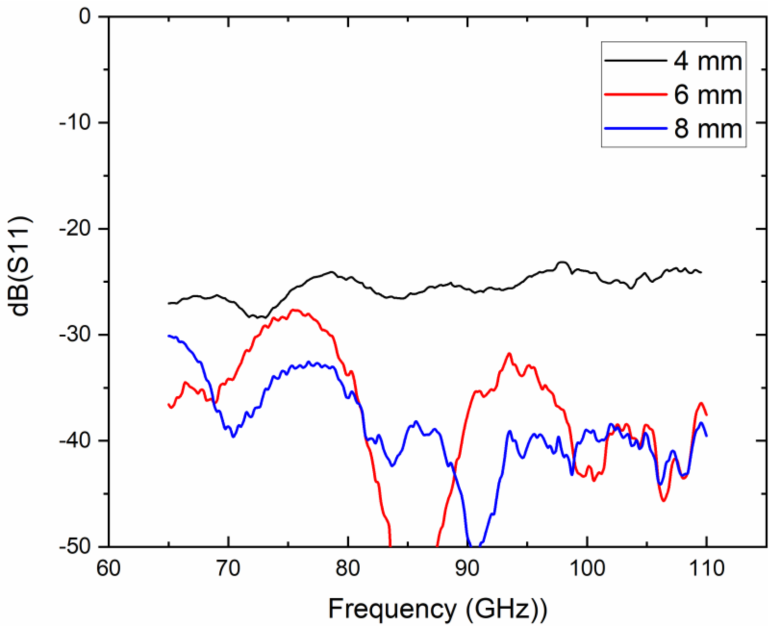


3. Cryogenic Characterization

High background optical characterization → In progress

- Cryogenic Optical set-up development
- Development of W-band cryogenic absorbers (straylight radiation)

