

Les KID en France (et pas que)

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Vue d'ensemble

1 – Les KID et leur histoire

Qu'est ce que c'est un KID?

Caractéristiques principales, avantages et désavantages

Timeline

2 – Développements des KID en France

LEKID, spectromètres, KID pour les faibles énergies ...

3 – Développements des KID ailleurs

Spectromètres, T-KID, dual-pol, ...

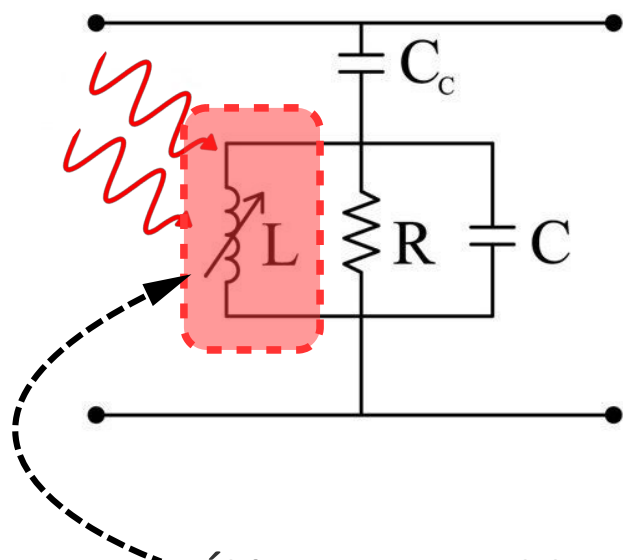
4 – Les KID

Instruments français et pas que

En Europe, Amérique,

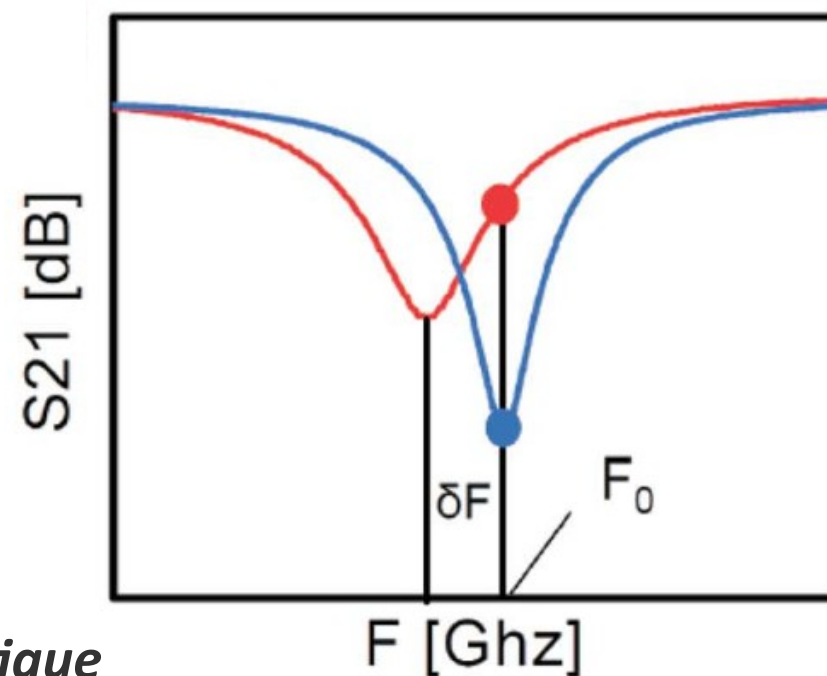
Qu'est ce que c'est un KID

KID = un **résonateur supraconducteur** dont la fréquence de résonance varie avec la puissance absorbée



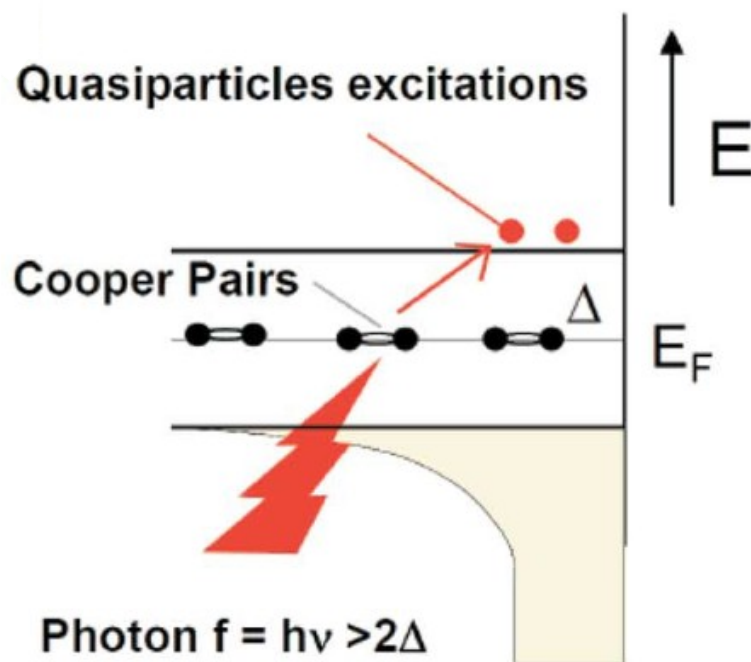
Élément sensible : **inductance cinétique** des paires de Cooper!

$$\delta P \propto \delta f_0$$



Qu'est ce que c'est un KID

KID = détecteurs 'à seuil' !



$$E_{min} = 3.5k_bT_c$$

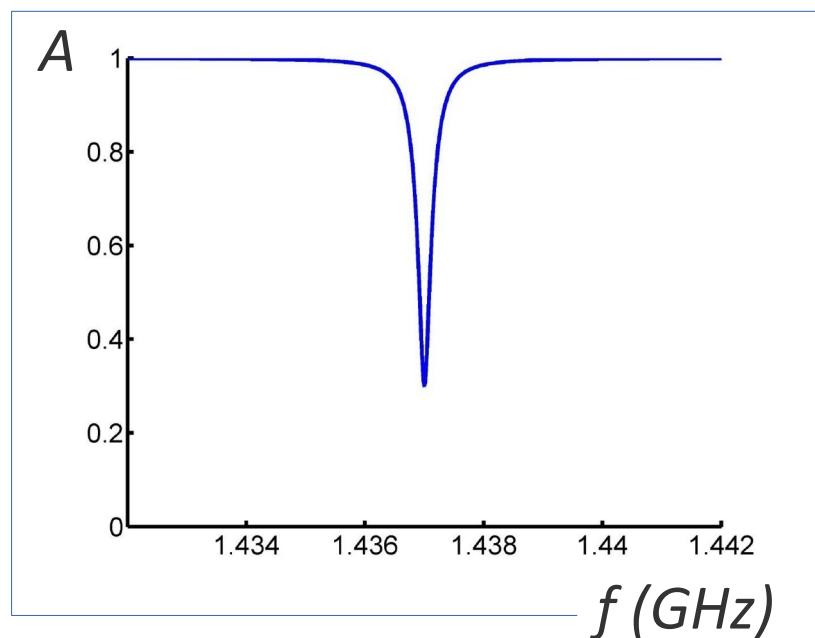
$$E_{min} \approx (73 \text{ Ghz/K}) * T_c$$

- **Peu sensibles à T** (si $T < T_c/6$)
- Non thermiques, donc **rapides**
- OK seulement à partir de $\sim 50\text{GHz}$
- Pas très adaptée aux faibles énergies (*)

(*)

Qu'est ce que c'est un KID

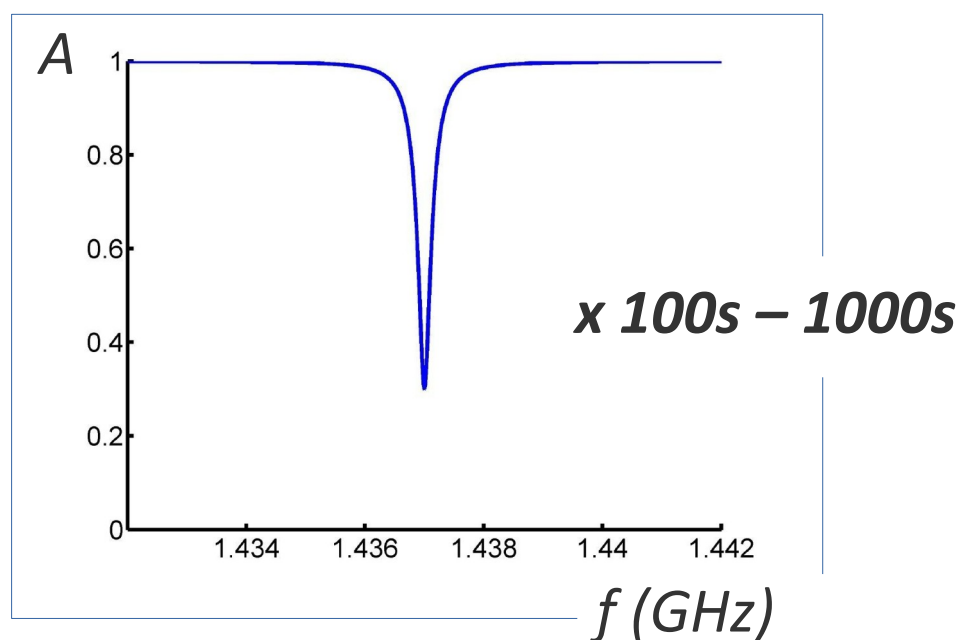
KID = résonateurs supra \rightarrow multiplexage intrinsèque!



$$Q = 10^4 - 10^6 !$$

Qu'est ce que c'est un KID

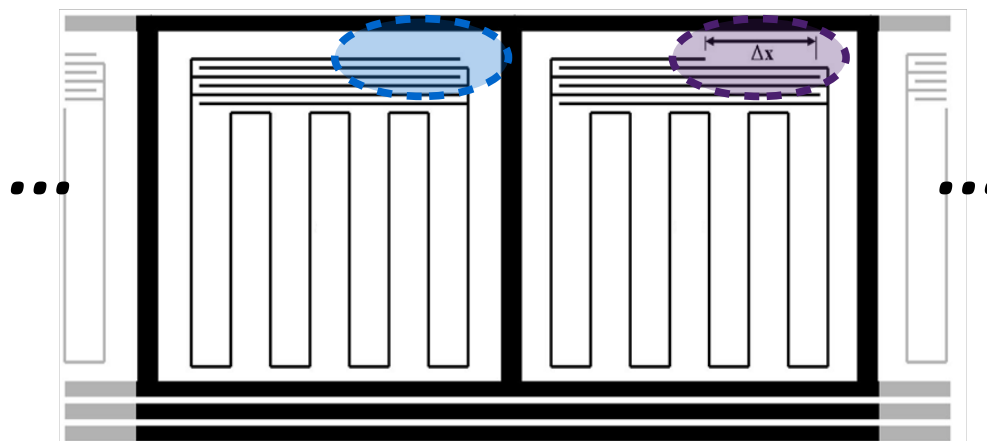
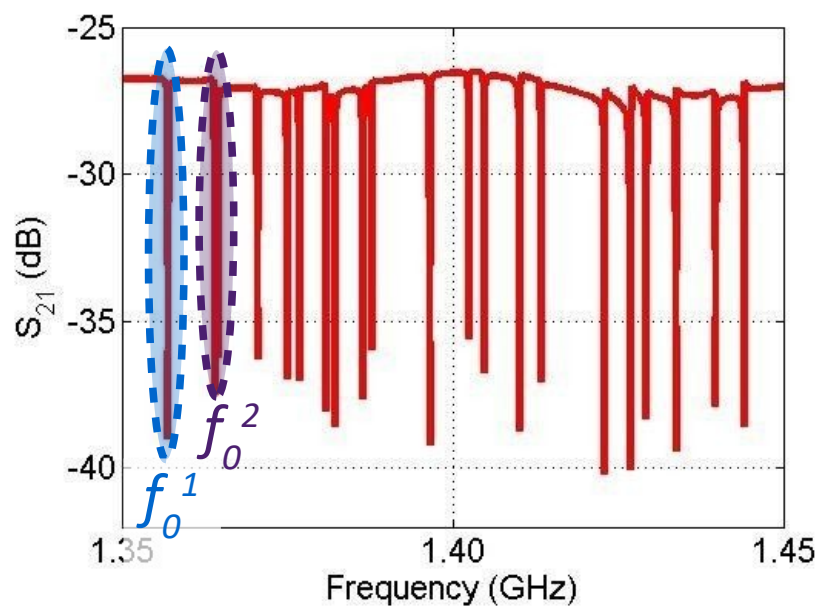
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$$Q = 10^4 - 10^6 !$$

Qu'est ce que c'est un KID

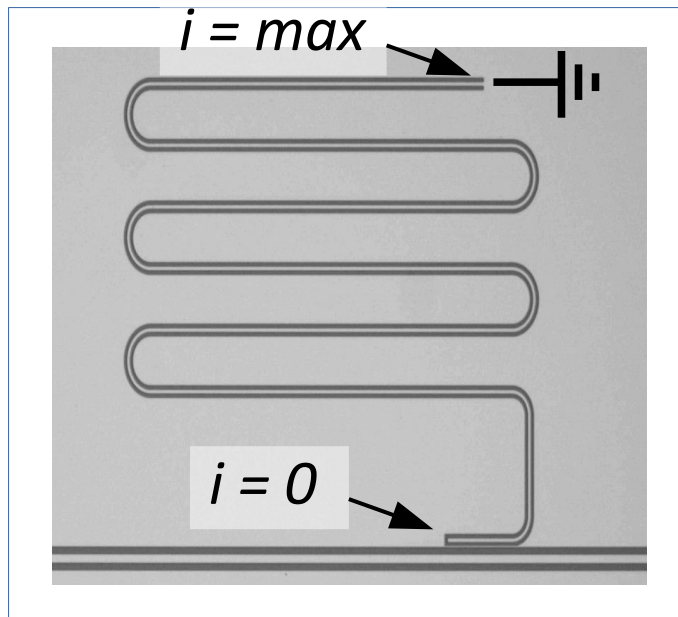
KID = résonateurs supra \rightarrow multiplexage intrinsèque!



- Chaque pixel a sa propre f_0
- 1 tone d'excitation par f_0
- \rightarrow Multiplexage **FDM** ! (Utilisé par d'autres applications aussi ! QuBit, TES..)

