On-chip spectroscopy with KIDs

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GIS-KIDs

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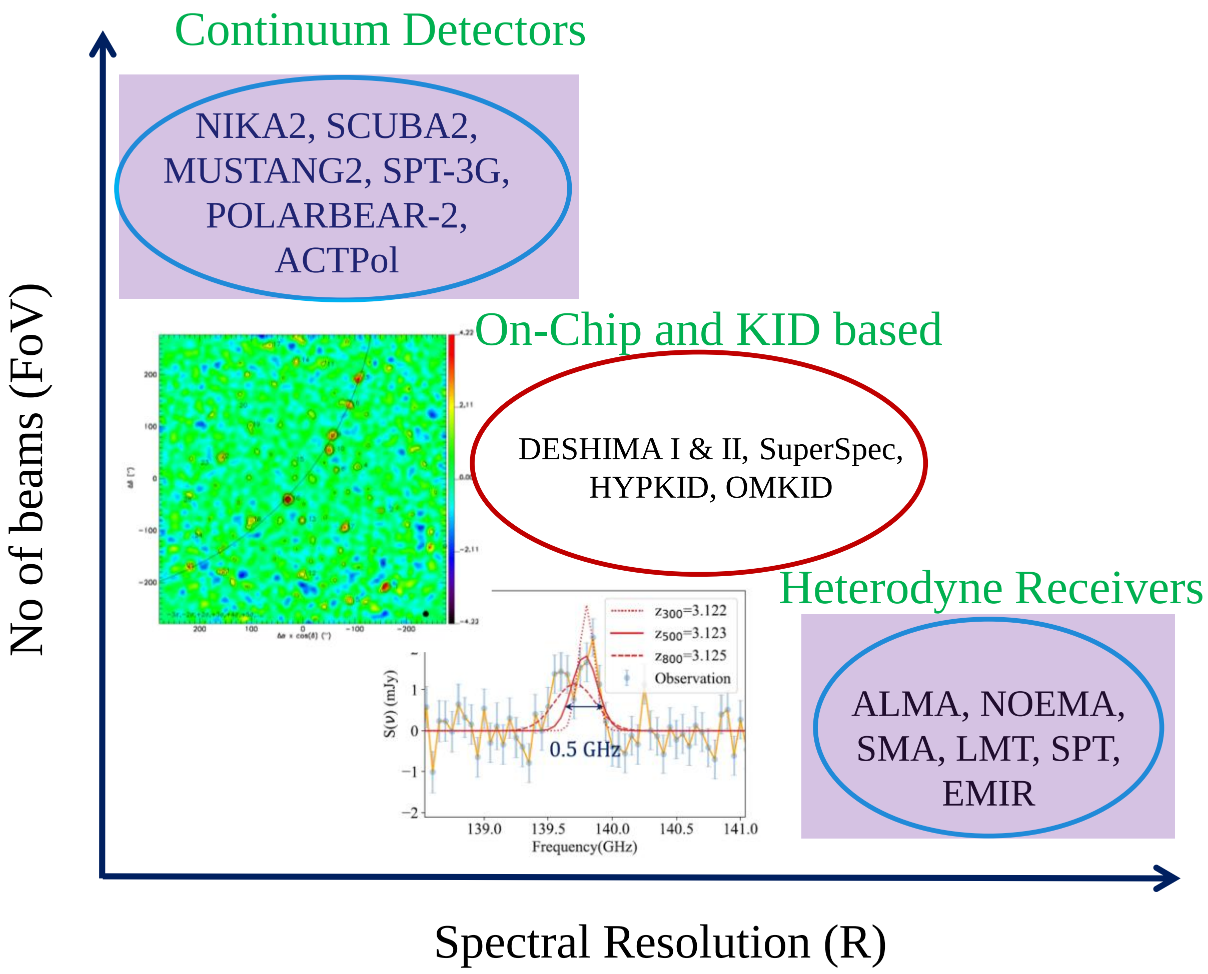
Outline:

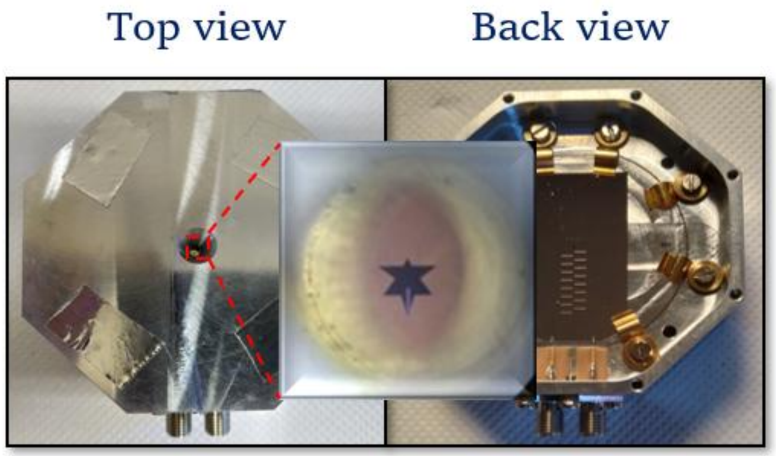
- Objective
- On-chip Spectrometers
- Basics of Superconducting circuits: LEKIDs
- HYKID: Prototypes
- Conclusion

Objective

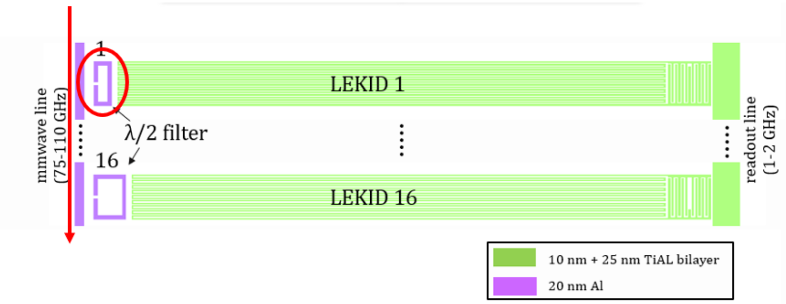


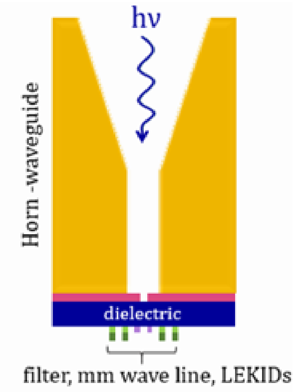
- Moderate Spectral Resolution, ***R* (*f*/ *Δf*) ~ 100 -1000**
- Detection (***f***) ~ 1mm (220-240 GHz), 2mm (120-170 GHz), 3mm (75-110 GHz) atmospheric windows
- Target Spectral Bandwidth **(*Δf*) ~ 0.5-3 GHz**

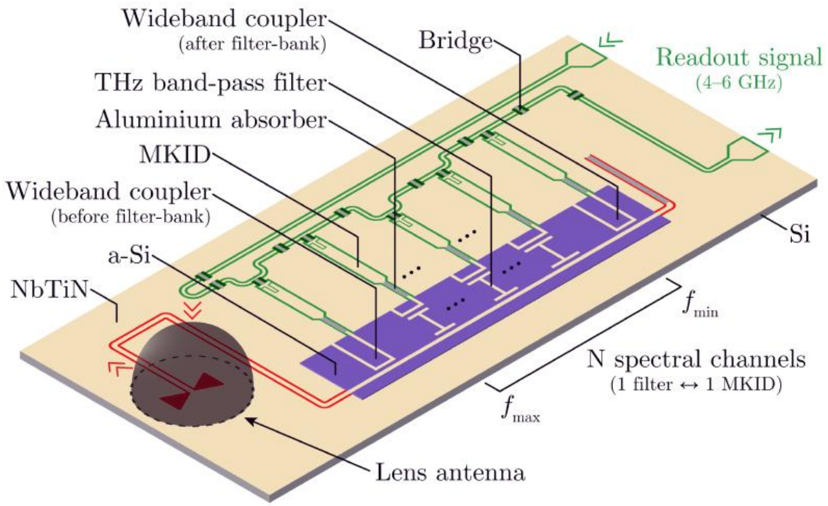
Examples of On-chip Spectrometers



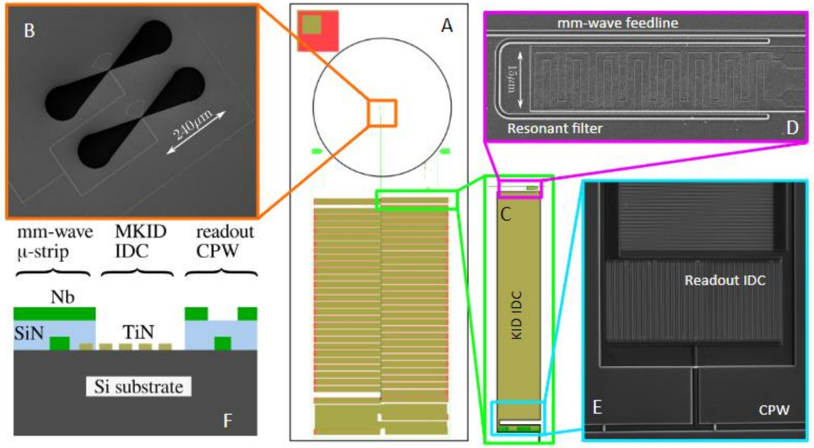
OMKID: 75-110 GHz







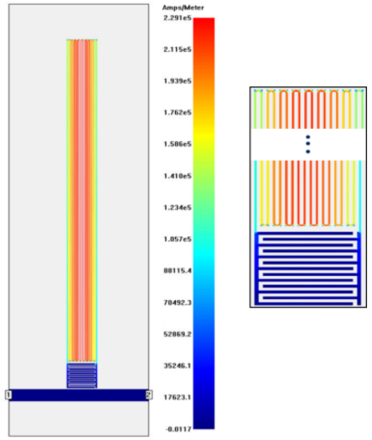
DESHIMA 1: 330-380 GHz
DESHIMA 2: 200-400 GHz



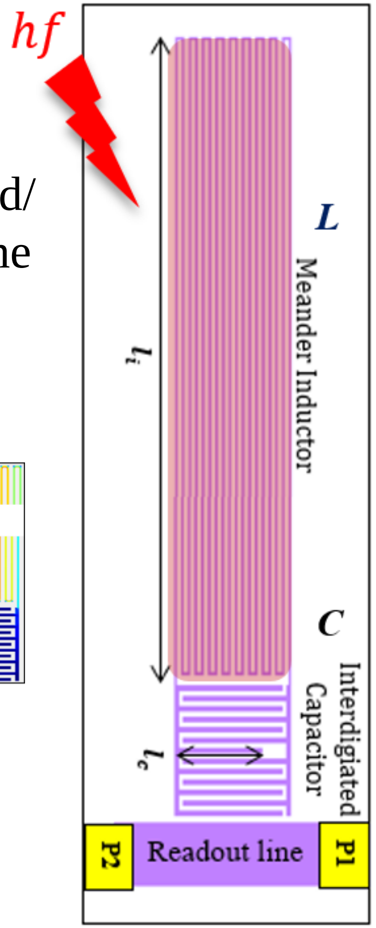
SuperSpec, 2019
180-300 GHz

Kinetic Inductance Detectors (*KIDs*)

Energy Coupled/ Absorbed by the meanders



Uniform Current Distribution at resonance



Working Conditions:

$T < T_c$, $f_r < f_g$

At resonance,

$$f_r \propto \frac{1}{\sqrt{LC}}$$

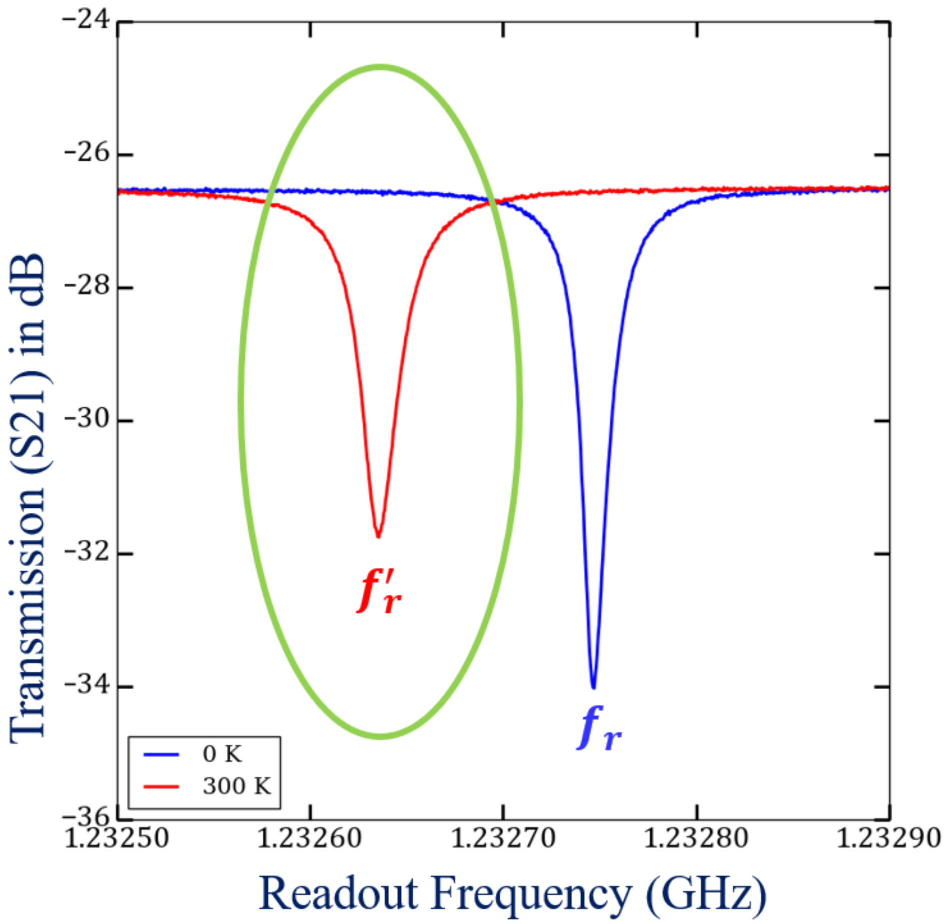
When illuminated/absorbed,

$$f'_r \propto \frac{1}{\sqrt{L'C}}$$

Frequency Shift,

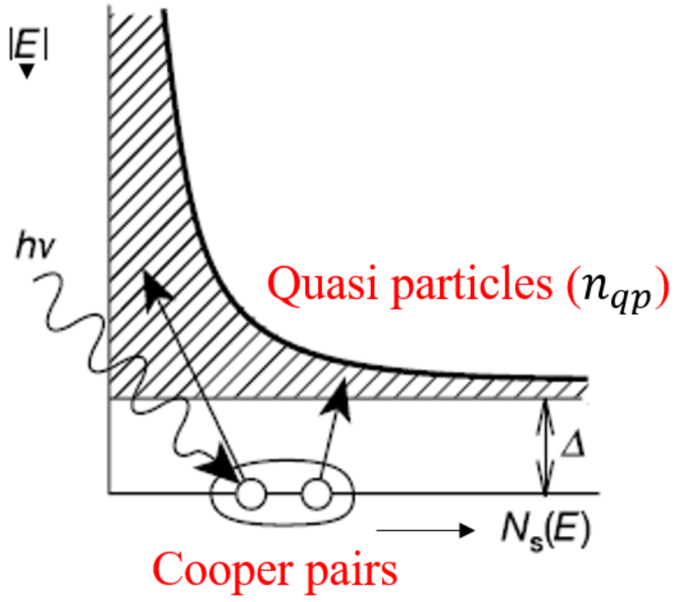
$$\Delta f = f_r - f'_r$$

Detection frequency, $f > f_g$



Superconducting Properties

Frequency and Material Dependent



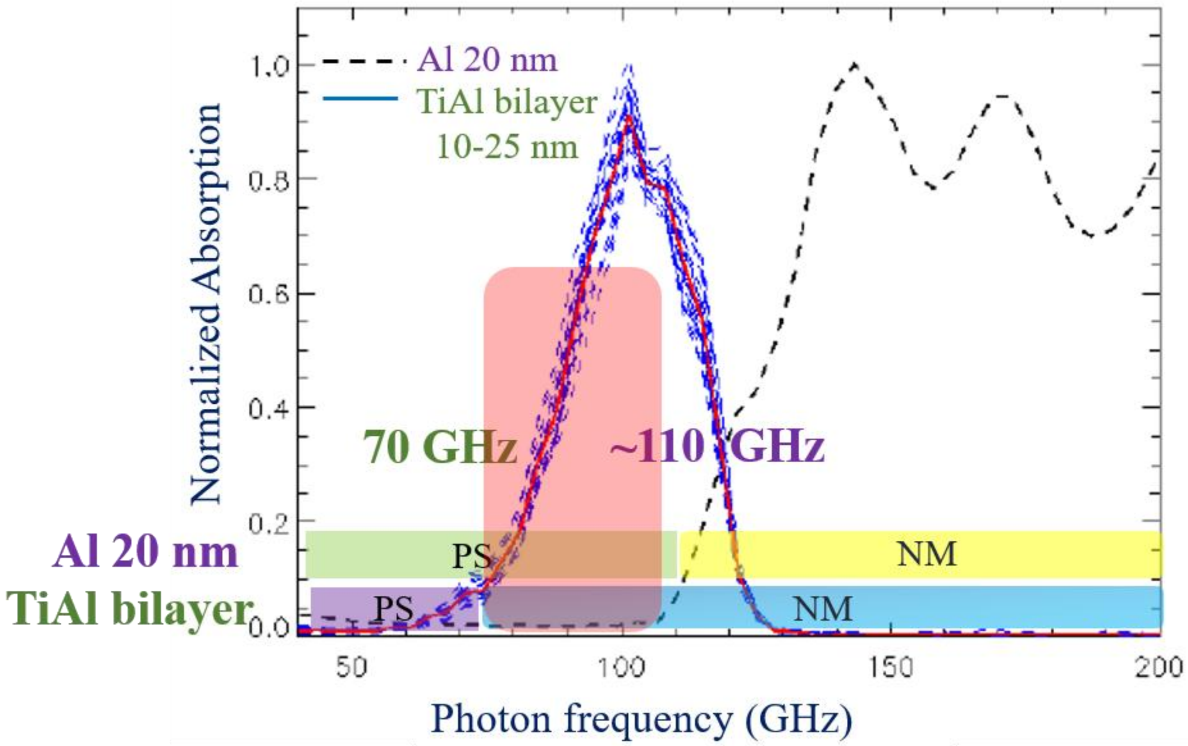
Superconducting gap energy,
$2\Delta = 3.52\ k_B T_c\ (meV)$

General optical cut-off frequency for supercondcutivity,

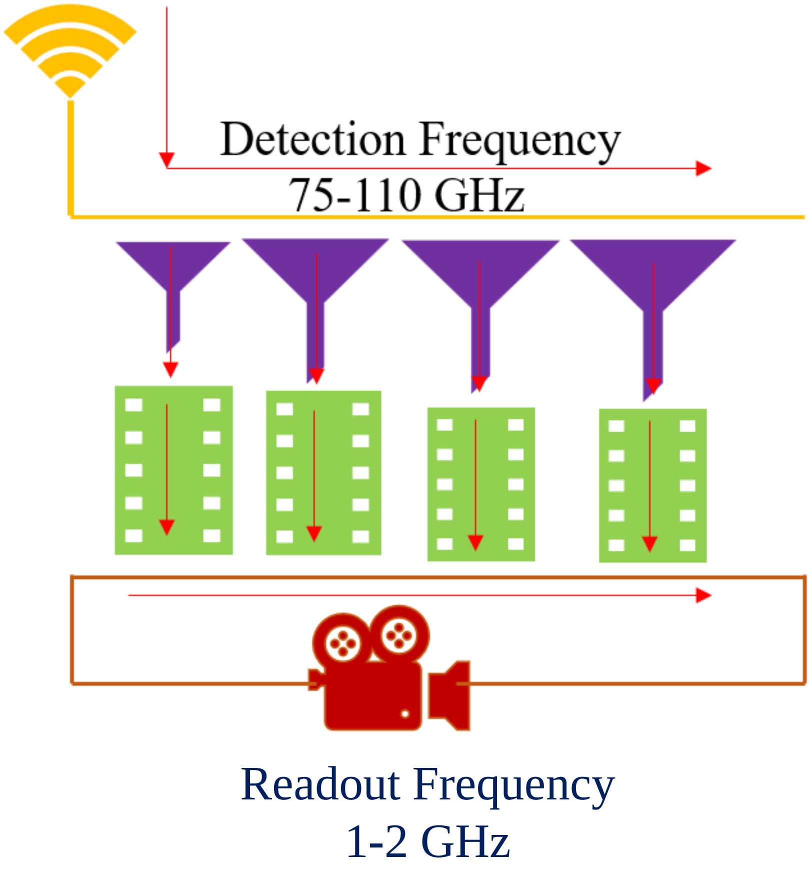
$$\boldsymbol{f_g = \frac{2\Delta}{h} = (73.5 \times T_C[K])\ \mathrm{GHz}}$$

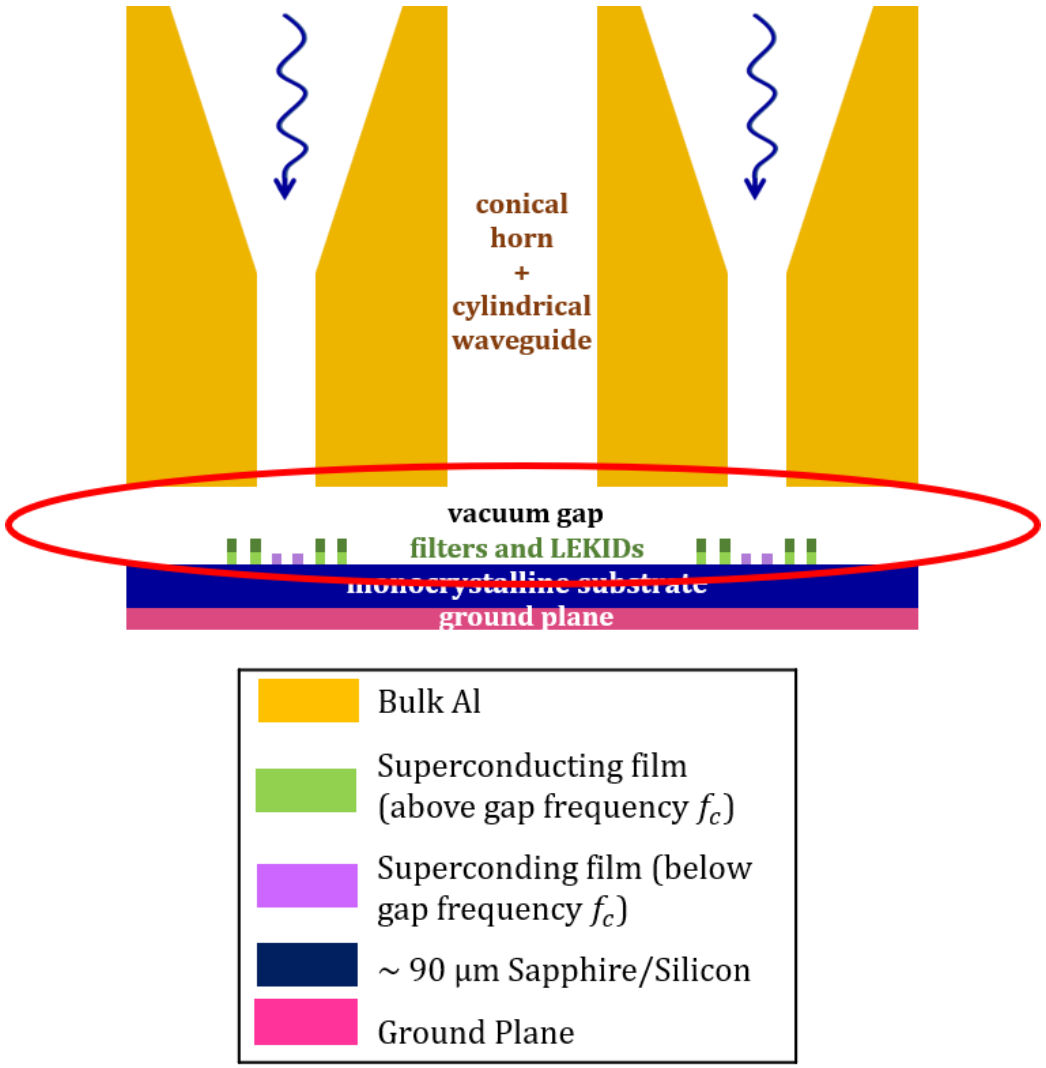
Below T_c, Incident Energy,

- ❑ $\boldsymbol{f < f_g}$ → Perfect Superconductor (PS)
- ❑ $\boldsymbol{f > f_g}$ → Normal Metal (NM)