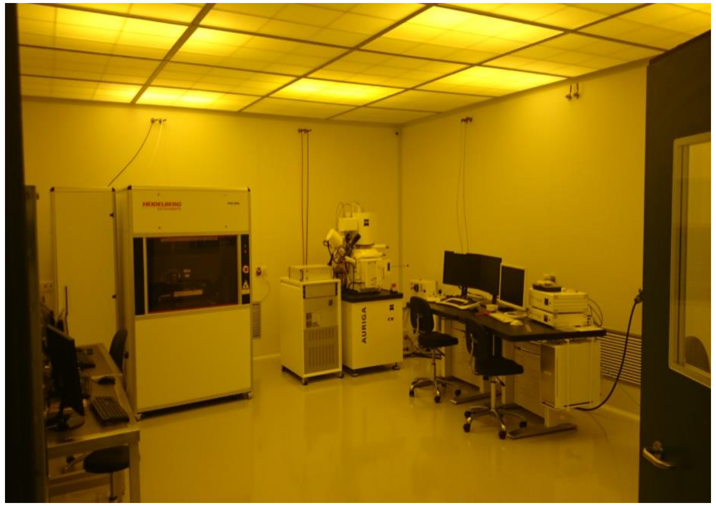


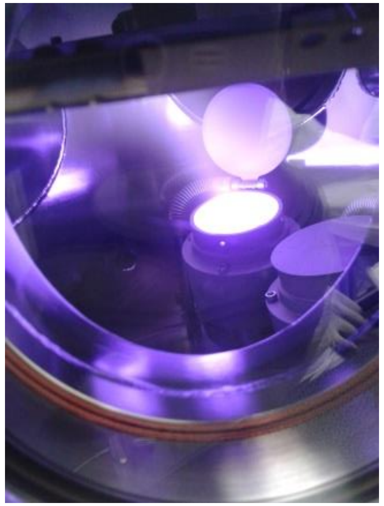


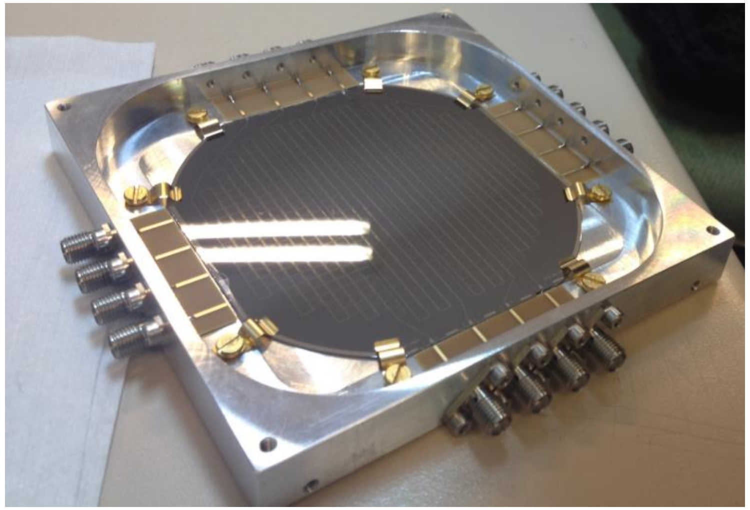
4. Increasing TRL → Future Space Applications

- ➢ Large format array cameras nanofabrication: Clean-room facilities adapted.

4 inch cameras with 1000 pixels → Yield>90%







4. Increasing TRL → Future Space Applications

KISS – QUIJOTE TELESCOPE (IAC)

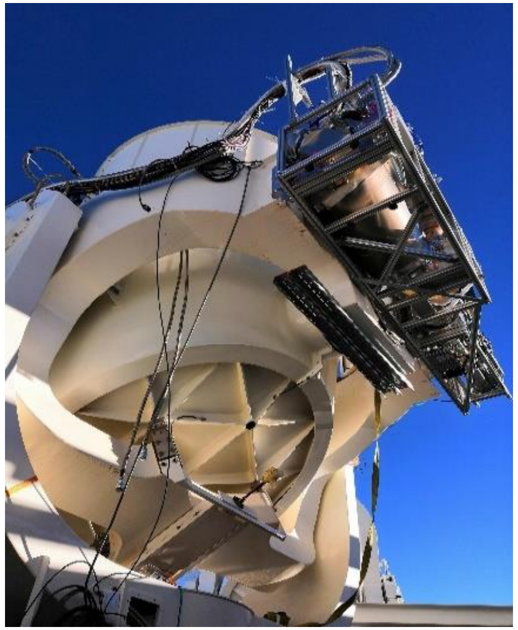
Spectrometer 80-300 GHz

(1 GHz), FoV 1º

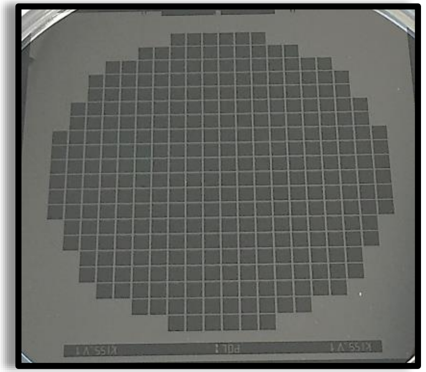
NIKA 2 – IRAM 30 m Granada

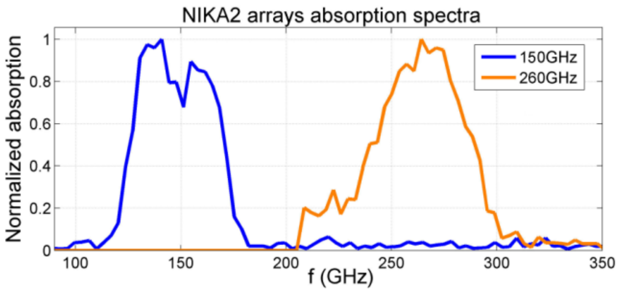
1020 KIDs @ 2 mm

1140 KIDs @ 1.15 mm x 2 polarizations



A. Fasano A&A (2021)





L. Perotto A&A (2020)

REQUIREMENTS

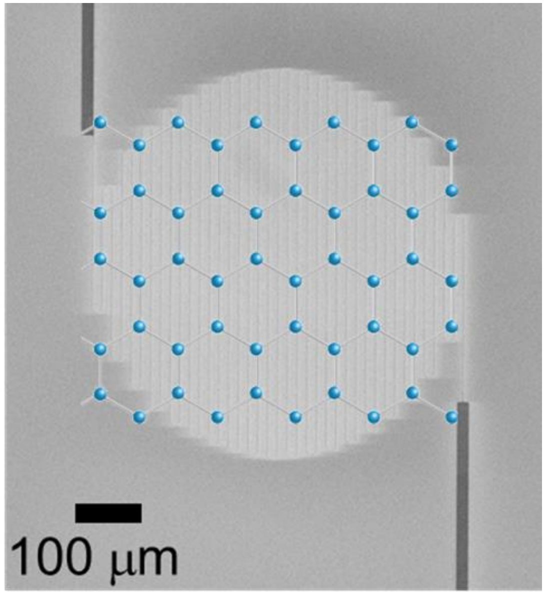
- High sensitivity.
- Large number of pixels.
- Low power dissipation.