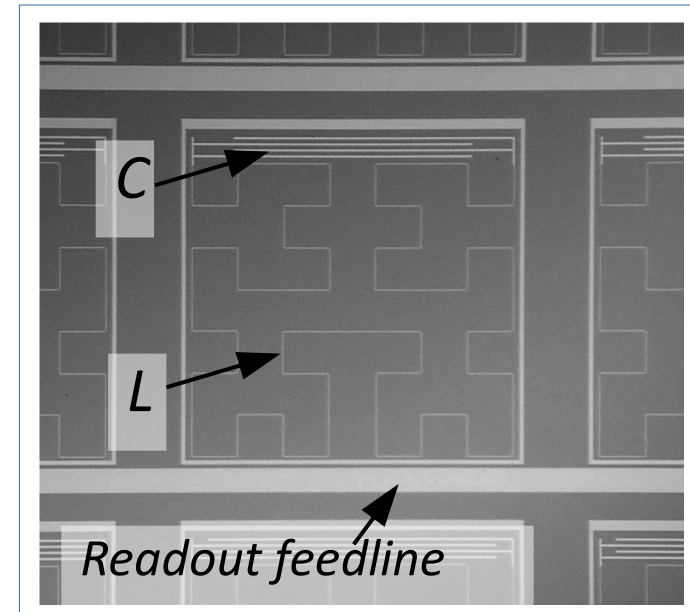
Les deux grandes familles de KID

KID distribué ($\lambda/4$)



$$f_0 \propto 1/l$$

KID à éléments concentrés



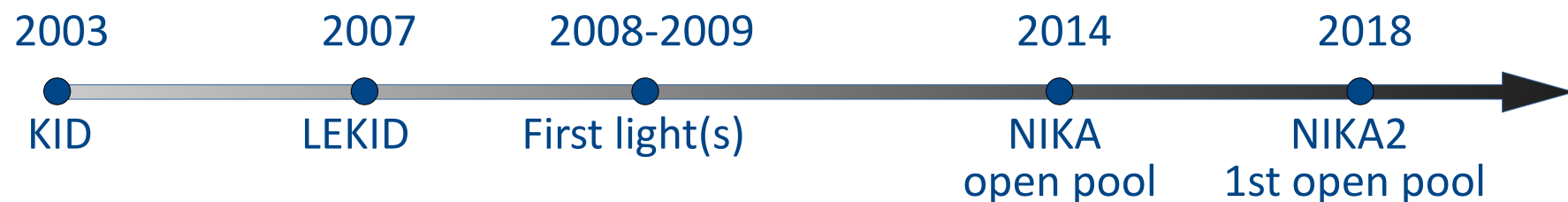
$$f_0 \propto 1/\sqrt{LC}$$

- Couplage optique plus difficile
- Plus grand contrôle sur les champs
- Adapté aux plans focaux 'évolués'

- Couplage optique optimal
- Champs plus 'ouverts'
- Adapté aux *filled arrays*

KID : les premières étapes

Une technologie 'simple' qui a évolué très rapidement



2003 Première proposition de la techno KID (P. Day et al, 2003)

2007 Géométrie 'Lumped Element KID' (S. Doyle et al, 2007)

2008 Premier KID 'on-sky' (J. Schlaerth et al, 2008)

2009 Première camera astronomique KID multipixel : NIKA (A. Monfardini et al, 2009)

2014 NIKA-NIKA2 ouverts aux astronomes. Premiers instruments KID (A. Catalano et al, 2014 / R. Adam et al, 2018)

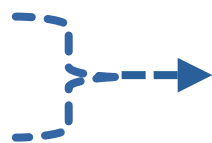
2018

+ plein de développement côté détecteurs

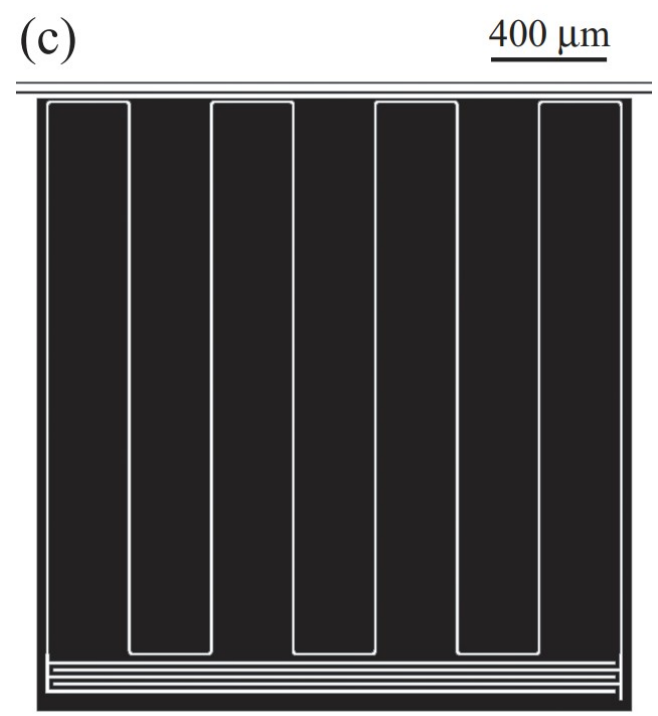
LEKID pour NIKA/NIKA2

Dessin simple et robuste

Absorption directe dans le détecteur

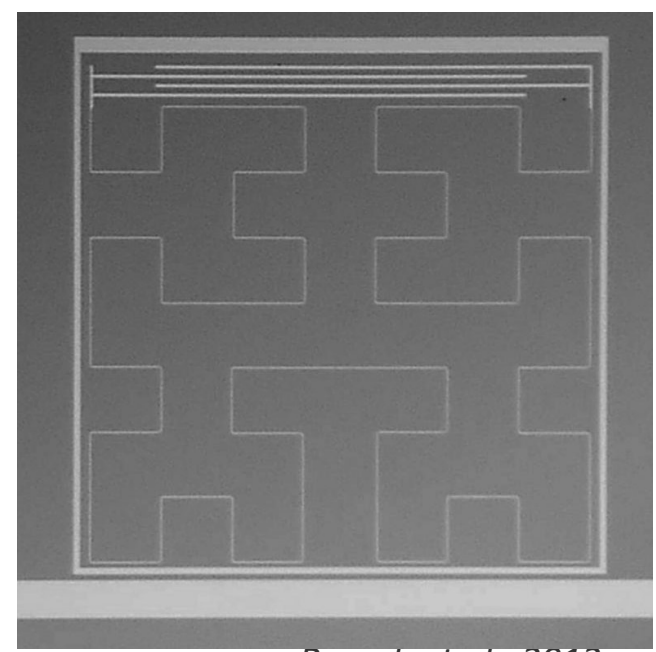


Plus de temps pour l'instrument dans son ensemble !



Monfardini et al., 2009

1-pol Al LEKID pixel



Roesch et al., 2012

2-pol Al LEKID pixel

Optimisation : matériaux, géométrie, substrat, ...



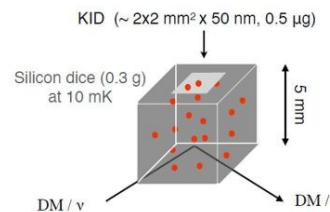
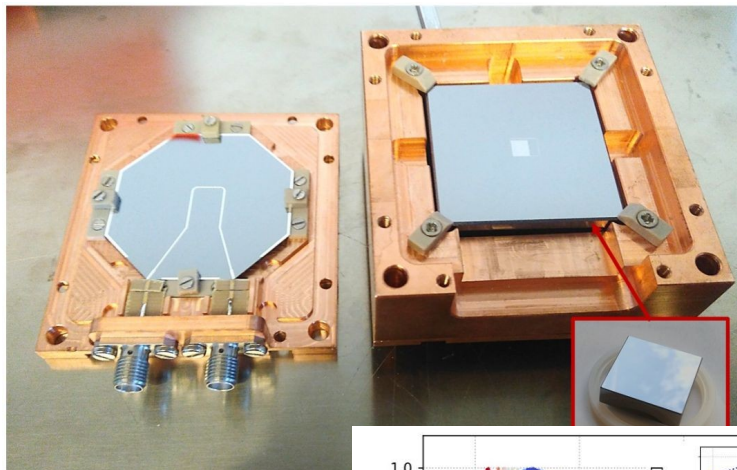
LEKID pour faibles énergies

GIS KID

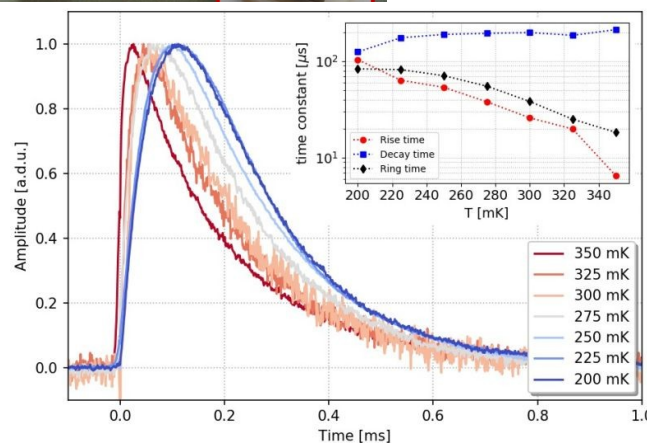
Dessin classique, détection 'phonon mediated'

WiFi KID (RICOCHET)

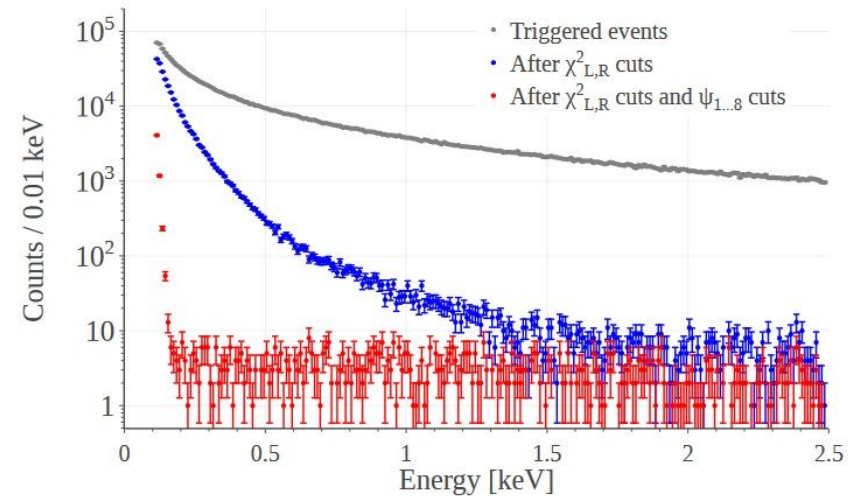
LEKID voxels (BULLKID)