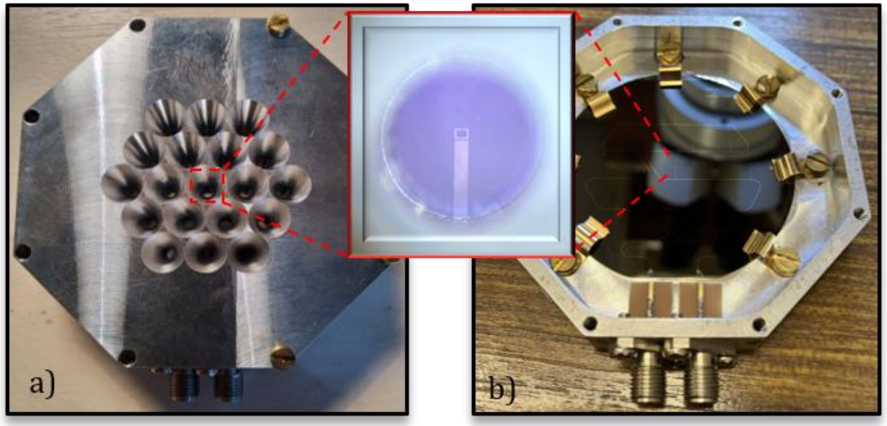
OnChip Spectometers: Concept



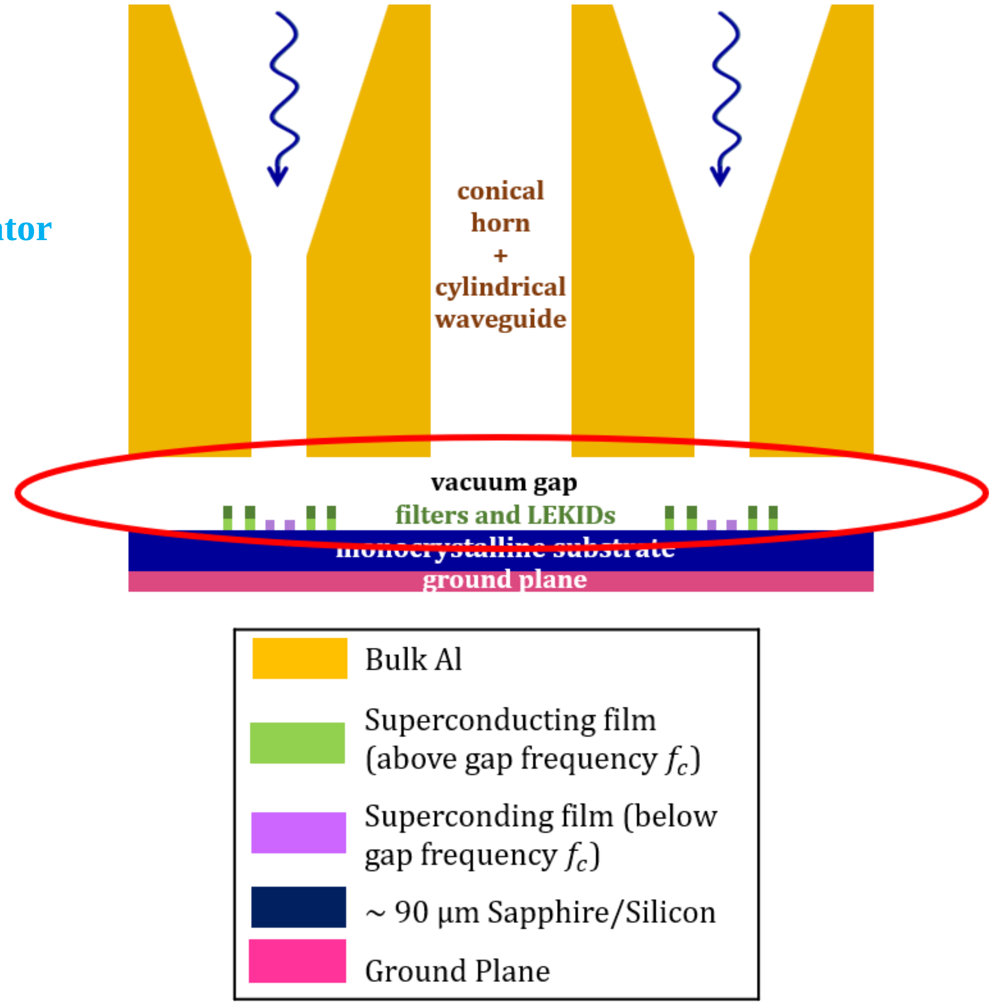


CNRS NÉEL institut UGA Université Grenoble Alpes iram Institut de Radioastronomie Millimétrique

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID)