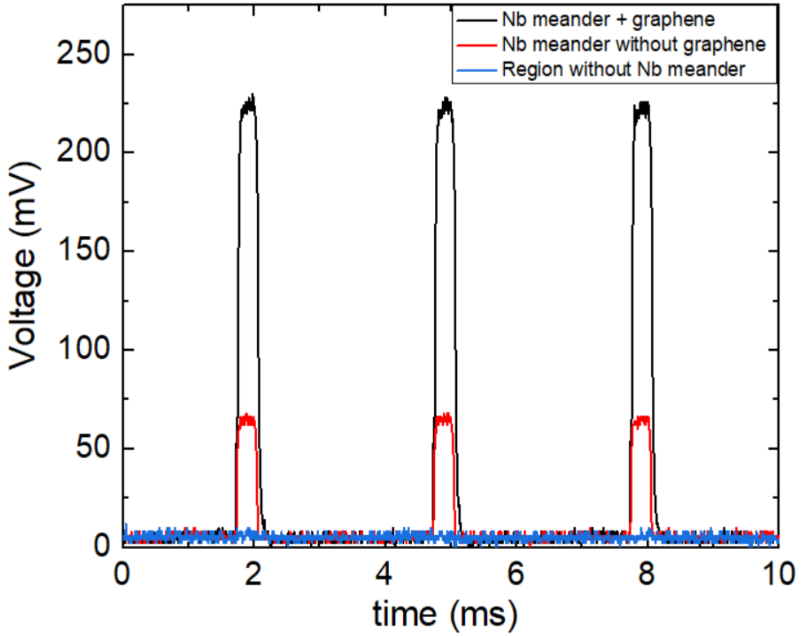
→ **Quantum technologies**

Quantum Key Distribution Applications

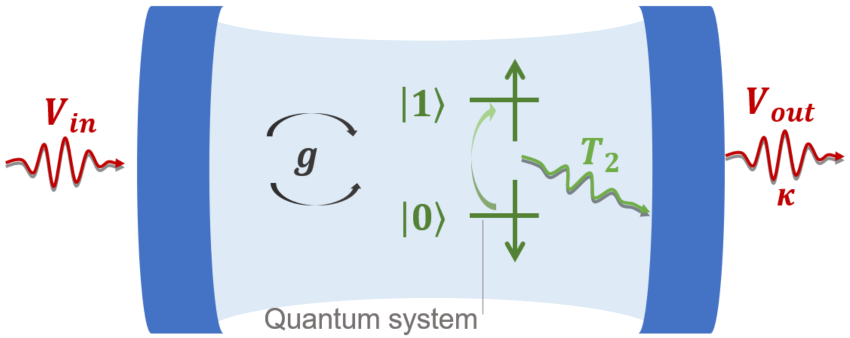
↓

Graphene-based Single Nanowire Single Photon Detectors





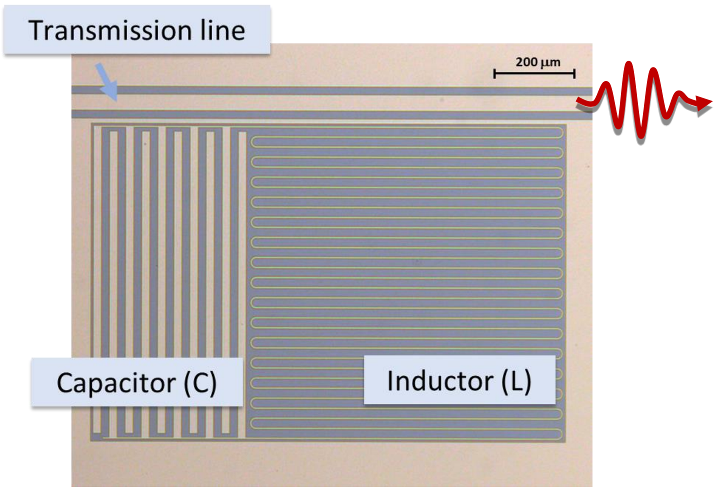
Quantum computing: quantum electrodynamics on a chip