Goupy et al., 2019



Resolution E: ~1keV



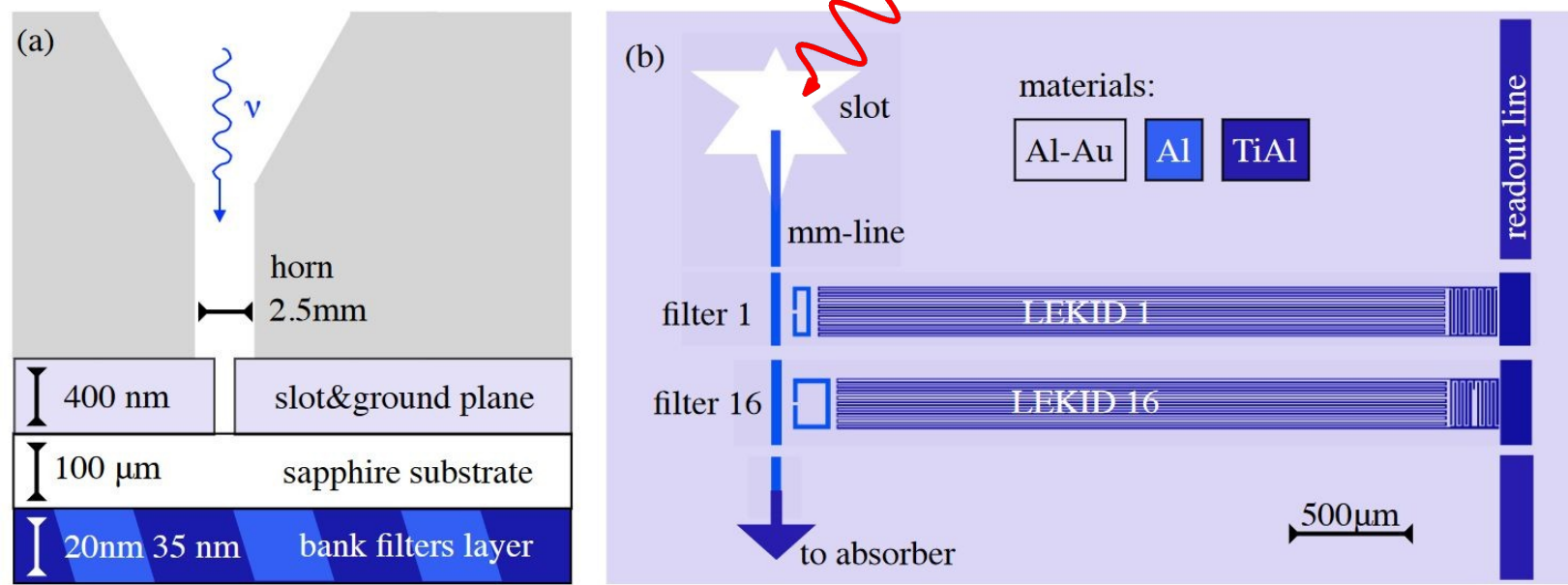
Delicato et al., 2024

Resolution E: ~30eV

Spectromètres: OMKID/HYPKID

Multiplexage → multi-fonctionnalité ! Eg : *spectromètre on-chip*

OMKID : 1 pixel 'spatial' / 16 couleurs

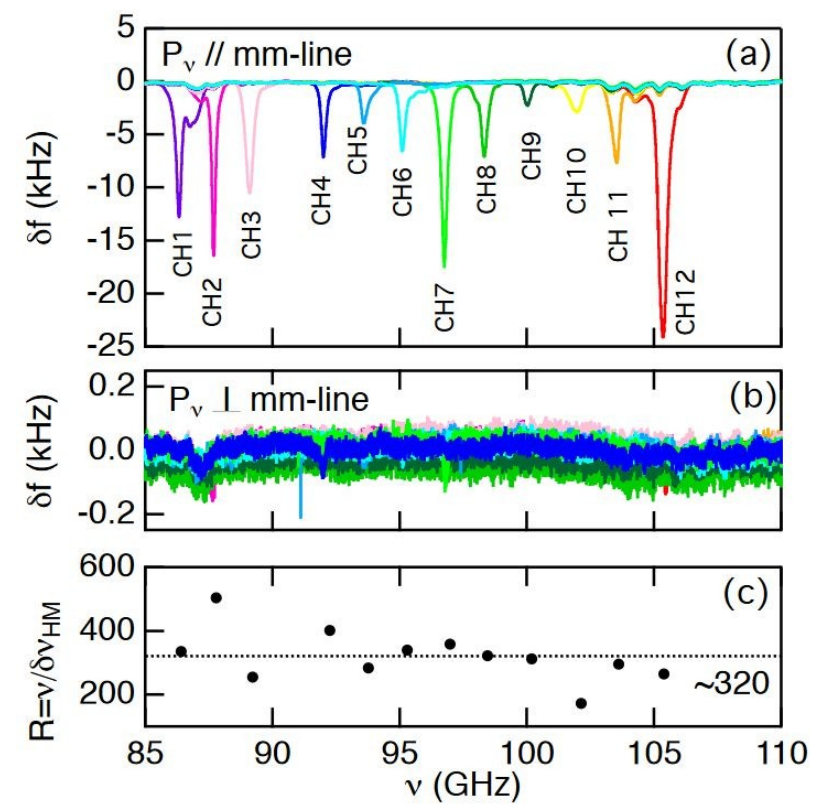
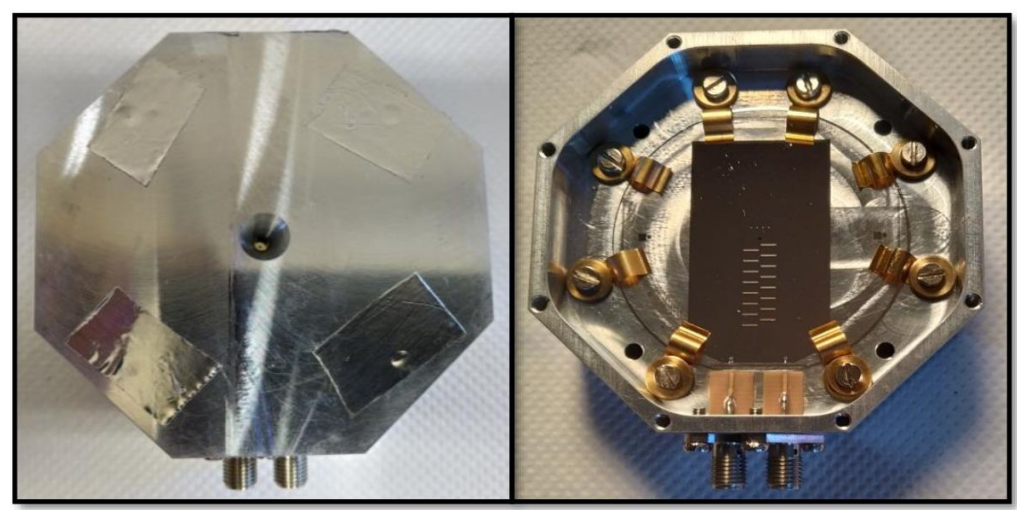


Chowdhury et al., 2023

Spectromètres: OMKID/HYPKID

Multiplexage → multi-fonctionnalité ! Eg : *spectromètre on-chip*

OMKID : 1 pixel 'spatial' / 16 couleurs



- Résolution **OK**
- Efficacité optique limitée (mais similaire aux autres techno on-chip..)

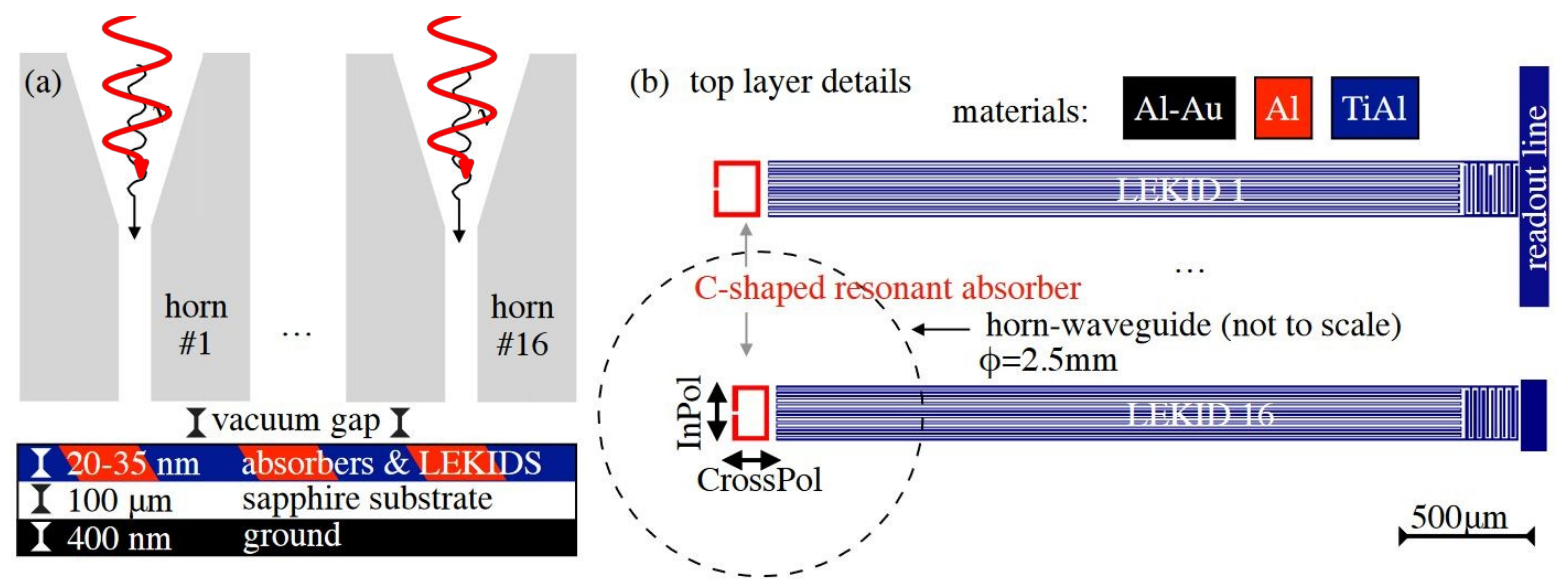
Chowdhury et al., 2023



Spectromètres: OMKID/HYPKID

Multiplexage → multi-fonctionnalité ! Eg : *spectromètre on-chip*

HYPKID : 16 pixel 'spatial' / 16 couleurs

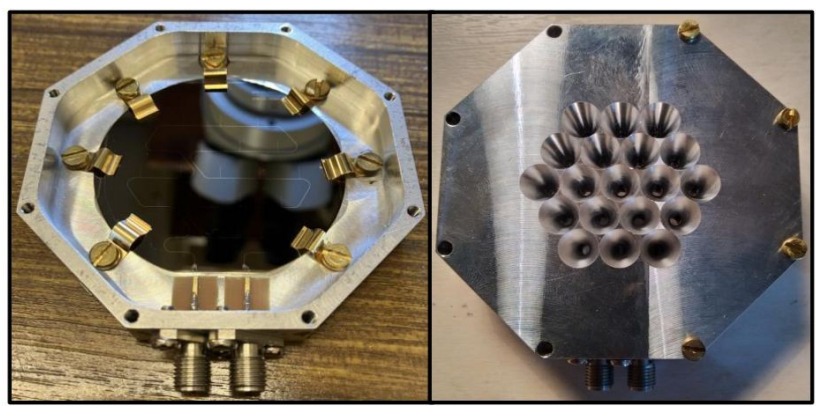


Chowdhury et al., 2023

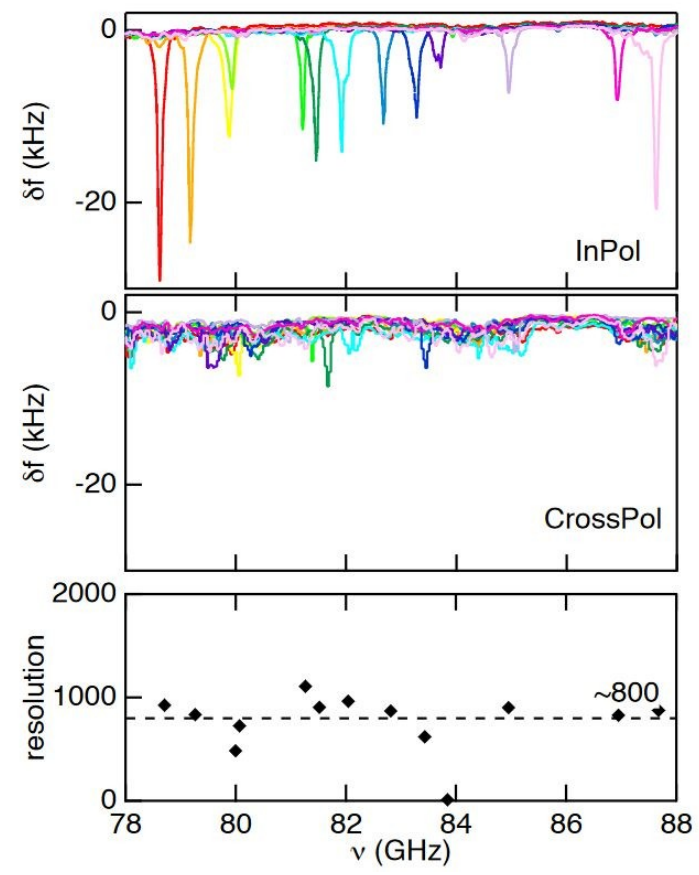
Spectromètres: OMKID/HYPKID

Multiplexage → multi-fonctionnalité ! Eg : *spectromètre on-chip*

HYPKID : 16 pixel 'spatial' / 16 couleurs



Chowdhury et al., 2023



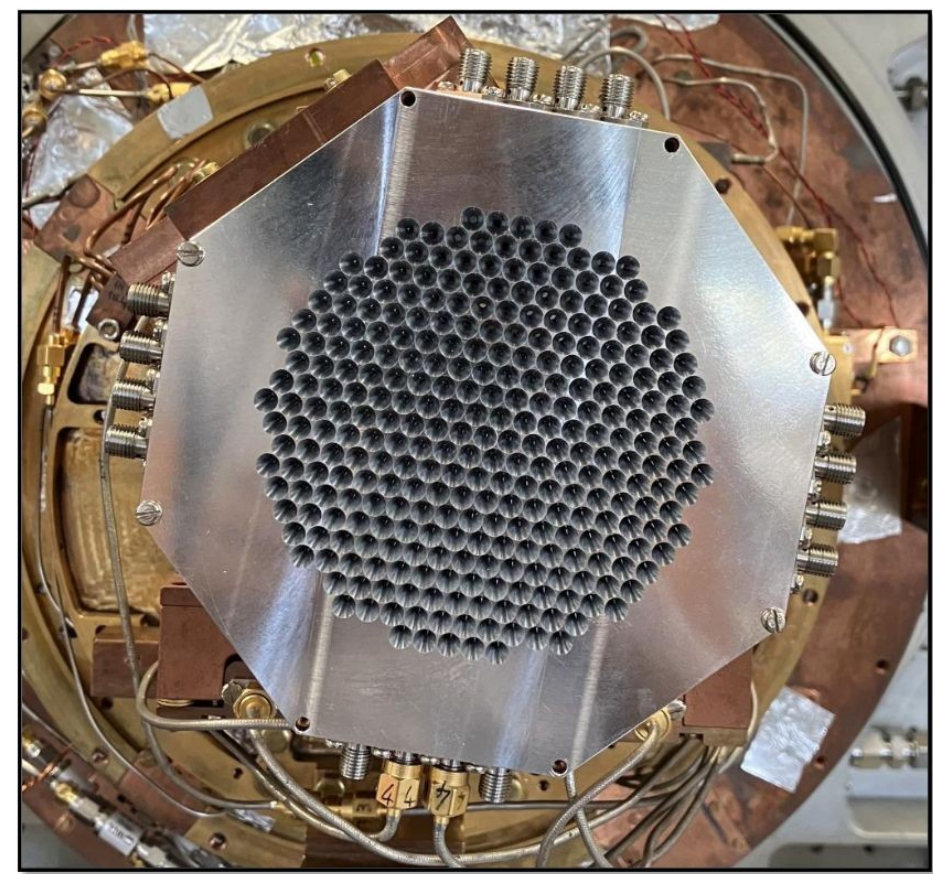
- Résolution **OK**
- Efficacité optique **OK**
- Lumière parasite à maîtriser