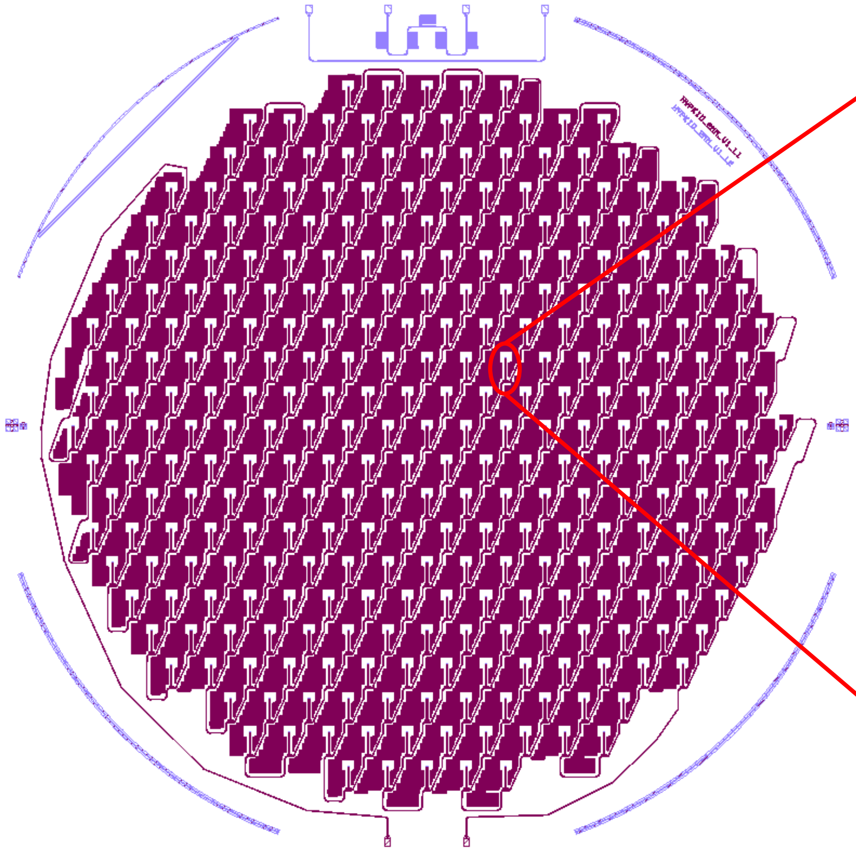


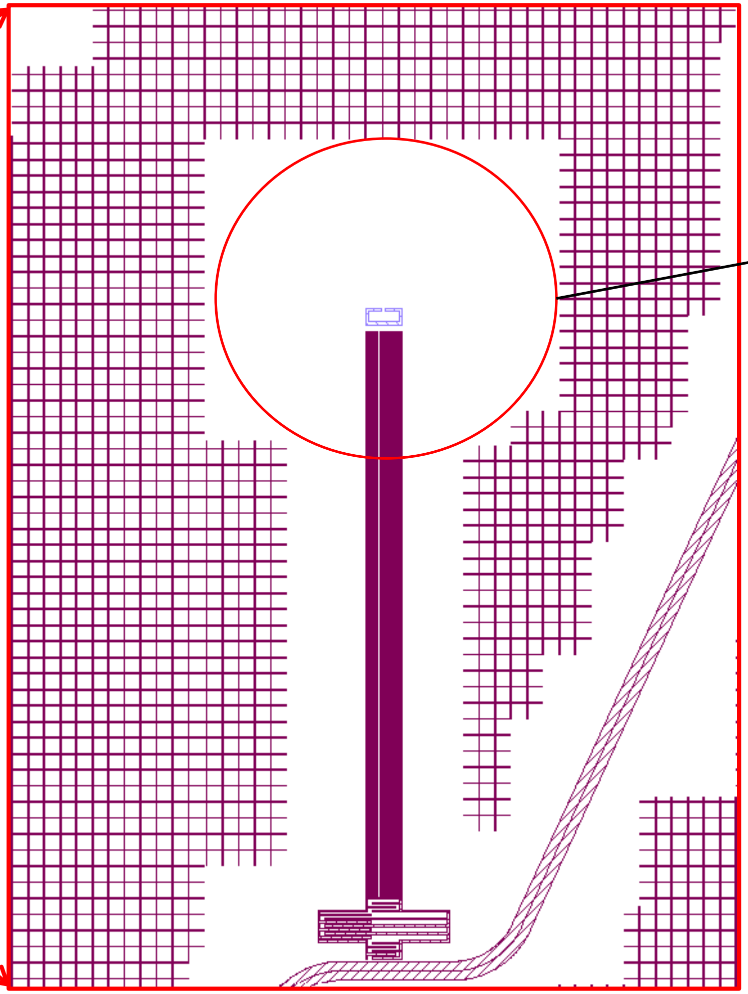
2 inch



HYPer-spectral device with Kinetic Inductance Detector (HYPKID) 2 mm

Plaquette: 90 µm



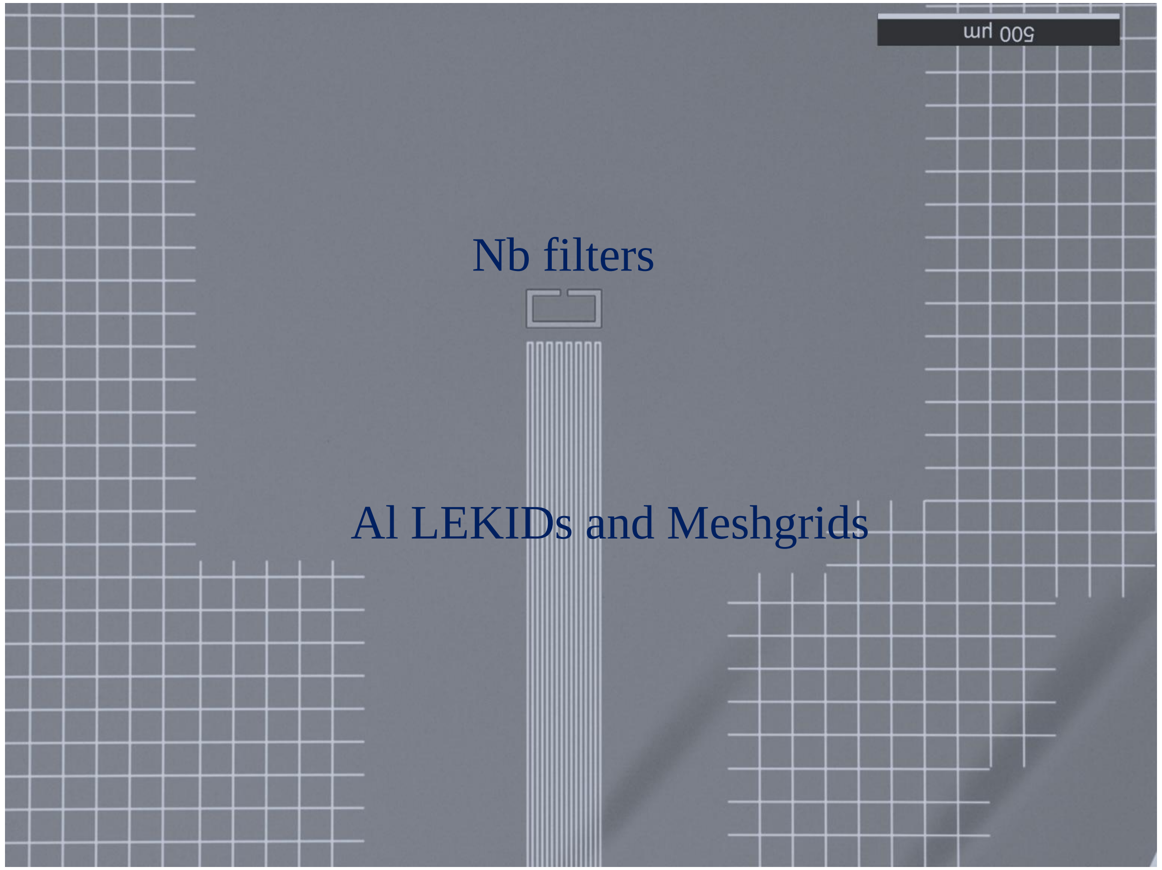


The horn

301 Al LEKIDs, 22 spectral channels with Nb filters, 5 Nb LEKIDs

OnChip Spectometers @ Institut Néel: 2023-2024

HYPer-spectral device with Kinetic Inductance Detector (HYPKID) 2 mm



	Frequency Bands		Properties
	3mm	2mm	
Filters	Al 20 nm	Nb 110 nm	Superconducting
LEKIDs	TiAl 35 nm	Al 20 nm	Normal Metal

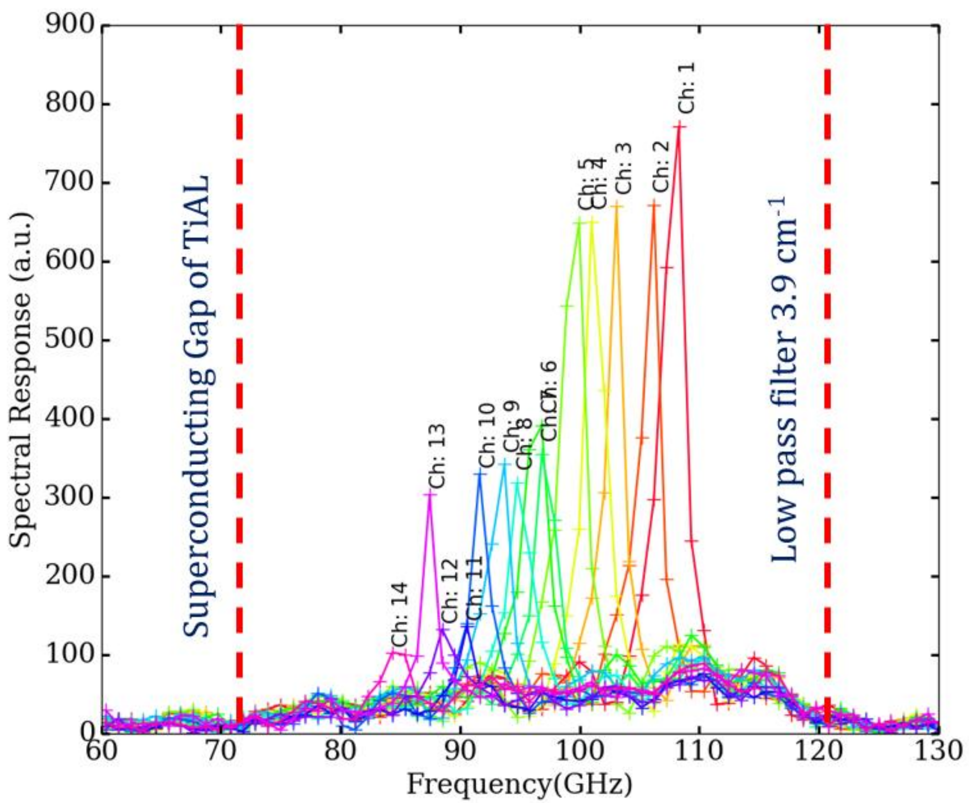
Superconducting cut-off Frequency (f_c)

- ✓ TiAl 35 nm: 70 GHz (~850 mK)
- ✓ Al 20 nm: 110 GHz (~1.45 mK)
- ✓ Nb 110 nm: 660 GHz(~9 K)

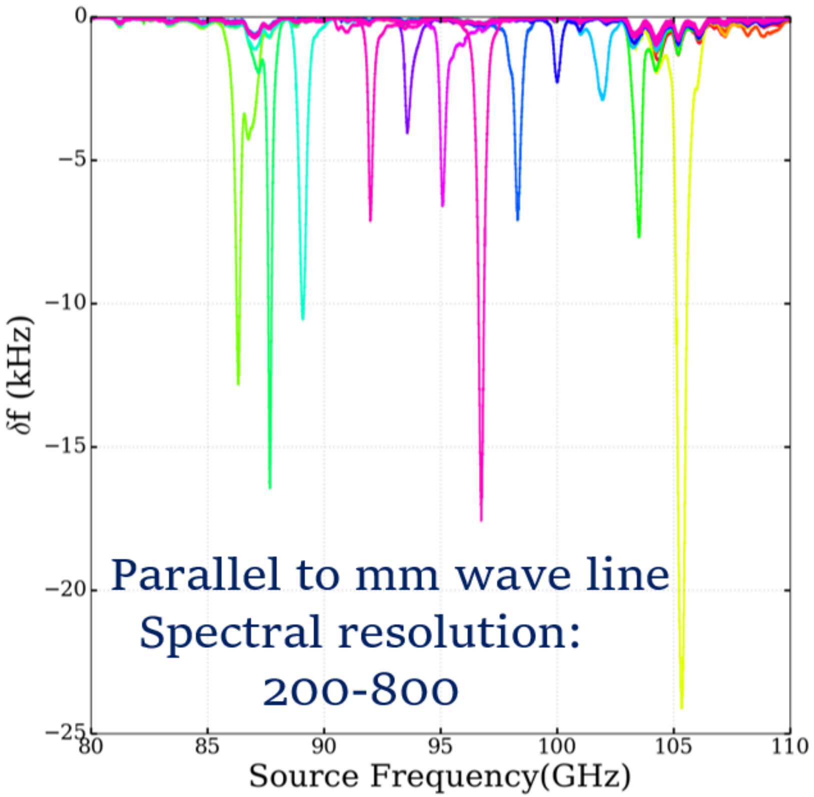
Defining «Optical» range

OnChip Spectometers @ Institut Néel: 2020-2023

*O*n-chip spectrometer using *M*icrostrip based *K*inetic *I*nductance *D*etector (OMKID)



16 Spectral Polarized channels



$\Delta f_{MP}^{min} = 1.2$ GHz $> \Delta f = 0.5$ GHz

Specific Spectral responses, Not resolved

Resolved Spectral responses

Source is not photometrically calibrated

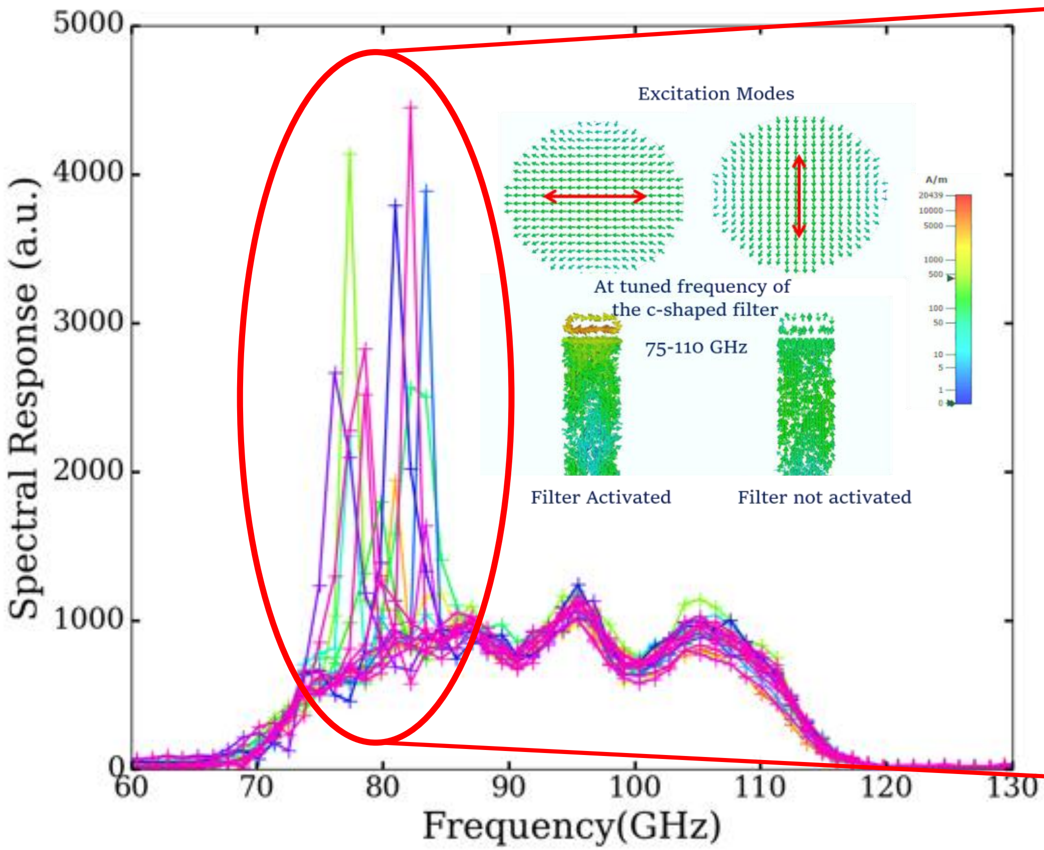
Chowdhury et al, A&A, 672:A7, 2023. doi: 10.1051/0004-6361/202244887

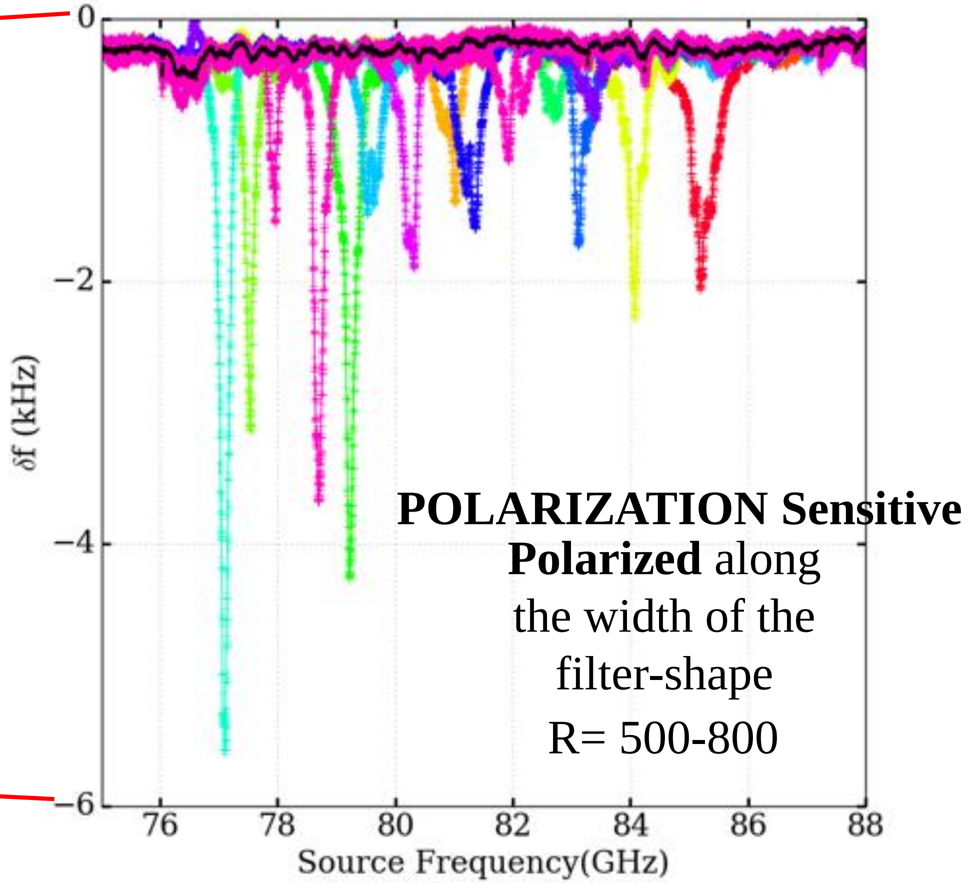
OnChip Spectometers @ Institut Néel: 2020-2023