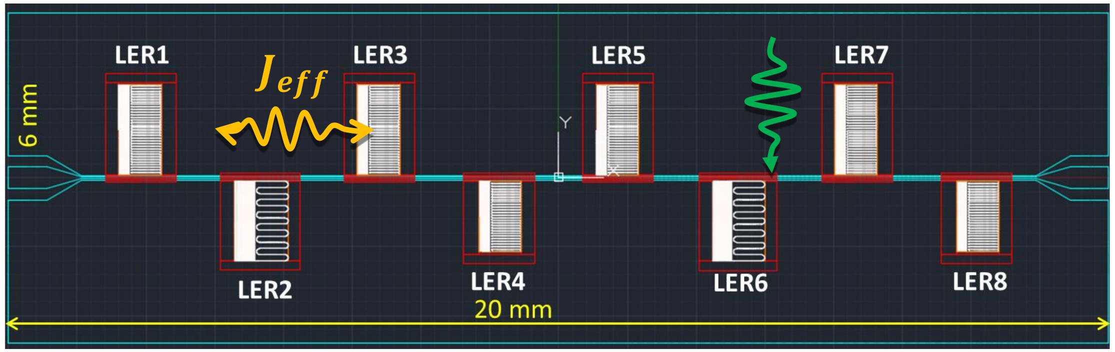


Resonant cavity
Photon

Qubit
Two level system

Resonant cavity → Superconducting Resonator

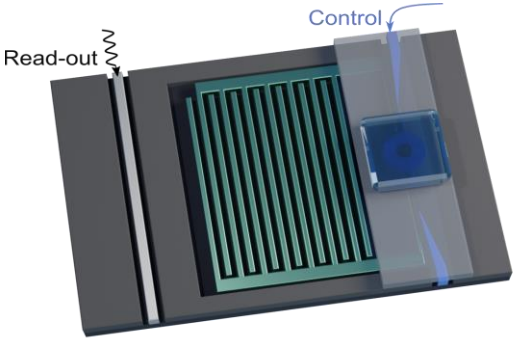


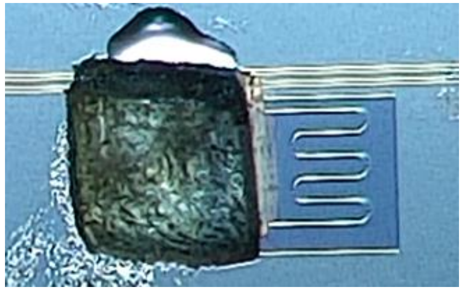


- ✓ Multiple read-out with a single transmission line.
- ✓ High power pulses to implement gates.
- ✓ Photon-mediated interactions between different qubits.