Spectromètres: OMKID/HYPKID

Multiplexage → multi-fonctionnalité ! Eg : *spectromètre on-chip*

HYPKID : 16 pixel 'spatial' / 16 couleurs

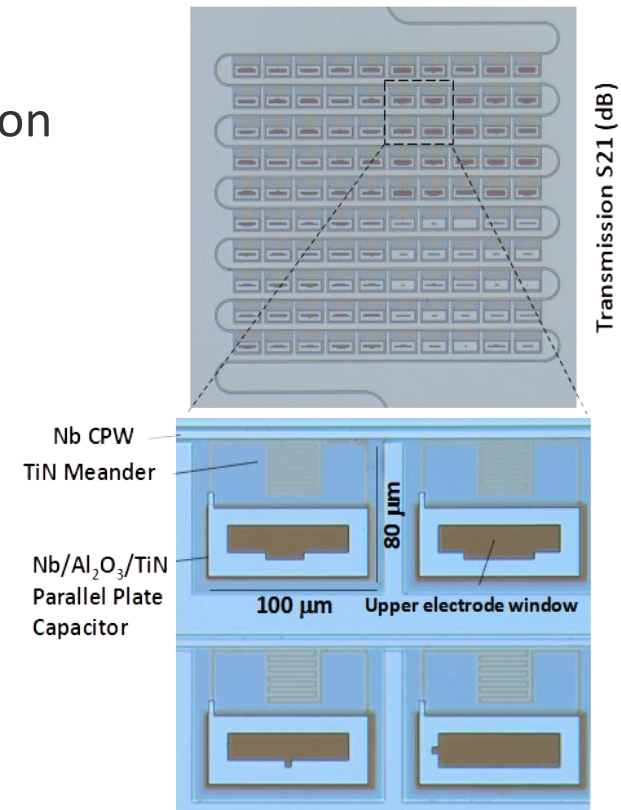
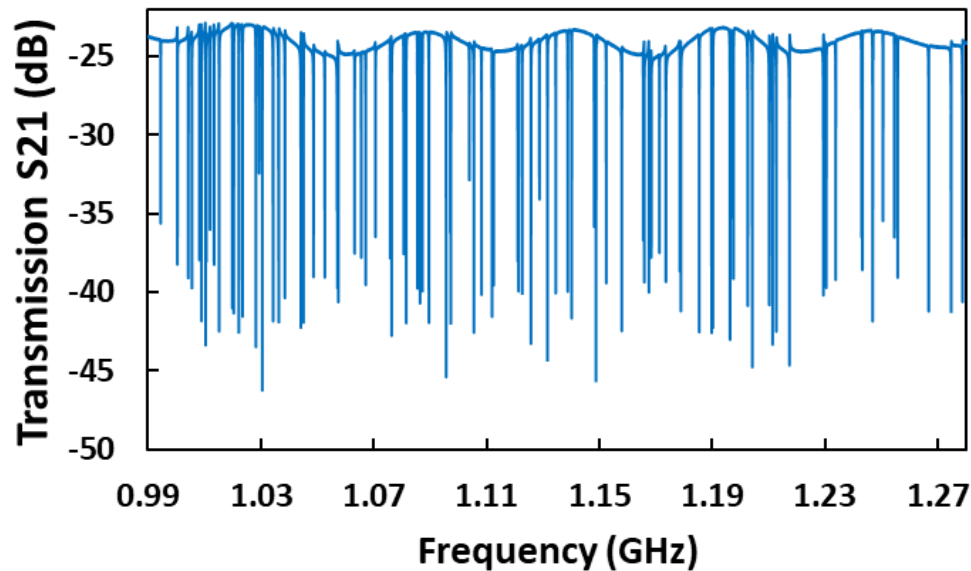


- Résolution OK
- Efficacité optique OK
- Lumière parasite à maîtriser
- On passe à la taille supérieure !

GIS KID

- **Dielectric-based Parallel Plate Capacitor KIDs**

- **Objectif** : réduire taille du pixel/augmenter résolution
- **Méthode** : remplacer IDC avec PPC diélectrique
- **Résultats** : haut Q_i mais fort bruit TLS

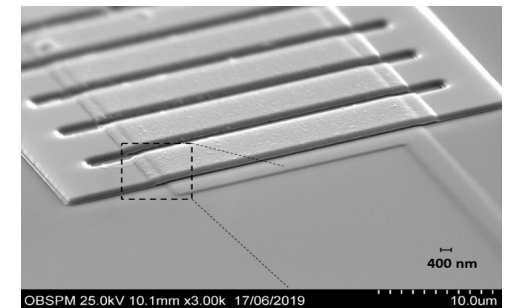
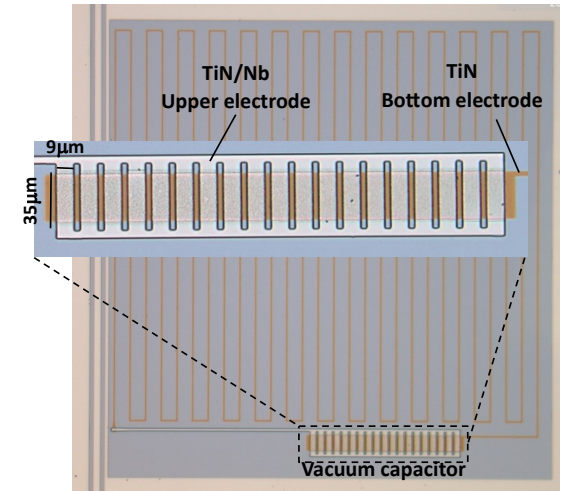


Beldi et al., 2019

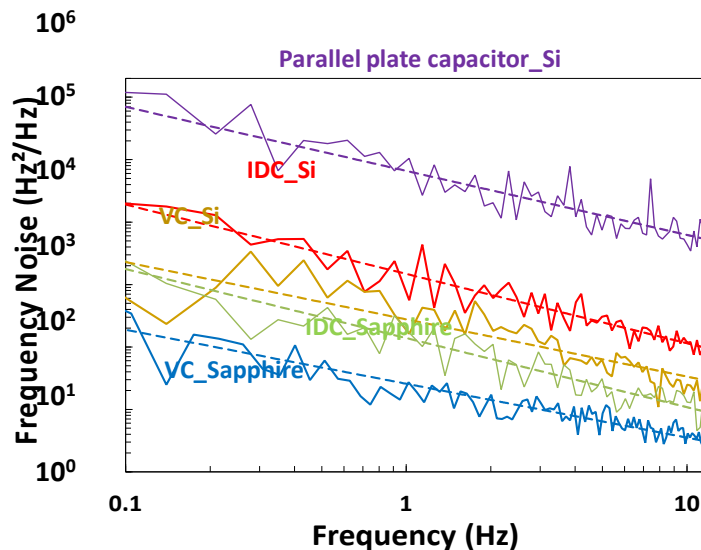


- **Vacum-based Parallel Plate Capacitor KIDs**

- **Objectif** : réduire le bruit TLS
- **Méthode** : remplacer diélectrique par vide dans le PPC
- **Résultats** : augmentation ultérieure du Q_i et réduction du bruit TLS

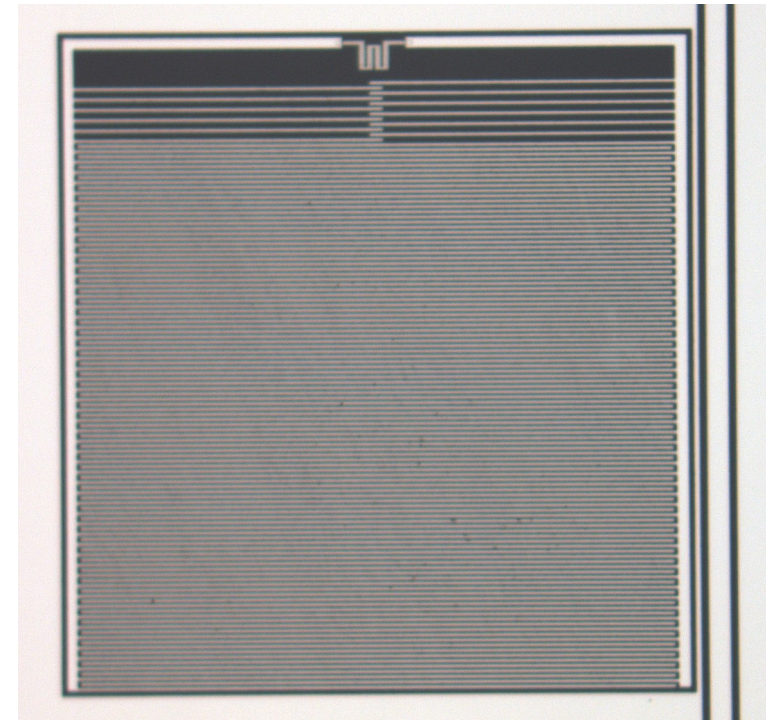


Boussaha et al., 2020

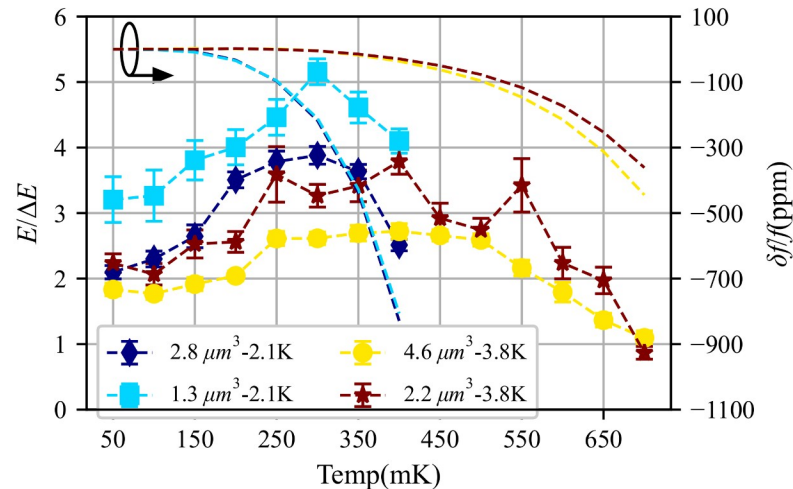
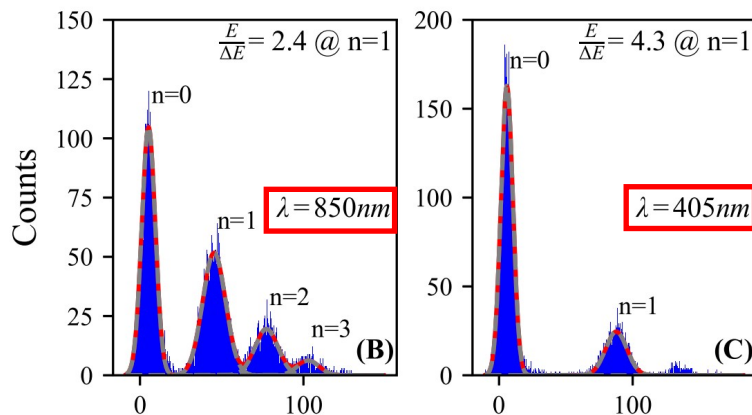


KID pour comptage de photon

- **Objectif** : comptage de photon à $T > 300\text{mK}$
- **Méthode** : inducteur à base de TiN stœchiométrique (T_c 4K)
- **Résultats** : démontré comptage de photons à 600mK, $R = 2-4$

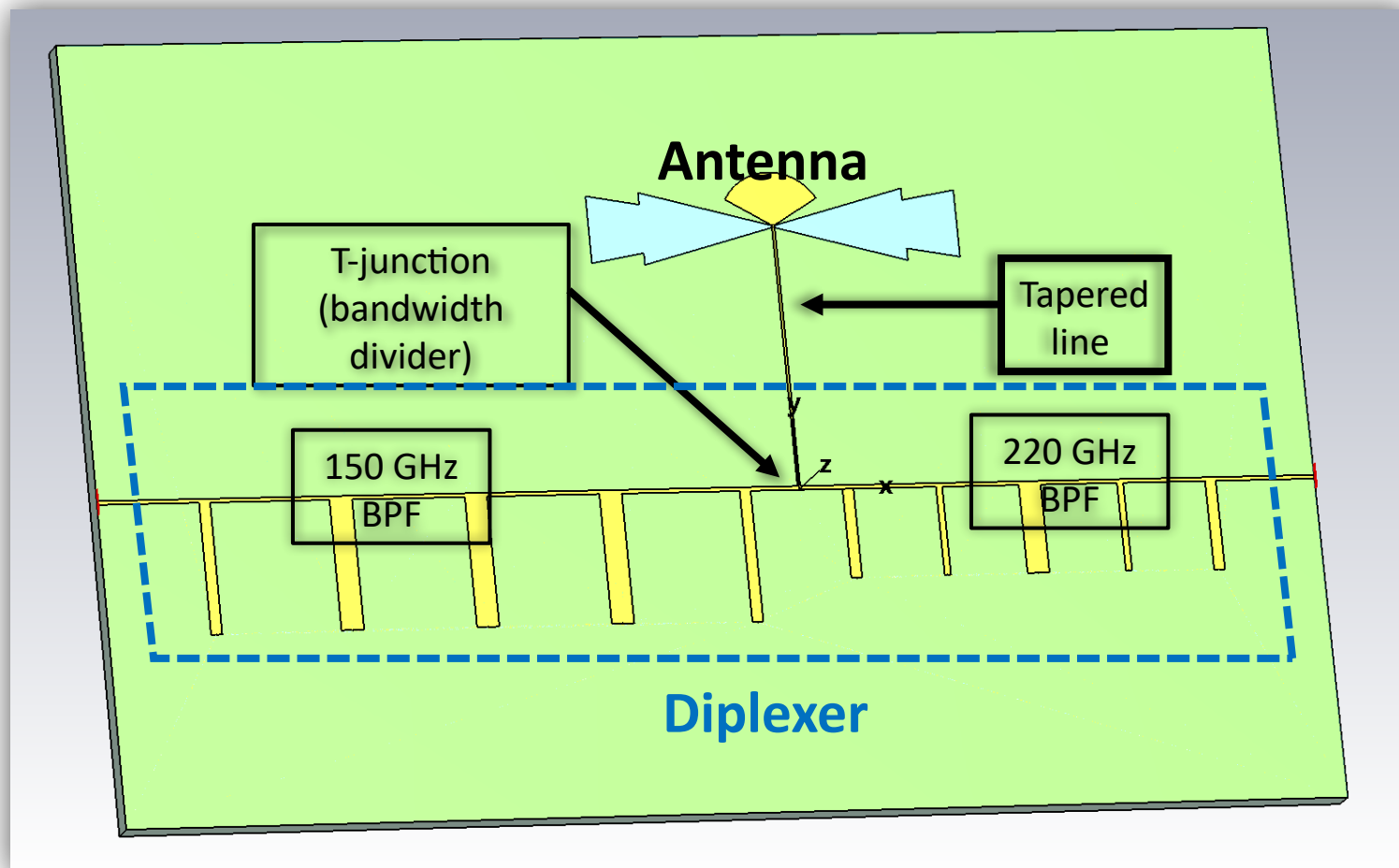


Boussaha et al., 2023



Diplexer à KID

- Séparer la lumière de deux bades on-chip
- Similaire aux spectromètres, mais large bande
- Premiers échantillons prêts à tester