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID)

Martin Puplett Interferometer

mm wave Source (75-110 GHz)



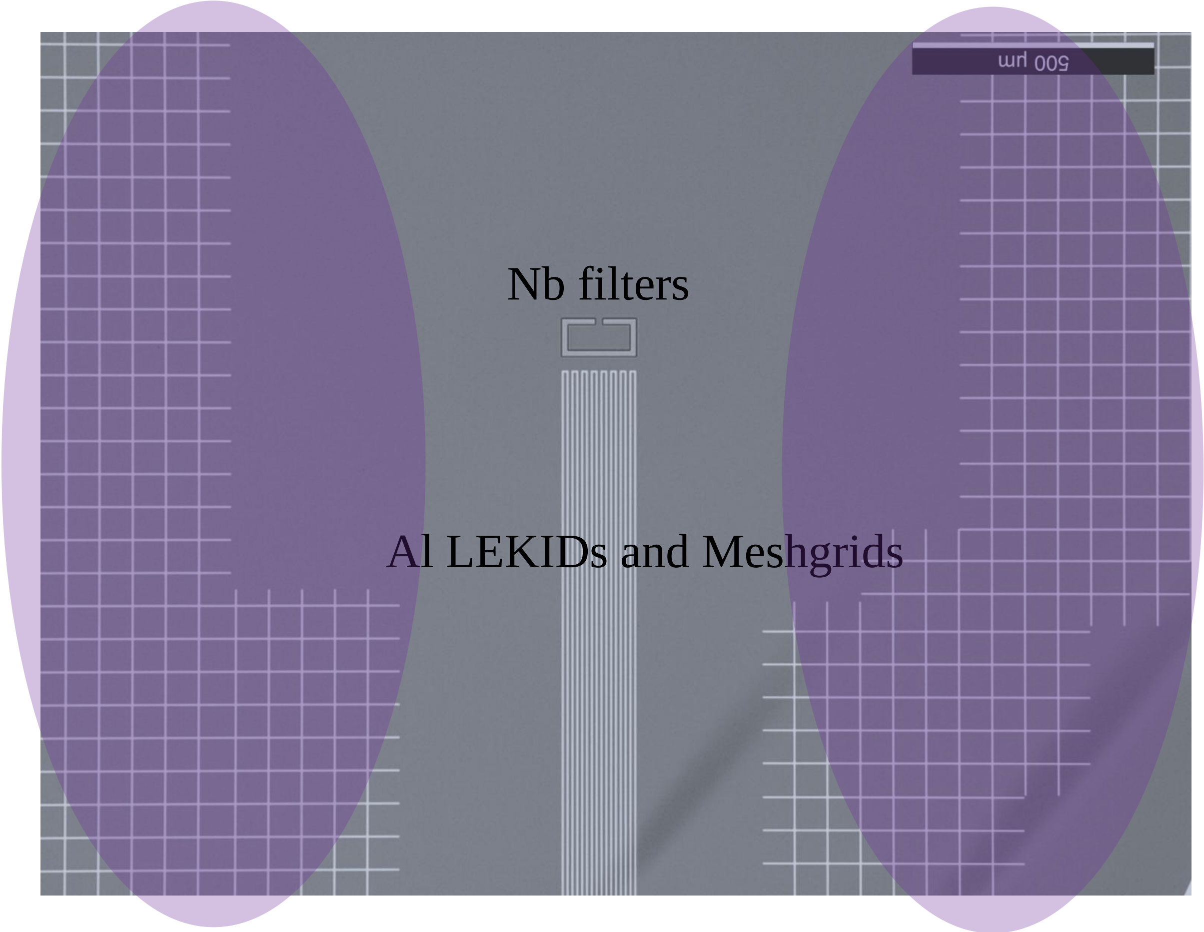


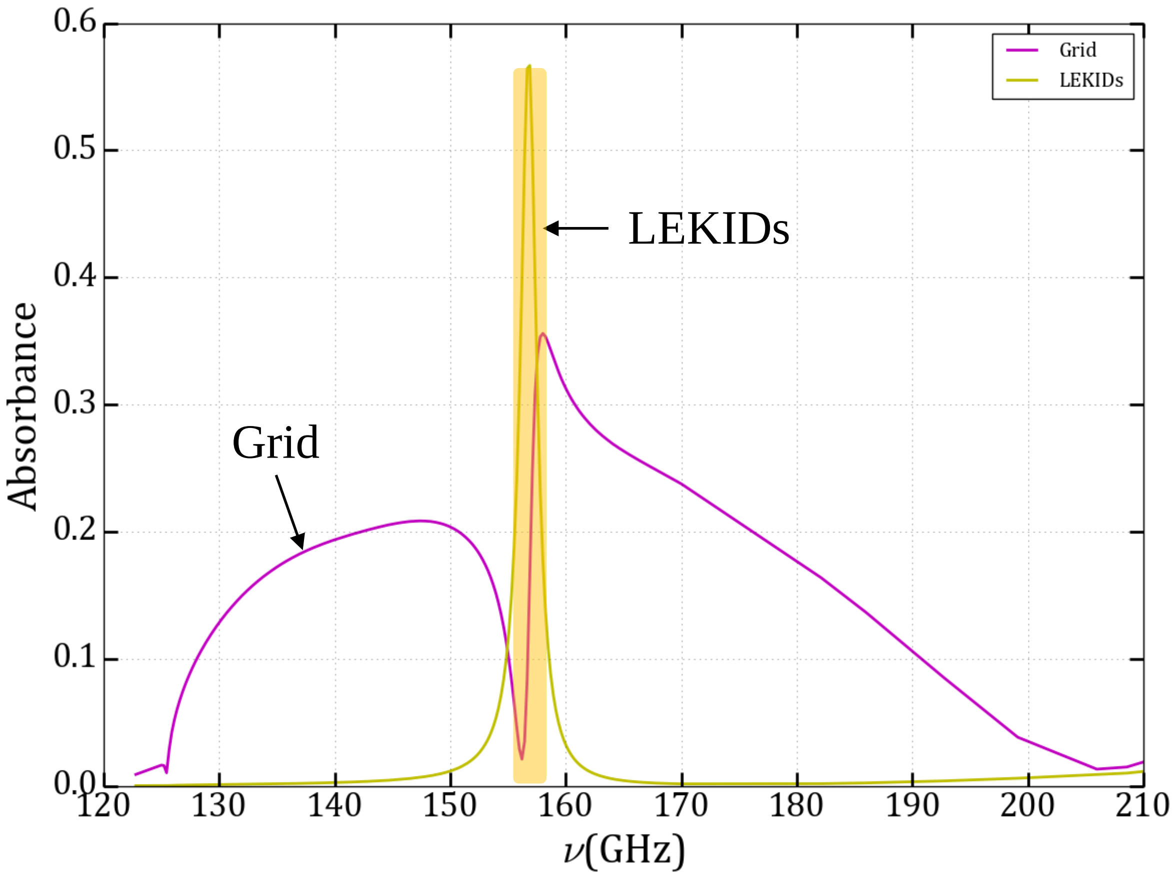
POLARIZATION Sensitive
Polarized along the width of the filter-shape
R= 500-800

Chowdhury et al, RAS Techniques and Instruments, 2(1):562566, 08 2023. ISSN 2752-8200. doi: 10.1093/rasti/rzad038

OnChip Spectometers @ Institut Néel: 2023-2024

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID) 2 mm





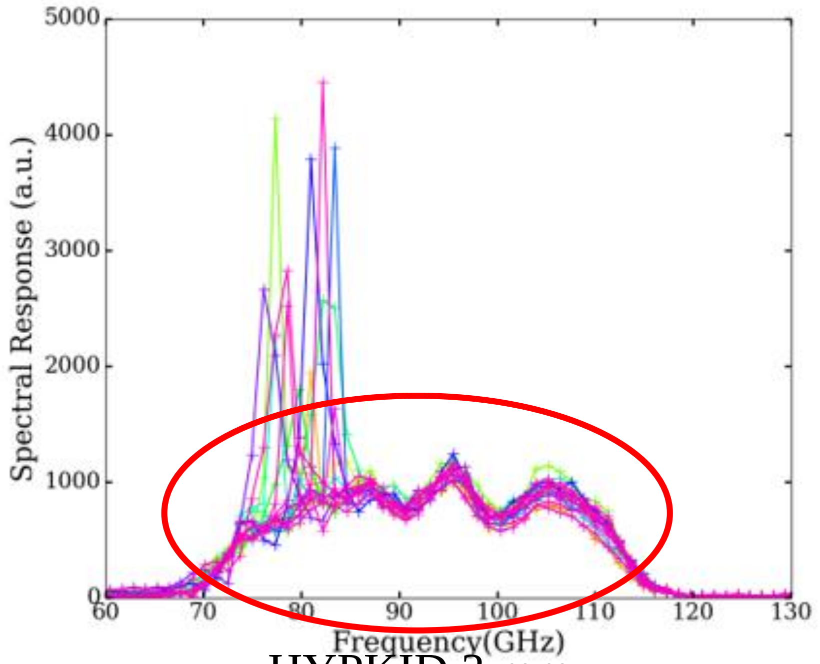
At resonance, all signals are absorbed by the LEKIDs

OnChip Spectometers @ Institut Néel: 2023-2024

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID) 2 mm

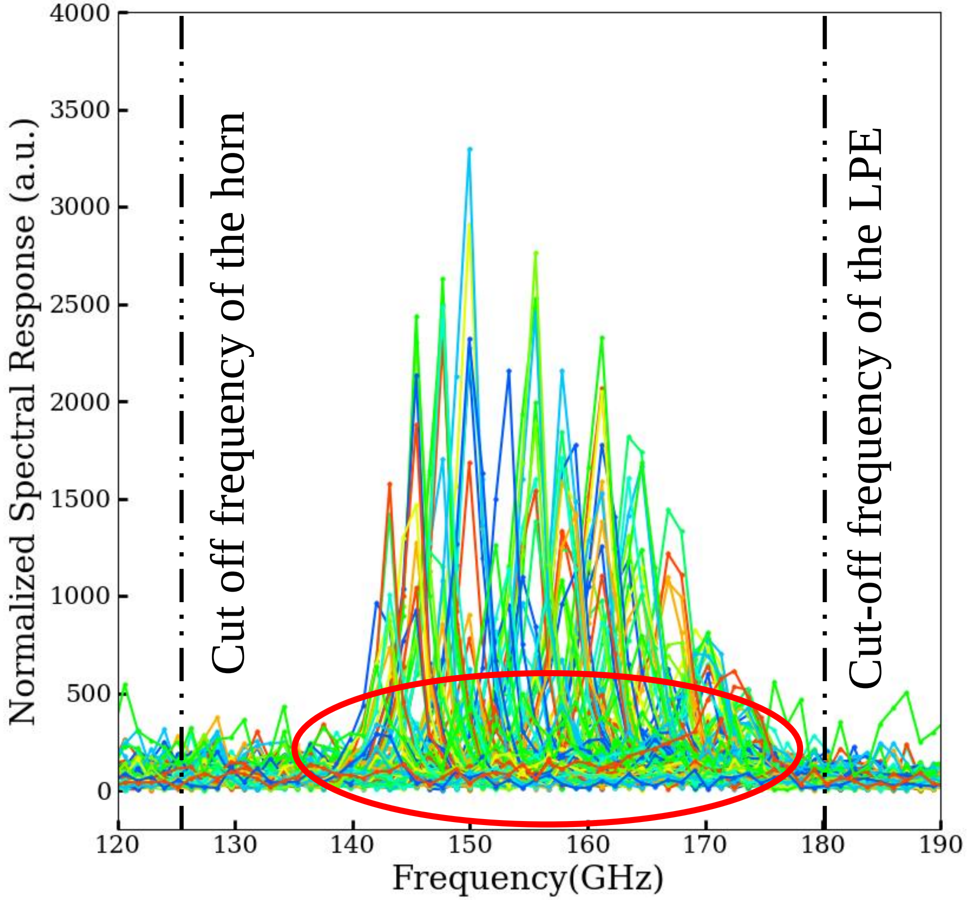
Common mode removal with Grid:

HYPKID 3 mm



HYPKID 3 mm

HYPKID 2 mm

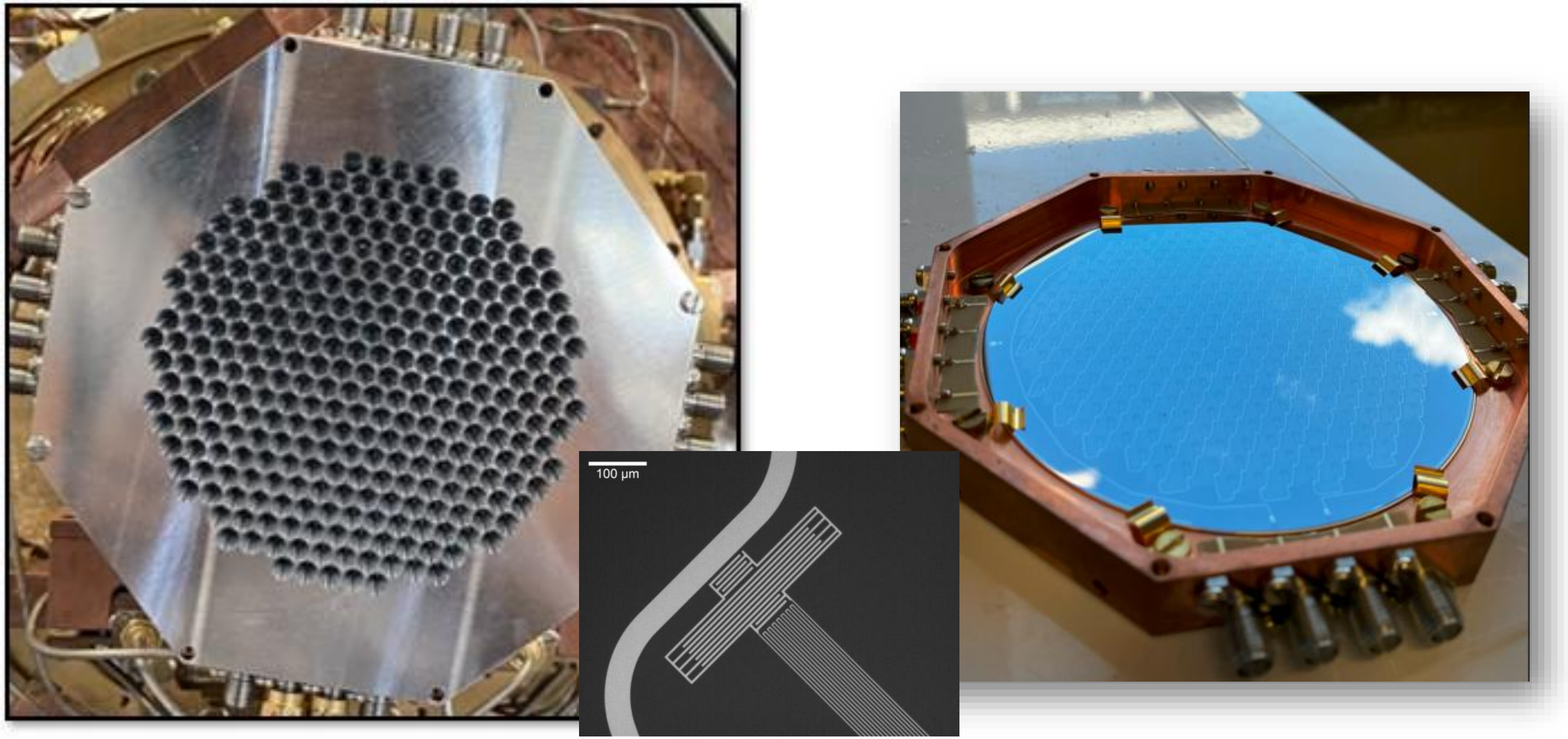


Spectral resolution
100-300

No common mode

OnChip Spectometers @ Institut Néel: 2023-2025

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID) 2 mm

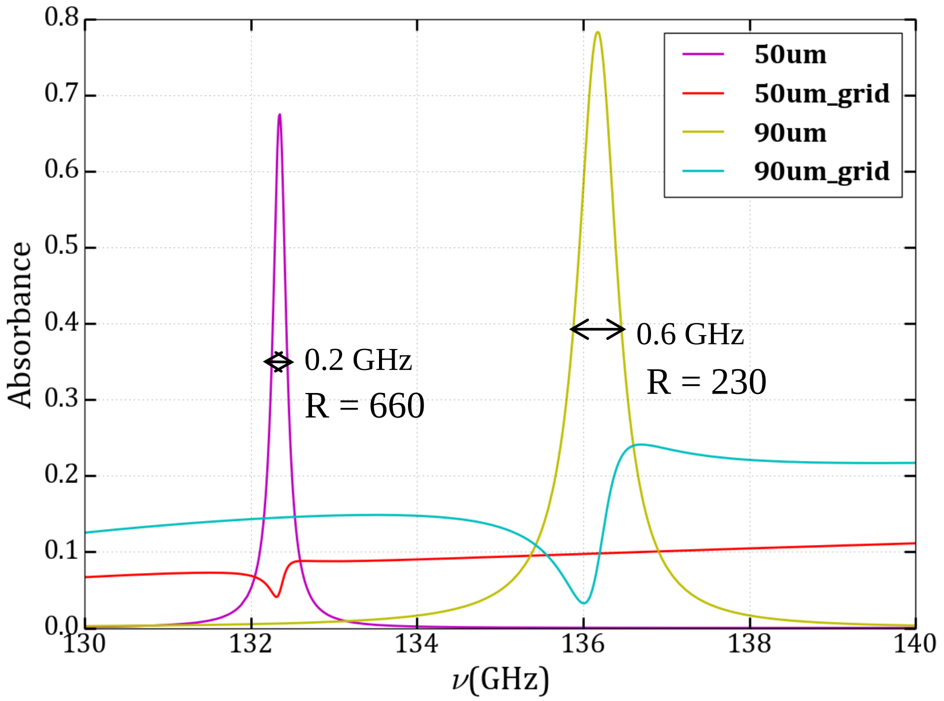


Overview of a 301 channels
HYPKID for 2 mm

OnChip Spectometers @ Institut Néel: 2023-2024

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID) 2 mm

Spectral width variation with etching:



Deep Reactive Ion Etching

Thickness of the substrate	Spectral Bandwidth
90	0.6 GHz
50	0.2 GHz

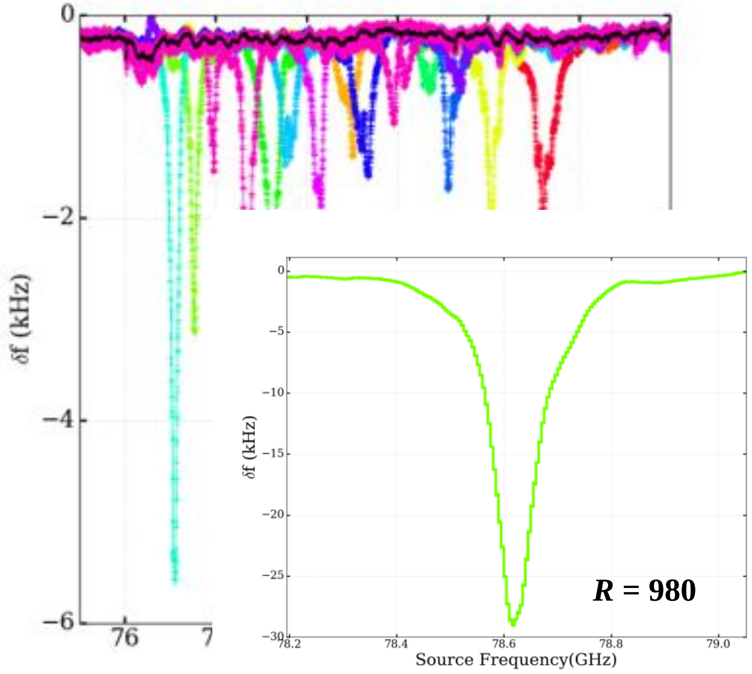
Tuning of the Spectral Bandwidth

OnChip Spectometers @ Institut Néel: 2023-2024

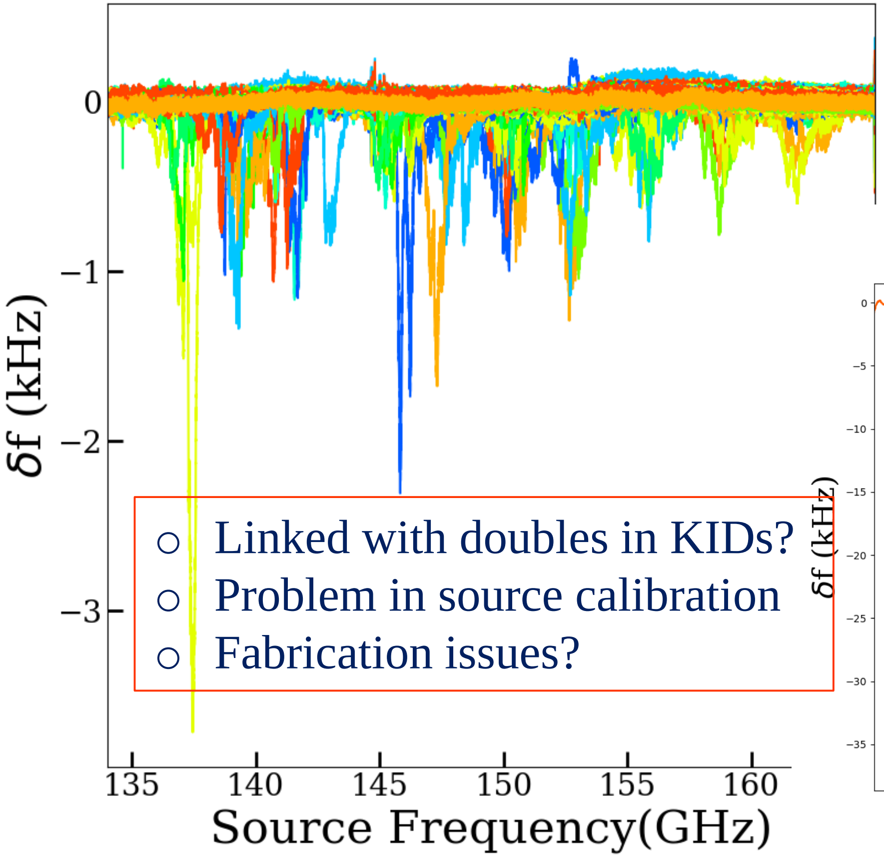
*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID) 2 mm

Issues with mm wave source:

HYPKID 3 mm
75-110 GHz

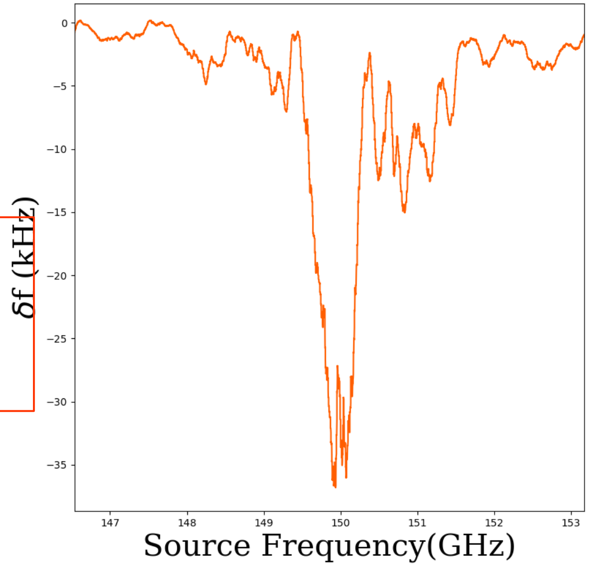


HYPKID 2 mm
110 -170 GHz



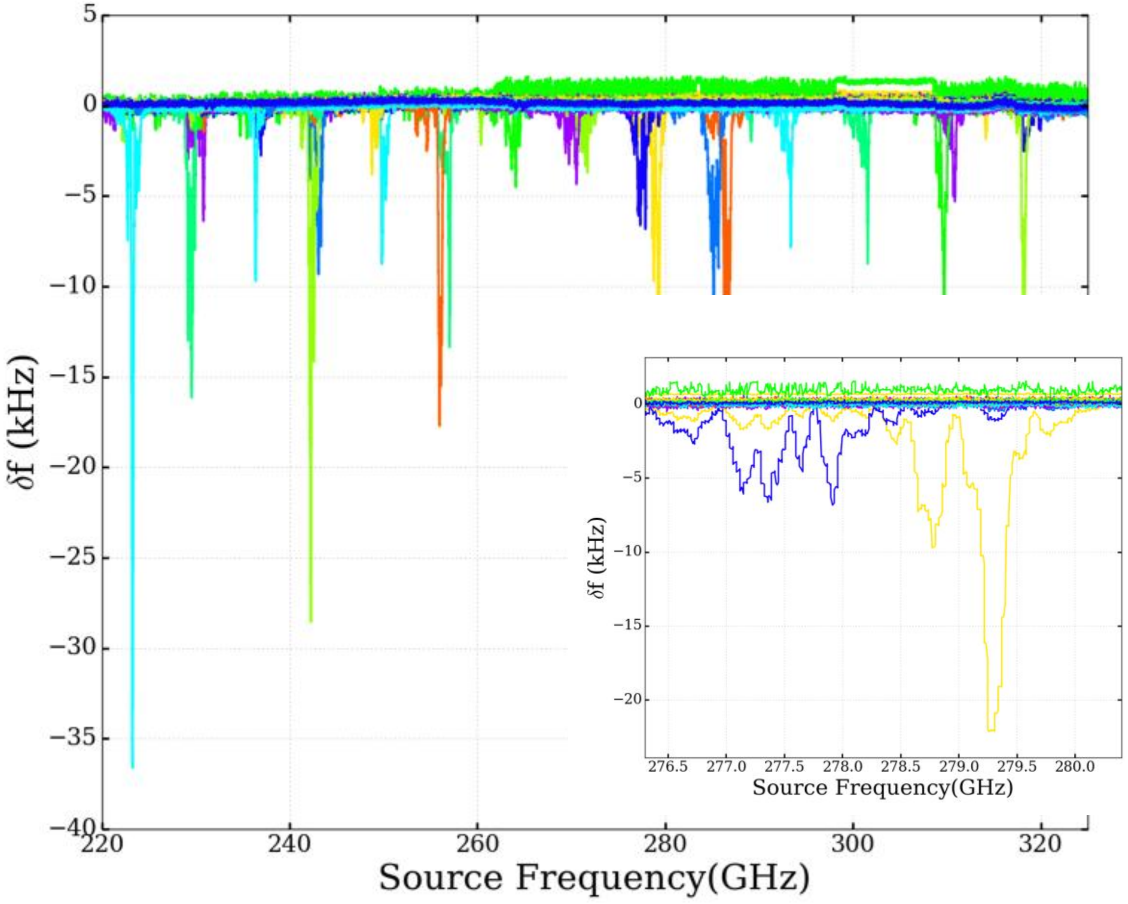
- Linked with doubles in KIDs?
- Problem in source calibration
- Fabrication issues?

Multiple band response

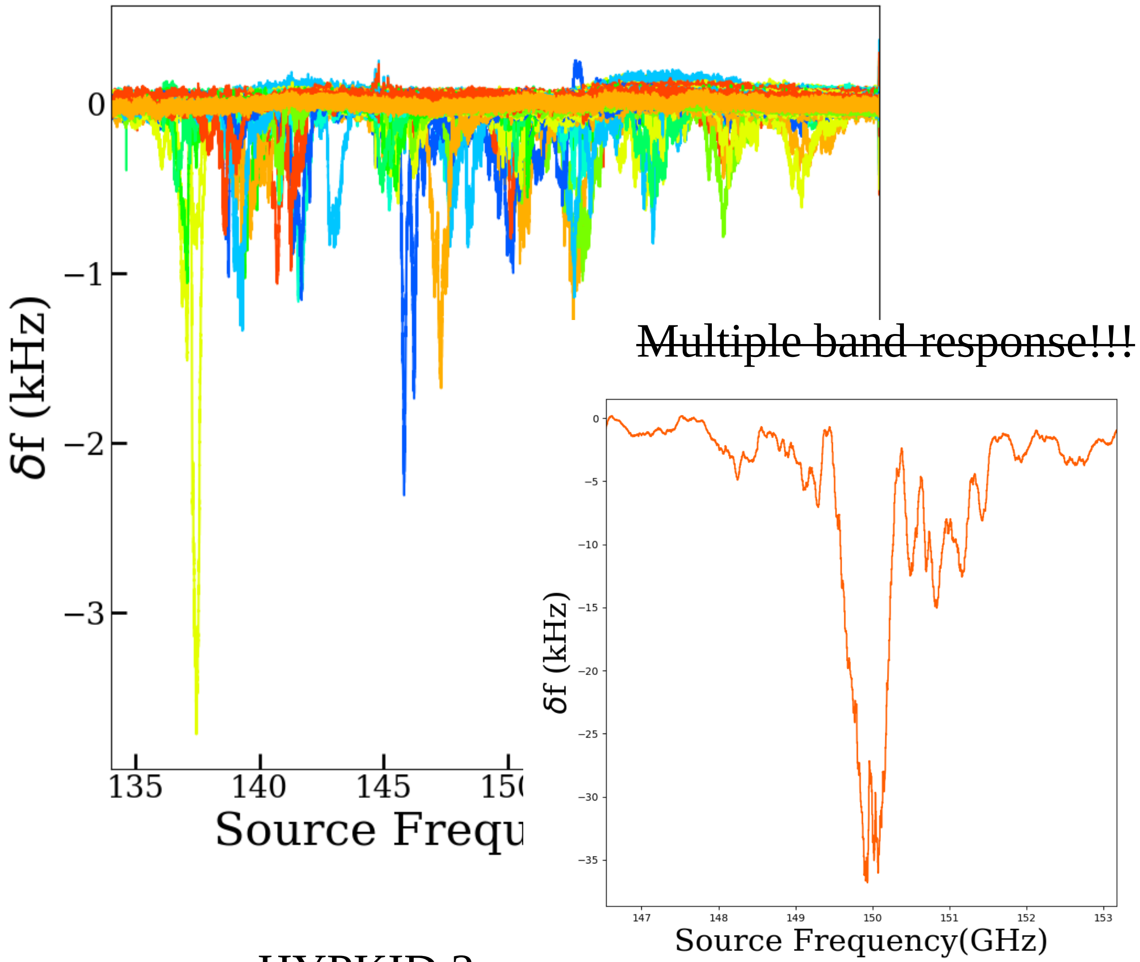


OnChip Spectometers @ Institut Néel: 2024-2025

- Problem in source calibration



DESHIMA test @ Néel
Source used: 220-325 GHz



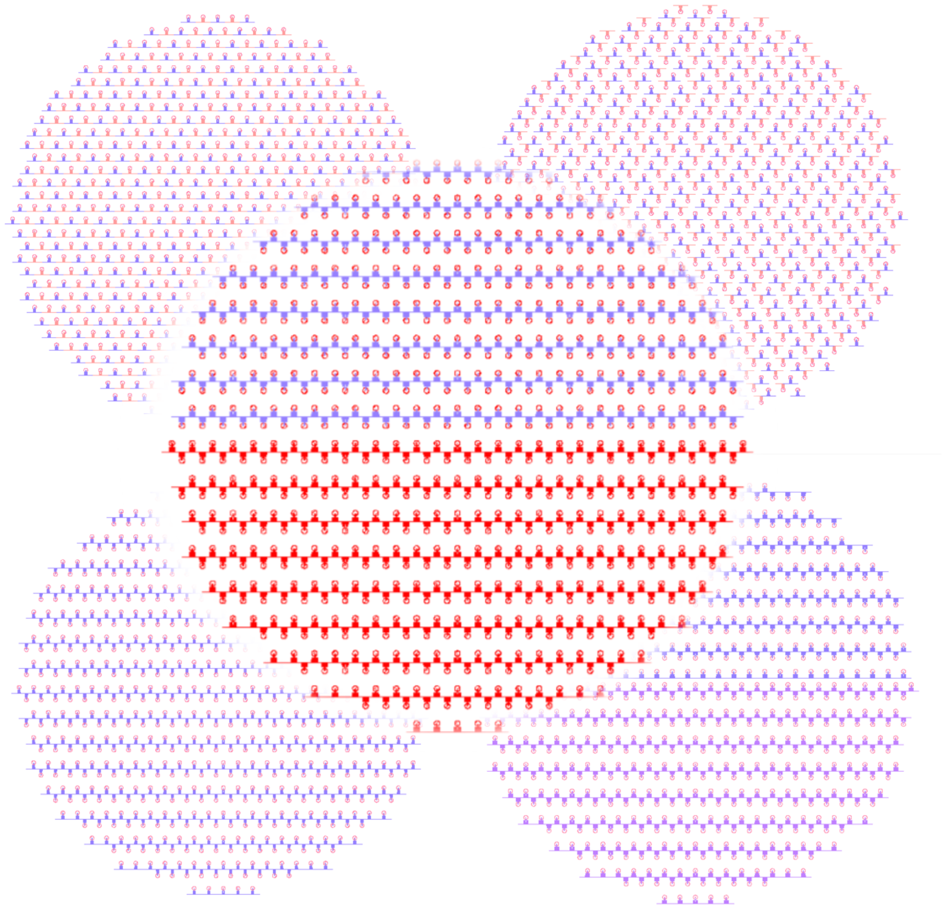
HYPKID 2 m...