LERs for Quantum Processors

Molecular spin quantum processor unit



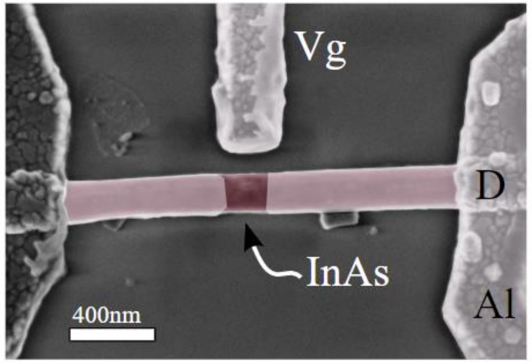


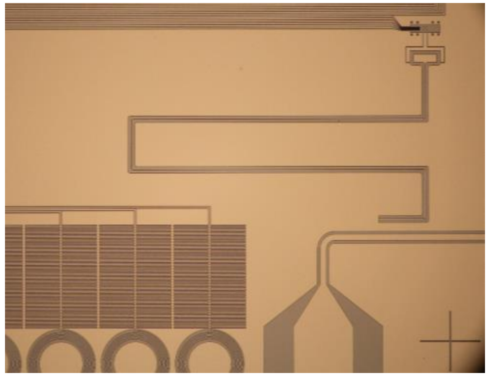
Fernando Luis

V. Rollano et al.
arXiv:2203.00965 (2022)

Coupling to semiconducting nanowires: Gatemon Qubits

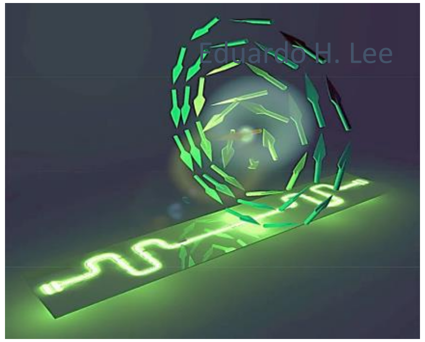
E. H. Lee





E. Prada, Nat. Rev. Phys. (2020)

Magnonic quantum systems: Magnetic vortices and FeB nanorods



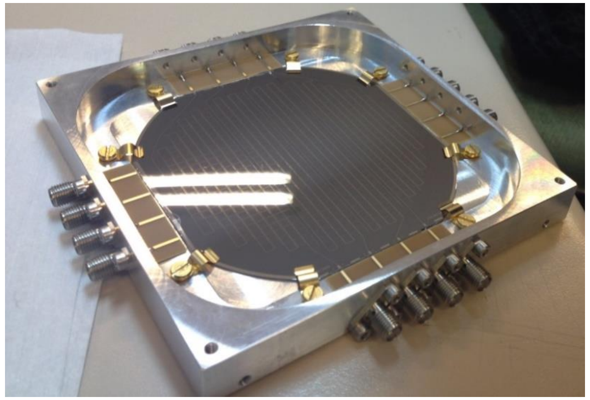
Pepa Martínez-Pérez

Jesús Mª González

M.J. Martínez-Pérez, ACS Photonics (2019)

Summary

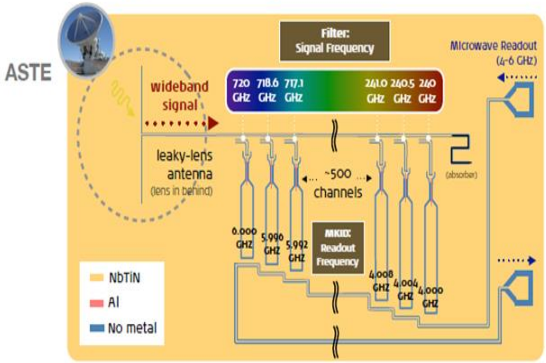
Kinetic Inductance Detectors (KIDs)



W-band KIDs

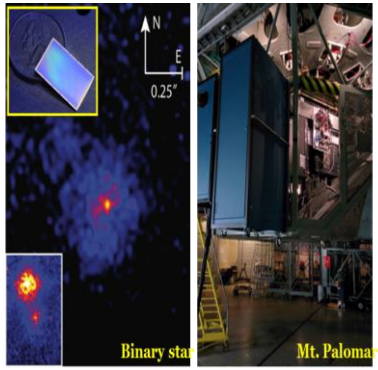
- Astronomy applications
- Dark matter experiments

On chip spectrometer



A. Endo (TU Deflt)

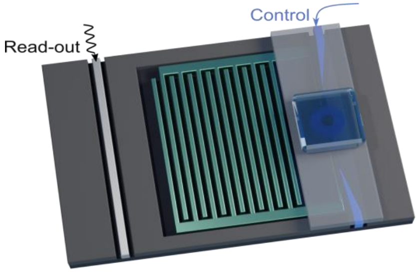
KIDs Visible/NIR

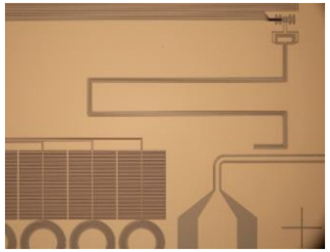


B. Mazin (UC Santa Barbara)

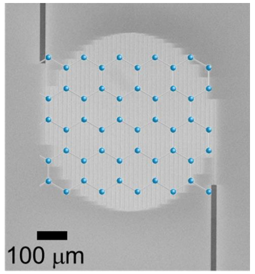
Superconducting quantum technologies

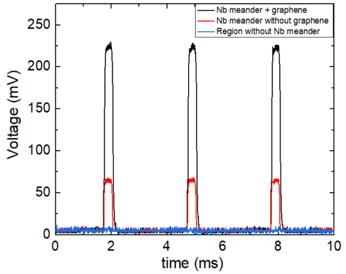
- Cavities for quantum processor unit





- Detectors for quantum key distribution





Superconducting resonators for space and quantum applications

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Thank you for your attention!!