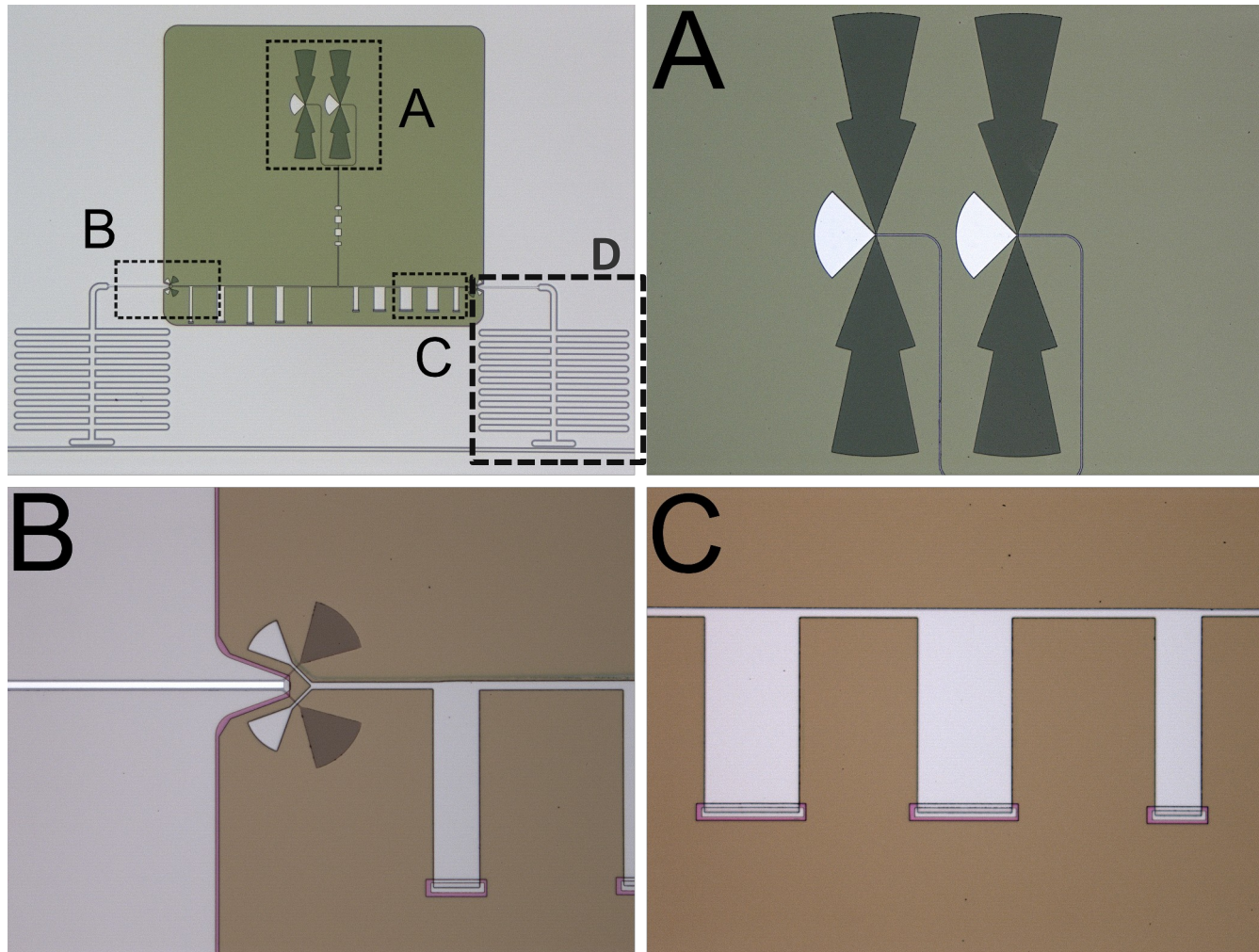


Credit : V. Dung



Diplexer à KID

- Séparation *on-chip* de la lumière en deux bandes
- Similaire aux spectromètres, mais large bande
- Premiers échantillons prêts à tester



A antenna

B couplage ustrip-CPW

C filtres du diplexer

D détecteur KID

Credit : V. Dung

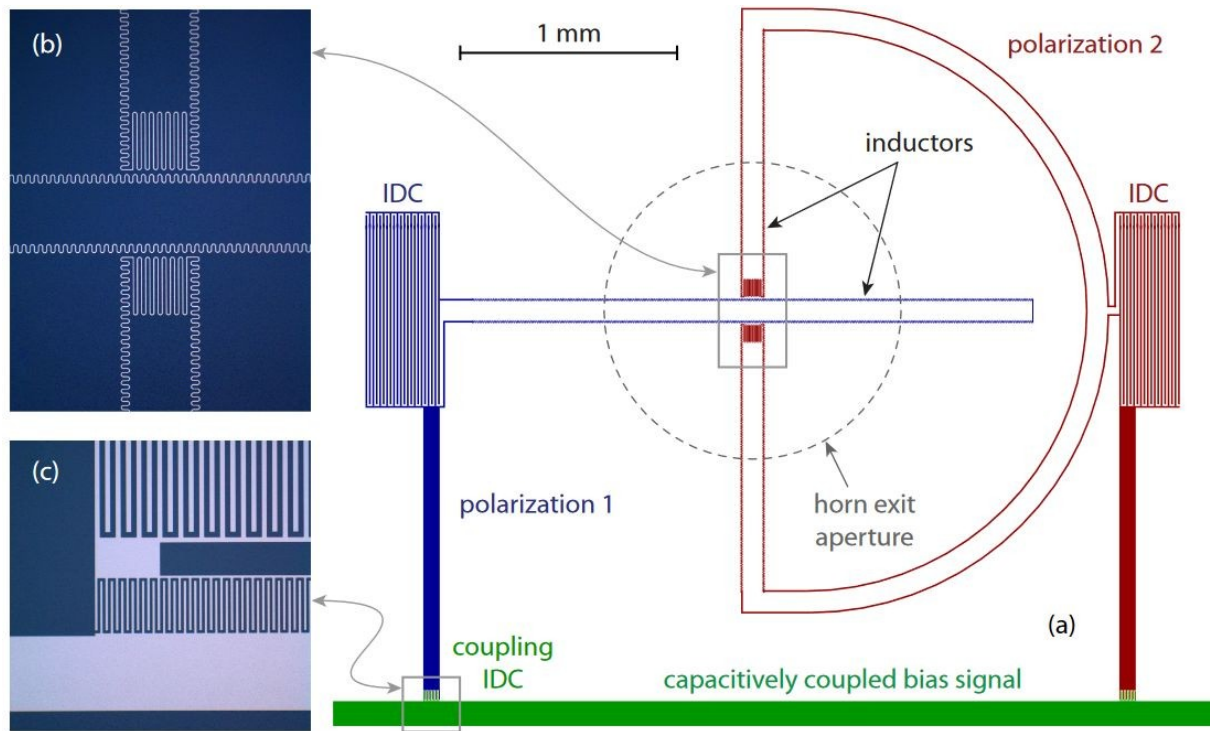


KID : nous ne sommes pas seuls !

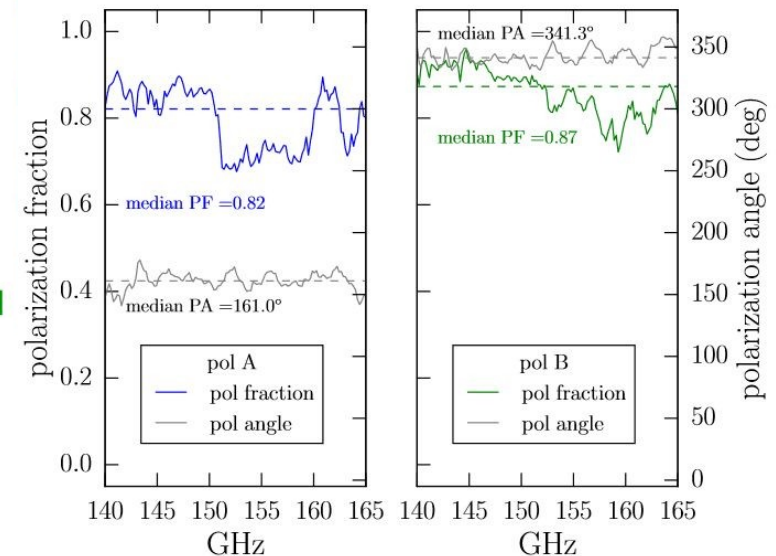
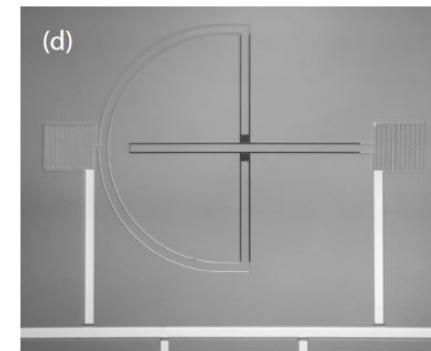
- Première idée : CALTECH (US)
- LEKID : Cardiff (UK)
- Quelques groupes (eg : GIS-KID, SRON (Pays Bas), UCSB (US) ...) depuis >20 ans
- **Beaucoup** de groupes depuis une dizaine d'années !
- Quelques exemples, liste *pas du tout* exhaustive

KID : nous ne sommes pas seuls !

- Dual-pol LEKID @ Columbia University (NY)

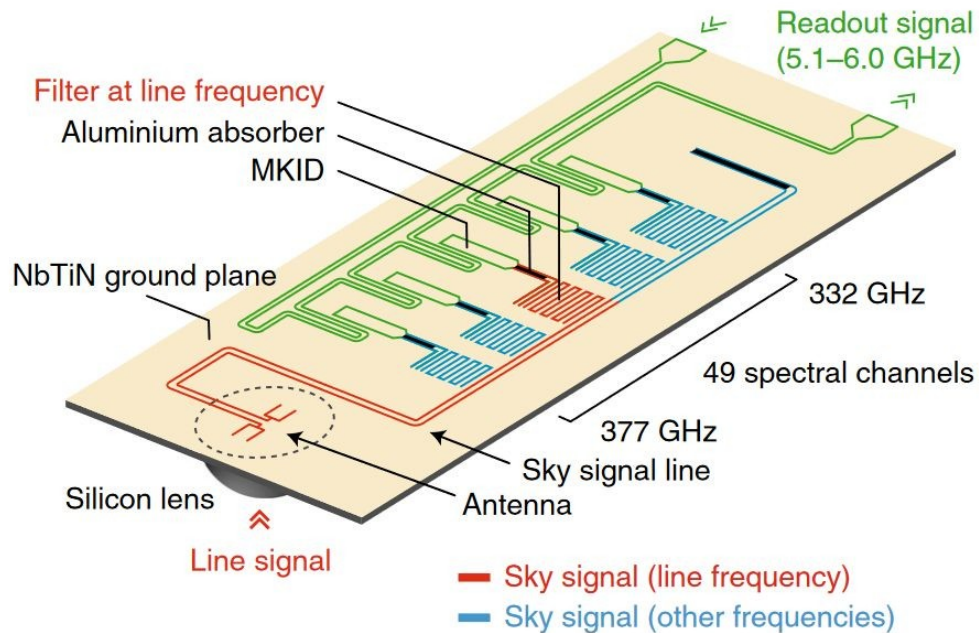


Mc Carrick et al., 2018

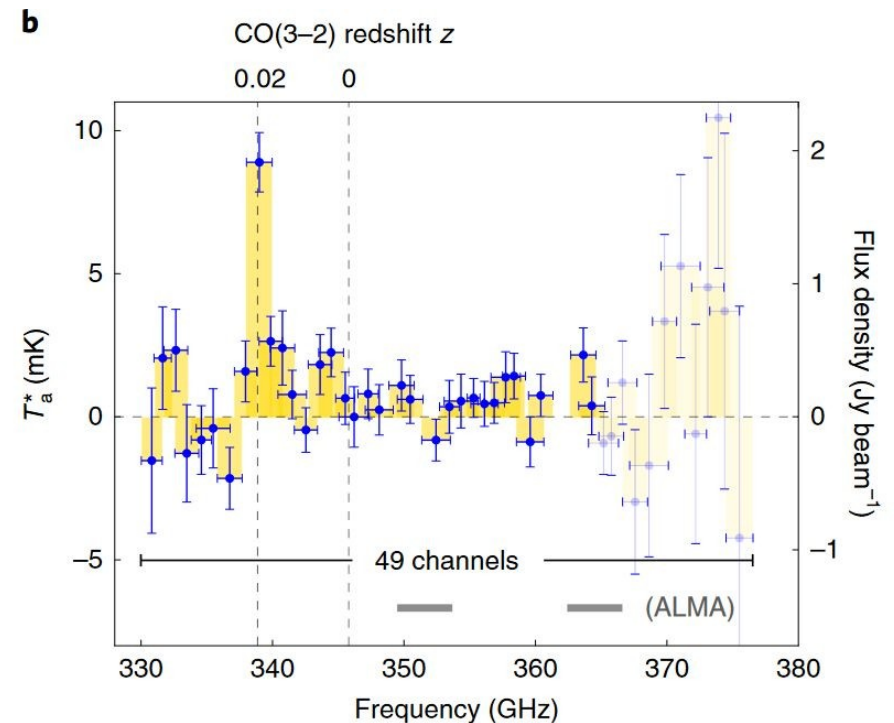


KID : nous ne sommes pas seuls !