Source used: 110 -170 GHz

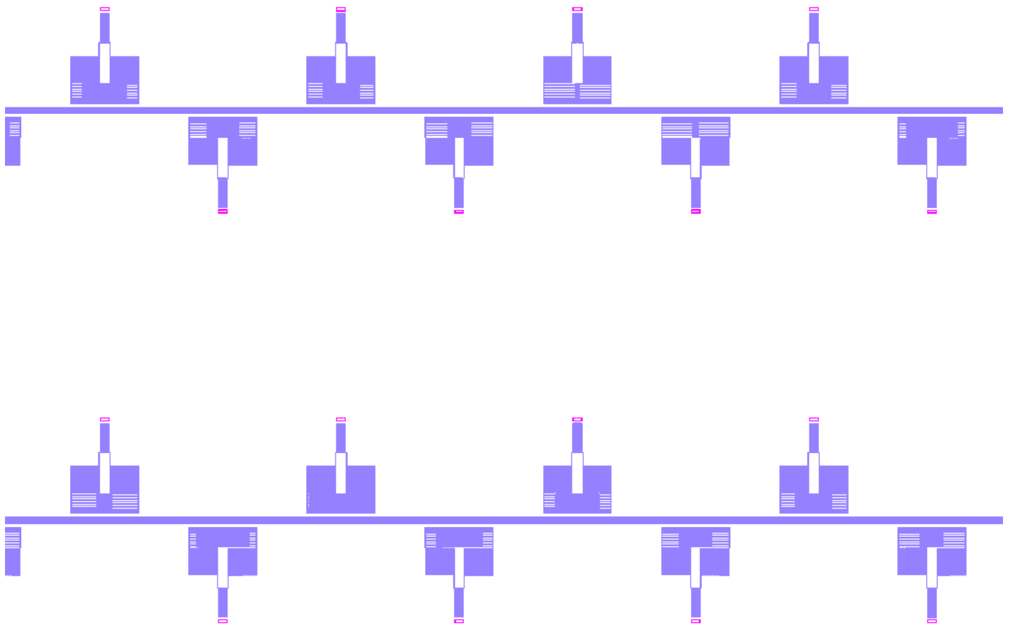
OnChip Spectometers @ Institut Néel: 2024-2025

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID) 1 mm

- Linked with doubles in KIDs?



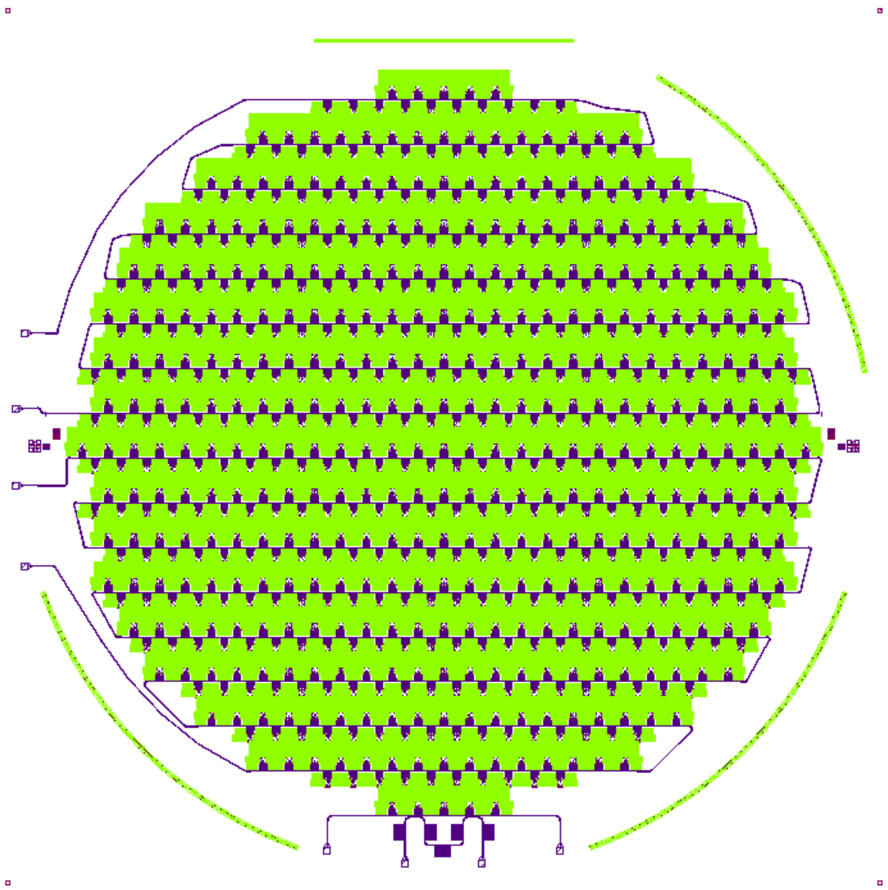
721 channels, 220 GHz-240 GHz



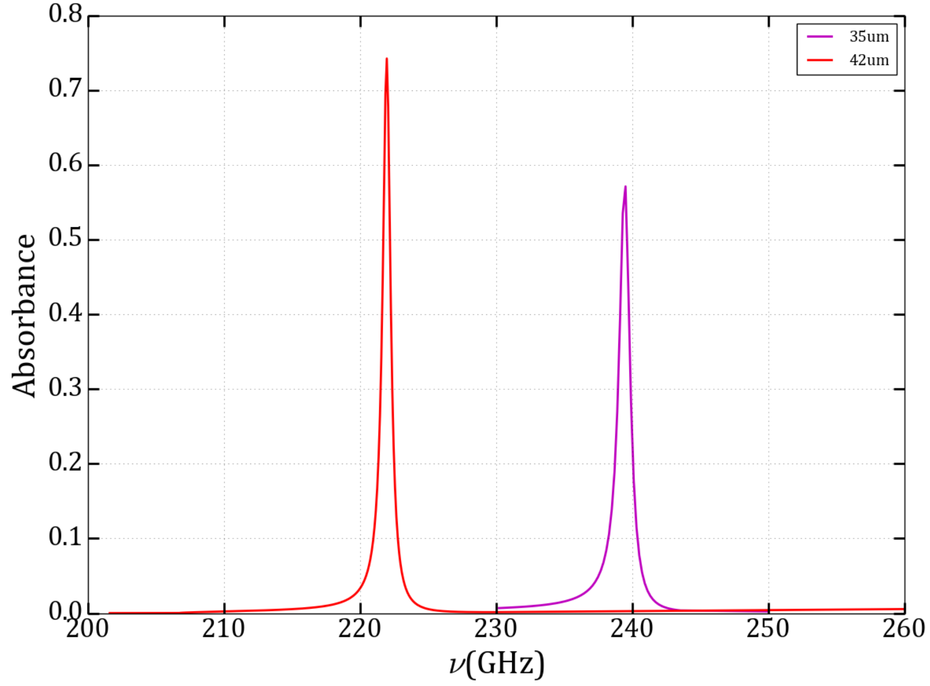
Distributed randomly:
Two next ones are differentiated by atleast 20 um
Frequency difference (minimum) = 70 MHz

OnChip Spectometers @ Institut Néel: 2024-2025

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID) 1 mm



721 channels, 220 GHz-240 GHz

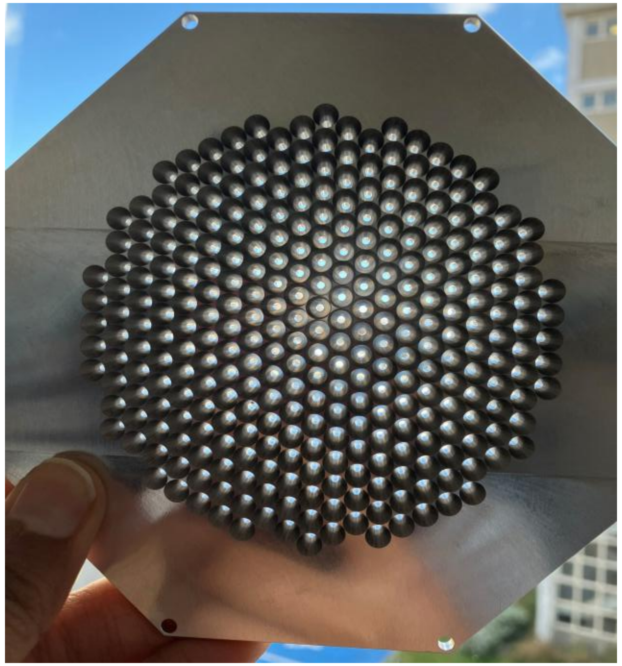


Spectral Bandwidth: 1.2-1.5 GHz

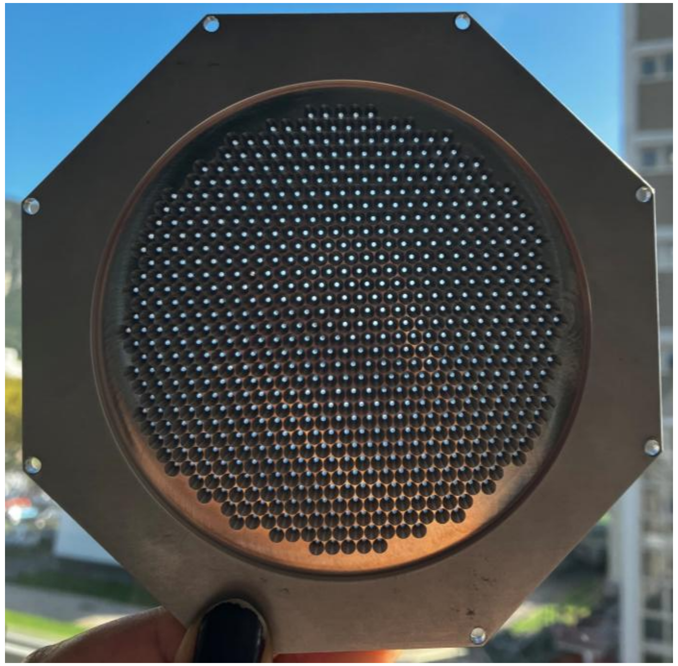
17 Spectral Channels for distributed among detection 360*2 channels
For two resolution in between 100-1000

OnChip Spectometers @ Institut Néel: 2024-2025

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID) 1 mm



301 horns: 2 mm



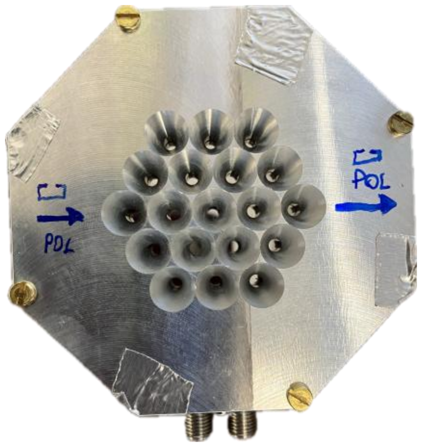
721 horns: 1 mm

Noise Equivalent Power, NEP = $< \mathbf{10^{-17}}\ \mathrm{W}/\sqrt{\boldsymbol{Hz}}$!!!

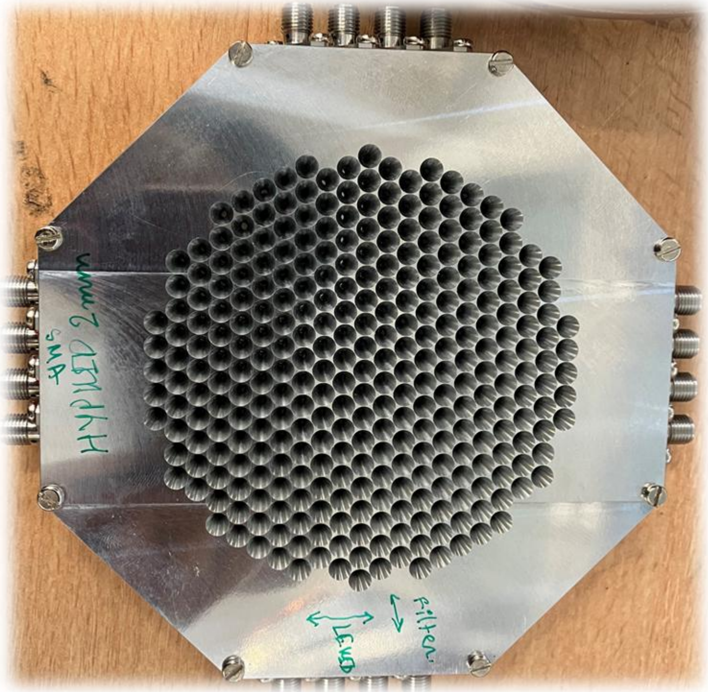
OnChip Spectometers @ Institut Néel

*HYP*er-spectral device with *K*inetic *I*nductance *D*etector (HYPKID) 3 mm, 2 mm, 1 mm

Polarization Sensitive Spectral channels
NEP # 10^{-17} W/$\sqrt{Hz}$
Difficult but less complicated fabrication process



3 mm, 16 channels



2 mm, 301 channels

1 mm, 721 channels

Thank you!!!