- Spectromètre on-chip @ TU Delft



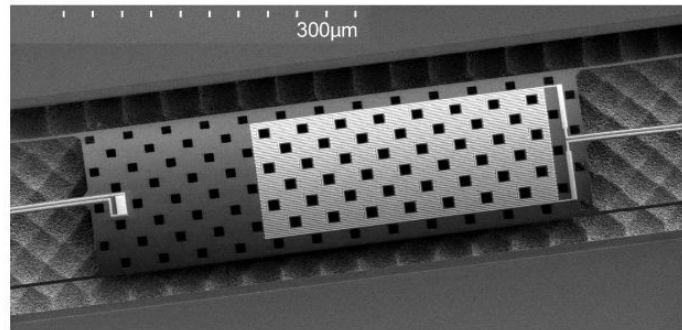
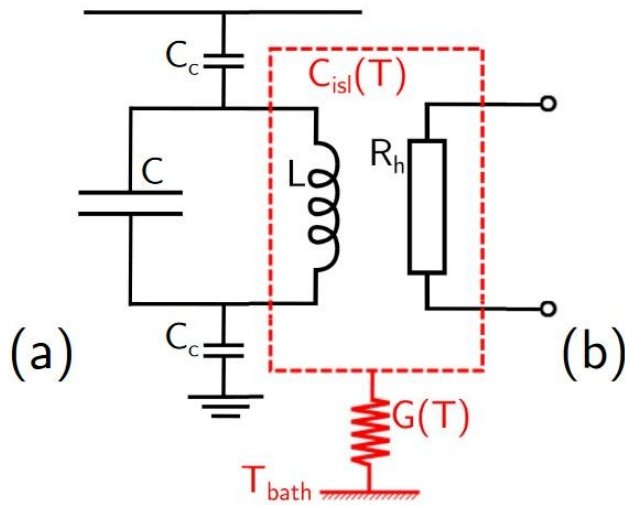
Endo et al., 2018



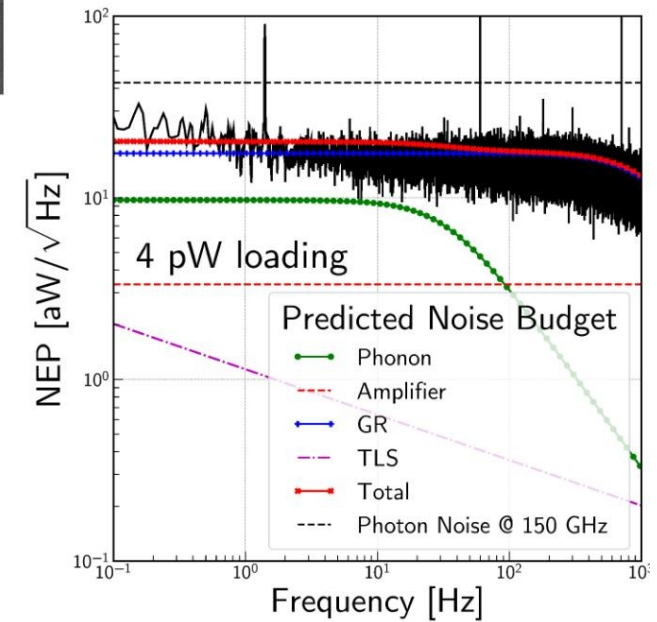
Premier spectromètre à mesurer sur le ciel, @ASTE (Chili, 5200m) !

KID : nous ne sommes pas seuls !

- KID thermiques @CALTECH



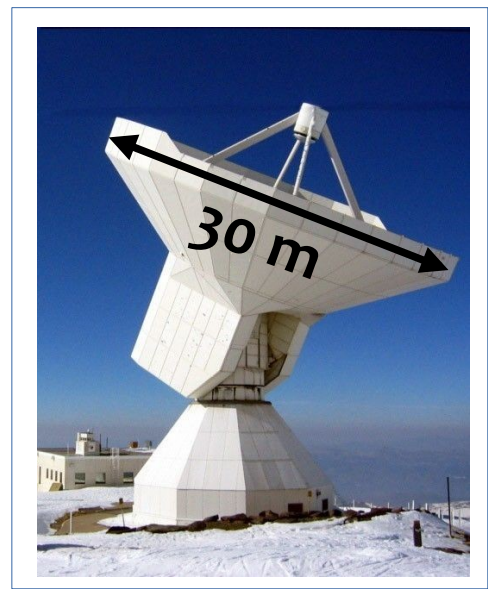
Wendui et al., 2020



NIKA & NIKA2

NIKA : la première camera KID au monde !

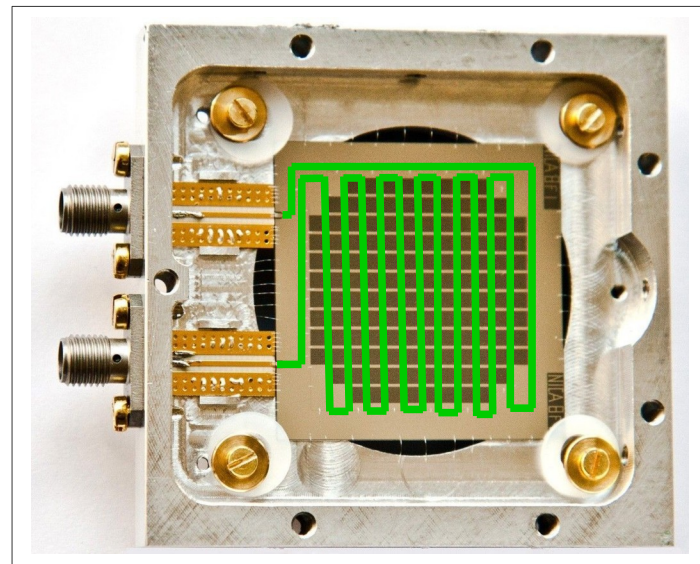
Acteurs principaux : IN, LPSC, IPAG, IRAM → **GIS KID**
 (+ autres en France et à l'étranger)



IRAM 30m, Espagne

Campagnes : 2009--2015

Configuration finale
 128/226 KIDs @ 2.14/1.25mm

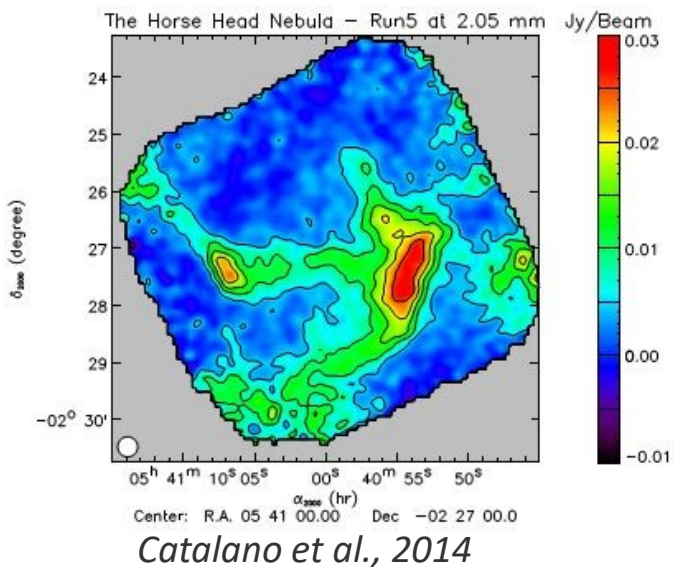
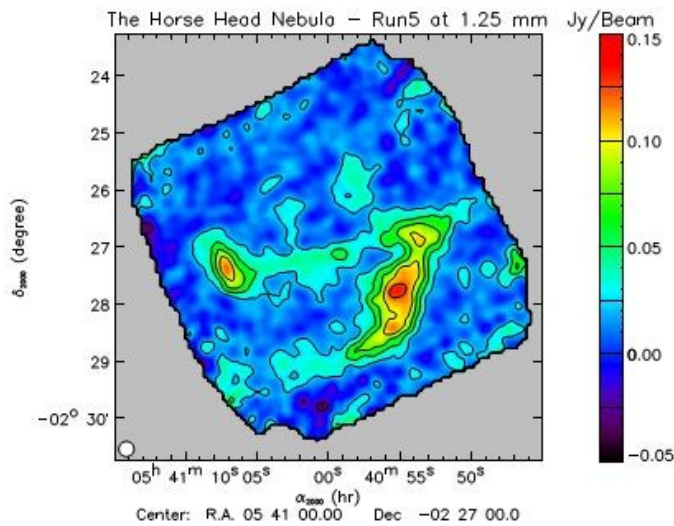


Array	1.25 mm	2.14 mm
Valid pixels	80 (run 5) 190 (run 6)	100 (run 5) 125 (run 6)
Field of view (arcmin)	2.2	2.2
Bandpass (GHz)	125–175	200–280 (run 5) 200–270 (run 6)
<i>FWHM</i> (arcsec)	12.3	18.1
Sensitivity (mJy s ^{1/2})	40	14
Mapping speed (arcmin ² /mJy ² /h)	8	57

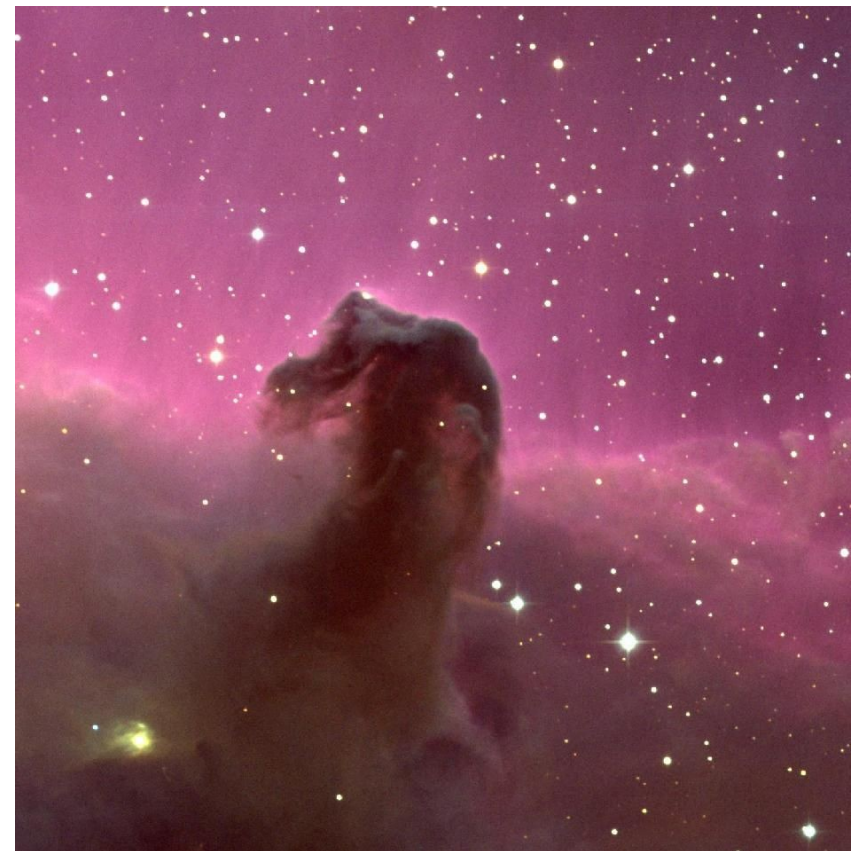
GIS KID

Catalano et al., 2014

NIKA : boost de confiance (très bienvenu !)



Horsehead nebula dans le visible

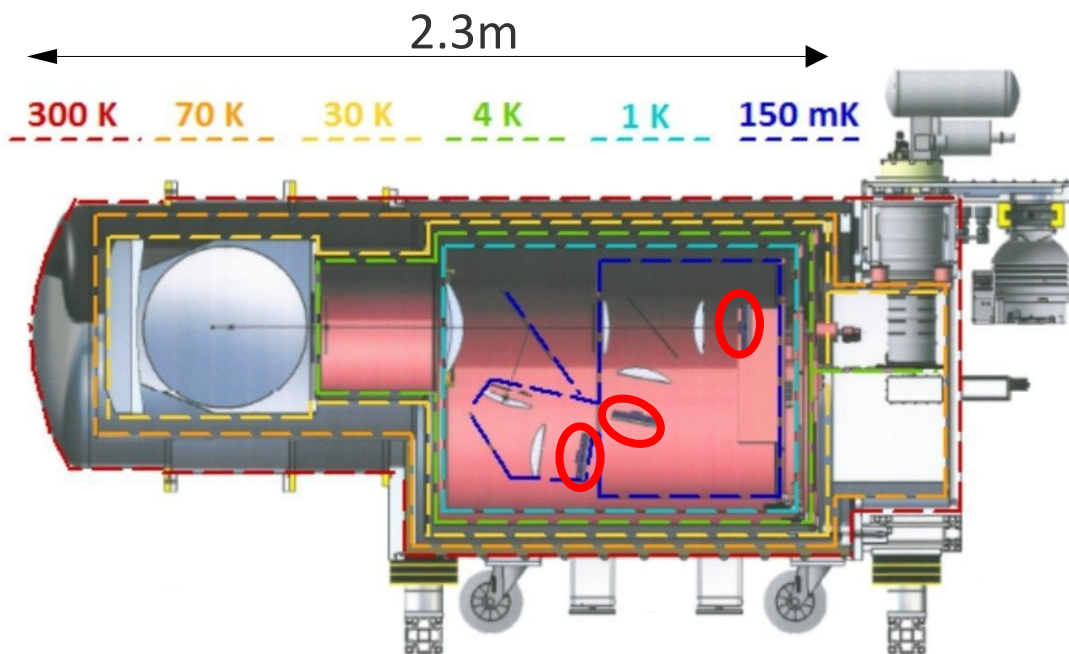


Horsehead nebula @ NIKA



NIKA & NIKA2

NIKA2 : maximisation du FoV pour un 'vrai' instrument

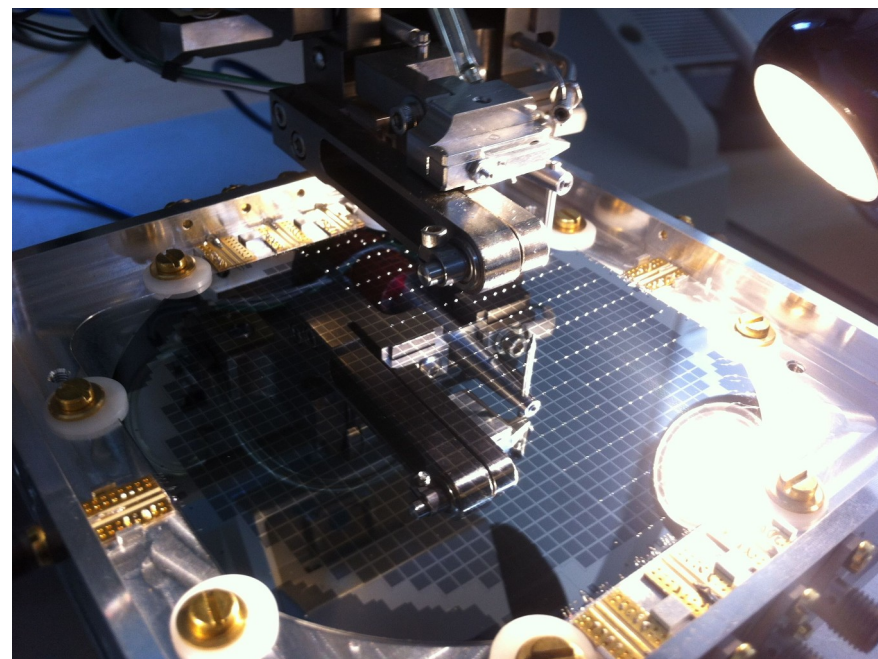


3x **array**, 4" wafer = diam. 10cm!

GIS KID

Campagnes : 2015--> ...

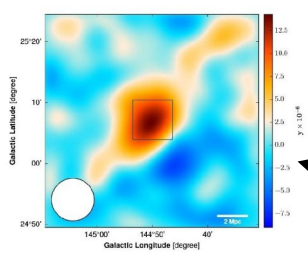
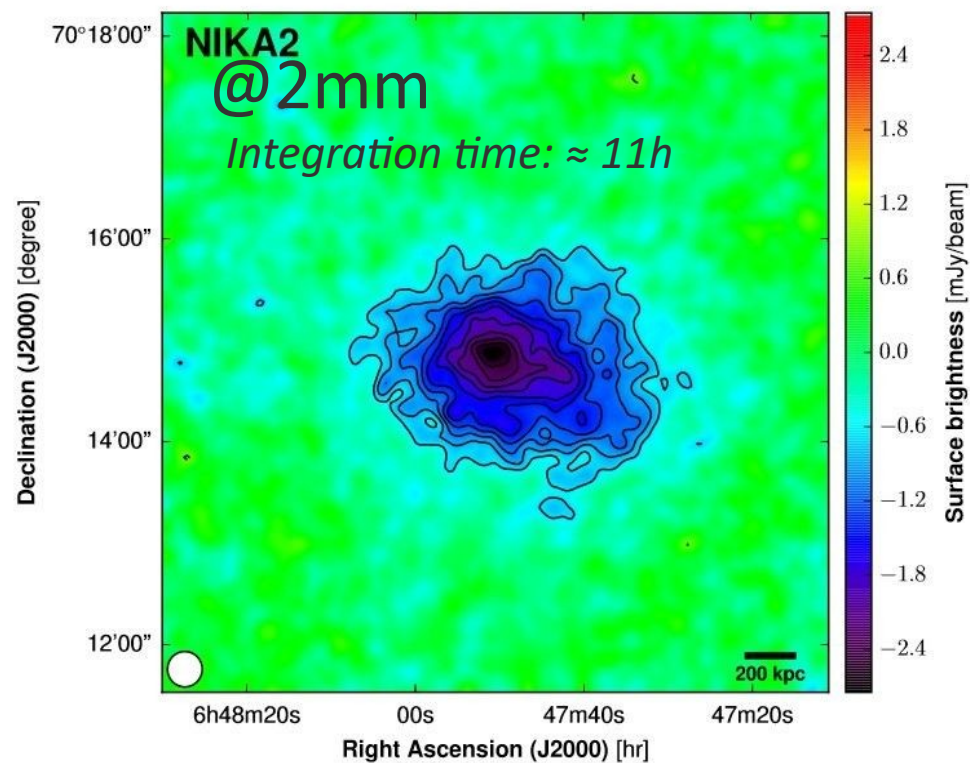
Configuration courante
616/2x1140 KIDs @ 2.14/1.25mm



Sample NIKA2 'CPW' array (vieille version!)

NIKA2 : la référence dans le millimétrique (encore aujourd'hui!)

PS22G144.83+25.11 (N2 run 10)



Ruppin et al., 2018
 Comparaison avec Planck

Table 19. Summary of the main characteristics describing NIKA2 measured performance

	Array 1&3	Array 2	Reference
Reference Wavelength [mm]	1.15	2.00	
Reference Frequency [GHz]	260	150	Sect. 8.1.1
Frequency [GHz]	254.7&257.4	150.9	Sect. 2.5
Bandwidth [GHz]	49.2&48.0	40.7	
Number of designed detectors	1140&1140	616	Sect. 2.3
Number of valid detectors ^a	952&961	553	Sect. 5.3
Fraction of valid detectors [%]	84	90	
Pixel size in beam sampling unit ^b [λ/D]	1.1	0.87	Sect. 5.2
FWHM ^c [arcsec]	11.1 \pm 0.2	17.6 \pm 0.1	Sect. 6.2
Beam efficiency ^d [%]	55 \pm 3	77 \pm 2	Sect. 6.3
Rms FWHM across the FOV [arcsec]	0.6	0.6	Adam et al. (2018)
Reference FWHM ^e [arcsec]	12.5	18.5	Sect. 8.1.1
Reference Beam efficiency ^f [%]	70 \pm 4	85 \pm 3	Sect. 8.1.3
Rms pointing error [arcsec]	< 3	< 3	Sect. 3.2
Absolute calibration uncertainty [%]	5	5	Sect. 9.1, App. A.1
Systematic calibration uncertainty ^g [%]	0.6	0.3	Sect. 9.1.3
Rms calibration uncertainty [%]	5.7	3.0	Sect. 9.2
α noise integration in time ^h	0.5	0.5	Sect. 10.3
NEFD ⁱ [mJy \cdot s ^{1/2}]	30 \pm 3	9 \pm 1	Sect. 10.3
M_s^j [arcmin ² \cdot mJy ⁻² \cdot h ⁻¹]	111 \pm 11	1388 \pm 174	

Notes.
^(a) Number of usable detectors, which have been selected in at least two FOV reconstructions ^(b) Calculated from real array pixel size [2.75

Perotto et al., 2020

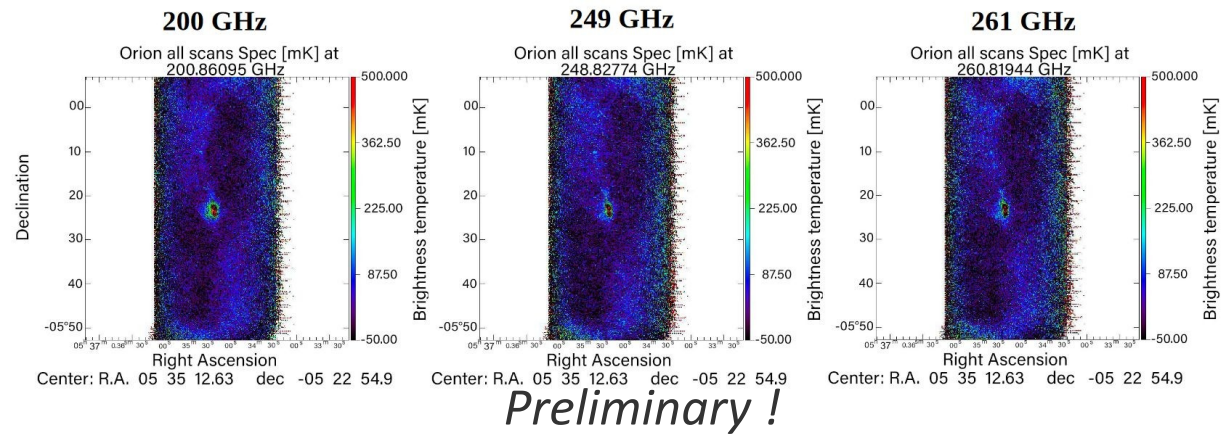
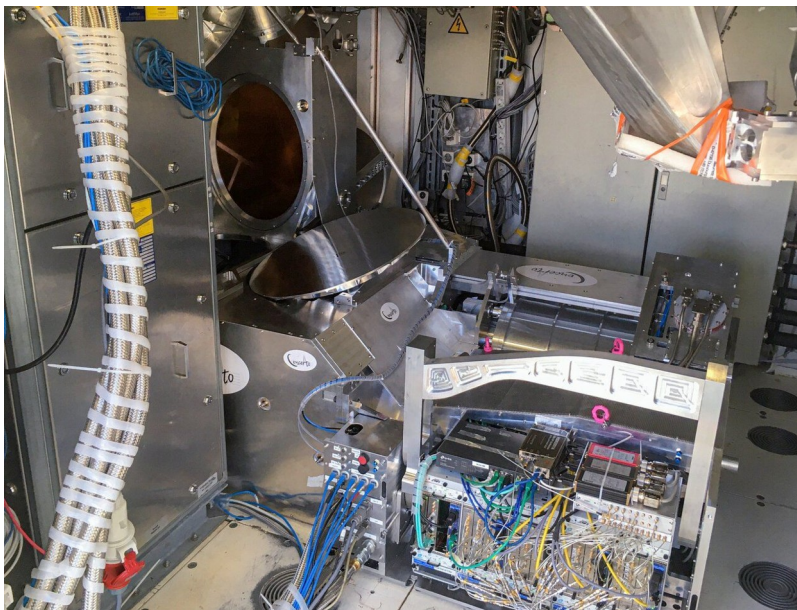


Améliorations/évolutions bientôt !

CONCERTO

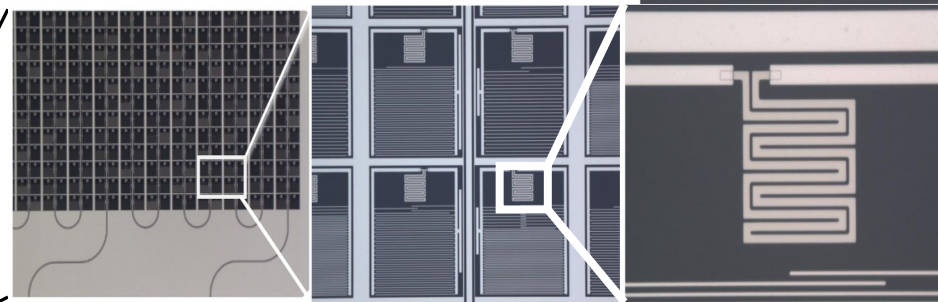
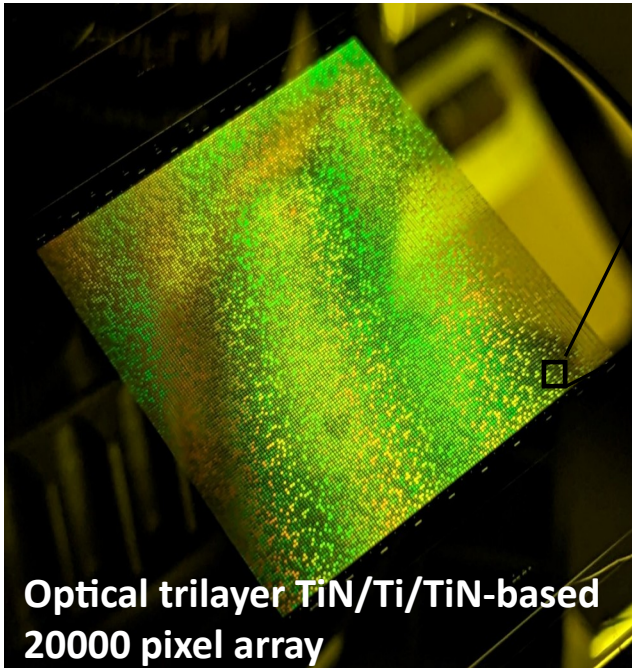
CONCERTO : spectromètre MPI, évolution de KISS

Opérationnel @ APEX en 2021-2023



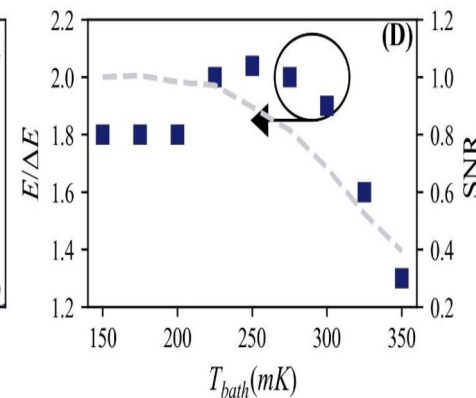
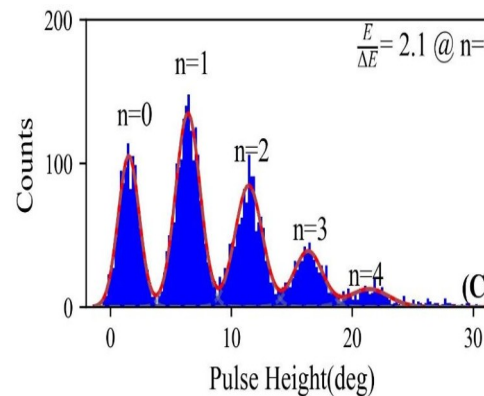
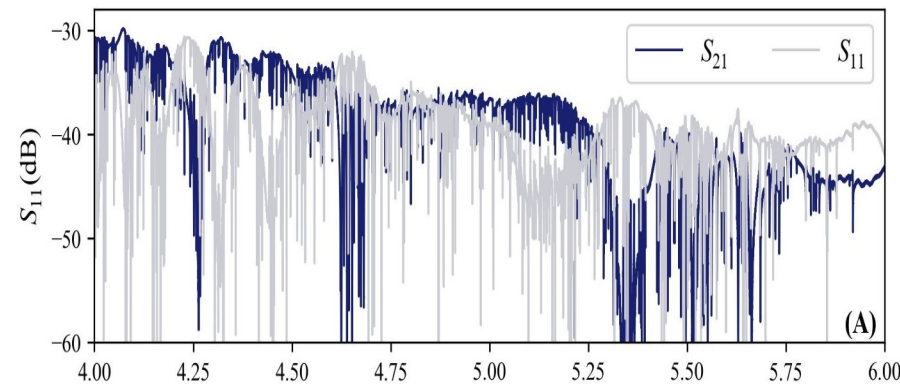
GIS KID

Spectro-Photometric Imaging in Astronomy with Kinetic Inductance Detectors



- Based on Sapphire
- Pixel distance: 180um
 - Angular resolution of 0.45"
- Meander size about 35x35 um
- Change of finger length larger than 1 um
- Frequency: 4-8GHz
- 2000 pixels per readout line
- $Q_c \sim 50000$

Hu et al., JLTP 2024
Hu et al., APL 2024

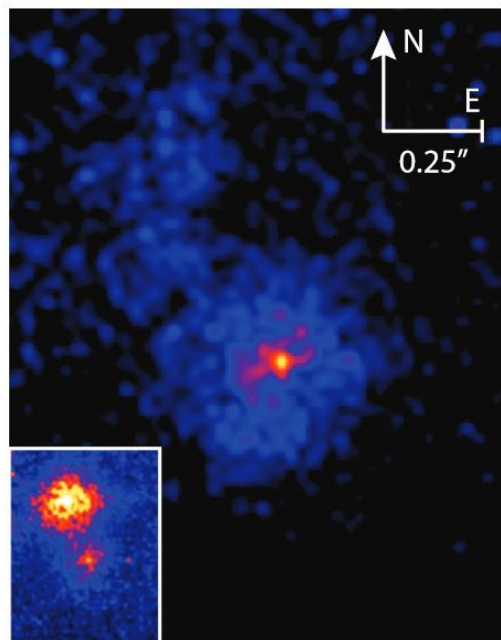


**On-sky in
 2025 !**

DARKNESS/MEC @UCSB

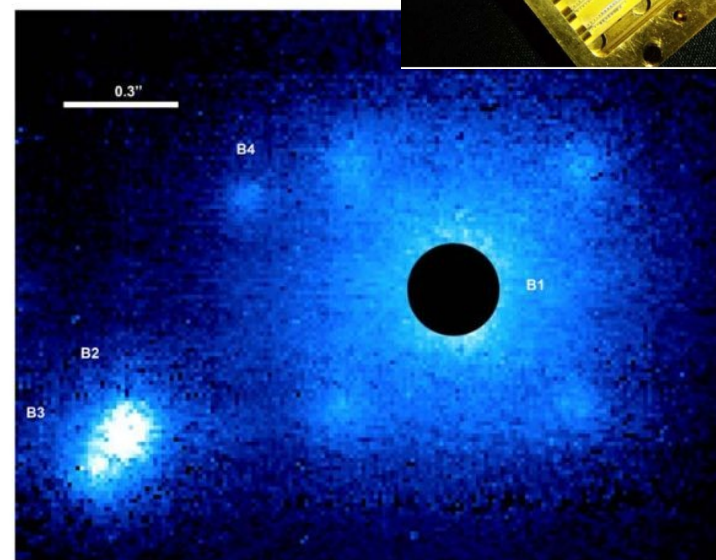
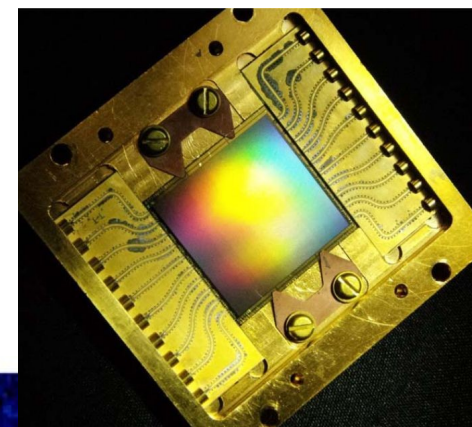
DARKNESS : première camera KID optique, télescope du Mont Palomar (California)

MEC : Opérationnel sur le télescope Subaru (Mauna Kea)



DARKNESS

Meeker et al., 2018



MEC

Walter et al., 2020

Et à venir...

TOLTEC : camera KID mm au LMT (*commissioning en cours, ~7500 KID*)

MUSCAT : camera KID mm au LMT (*commissioning en cours ?*)

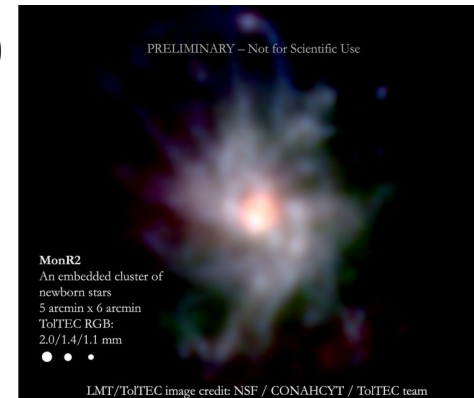
AMKID : camera KID sub-mm à APEX (*commissioning en cours*)

TIFUUN : spectromètre KID sub-mm à ASTE (*en cours de développement*)

MISTRAL : camera KID mm au SRT (*commissioning en cours*)

PRIMA : satellite FIR avec KID (*prévu pour la décade ~2030*)

Et peut être d'autres...



Conclusions

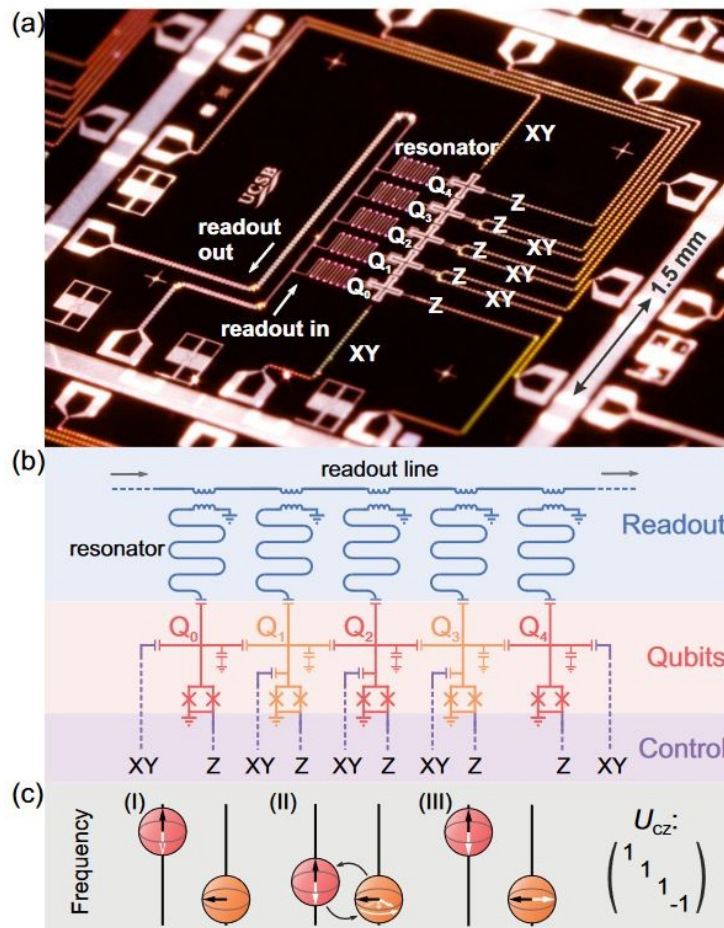
- Les **KID** ont montré leur flexibilité et leur excellentes performances
- Au labo, et **sur le ciel** !
- Plein d'idées, et de travail à faire
- Points de contact avec d'autres communautés (eg : QuBit)
- Un domaine en plein expansion, n'hésitez pas à le rapprocher !

Merci !

Superconducting resonators

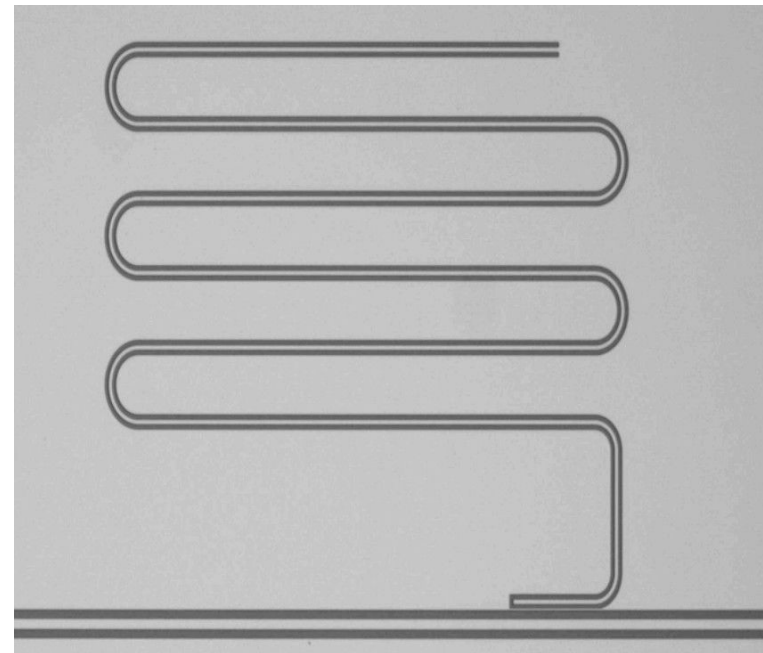
- Many (most?) QuBits are superconductors-based, and multiplexed readout is achieved using *superconducting resonators!* ('=' KIDs!)

R. Barends et al.,
 Nature, 508 (2014) 500



QuBit ←

KID ↓



Materials for QuBits (/KID)

- QuBits: often need to introduce a non-linear element → interest in high K.I.
- KIDs: high K.I. translates into high responsivity (interesting for extremely low signals)

An example: **GrAl!**

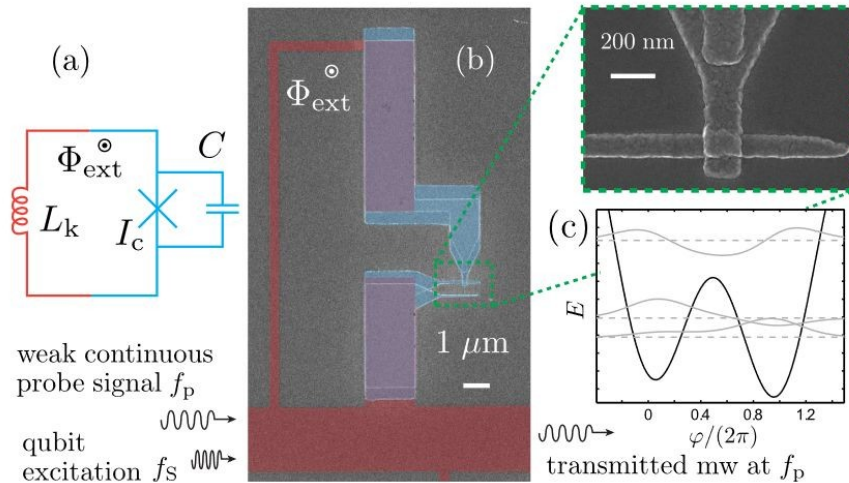
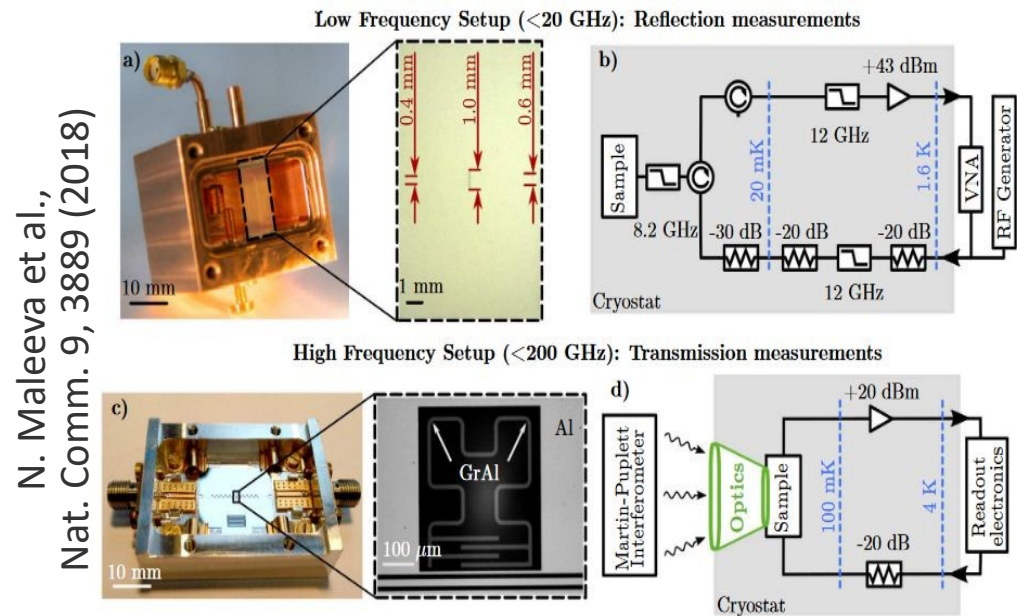


FIG. 1. (a) Schematic circuit representation of a hybrid rf SQUID. A superconducting loop with high kinetic inductance (red) is closed with a single Josephson junction (blue) and placed into perpendicular external magnetic field. (b) False-

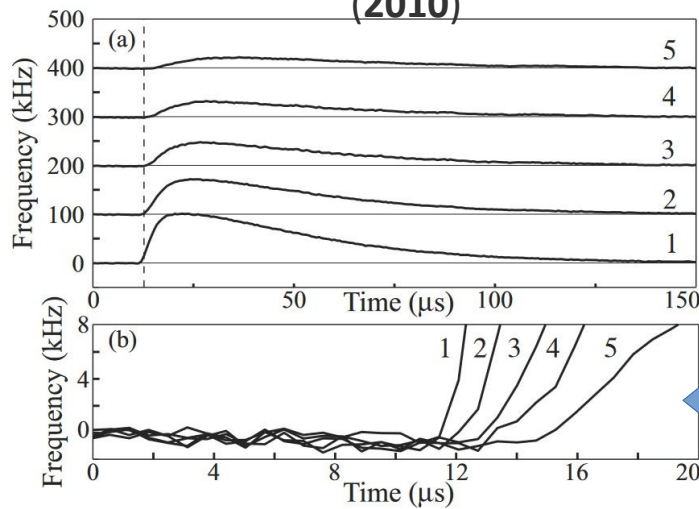


N. Maleeva et al.,
 Nat. Comm. 9, 3889 (2018)

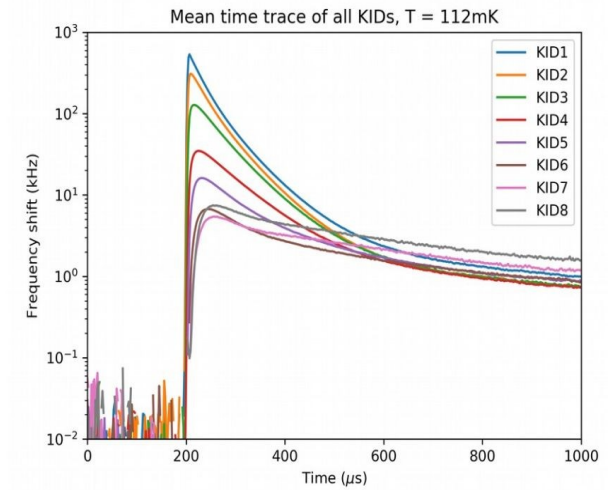
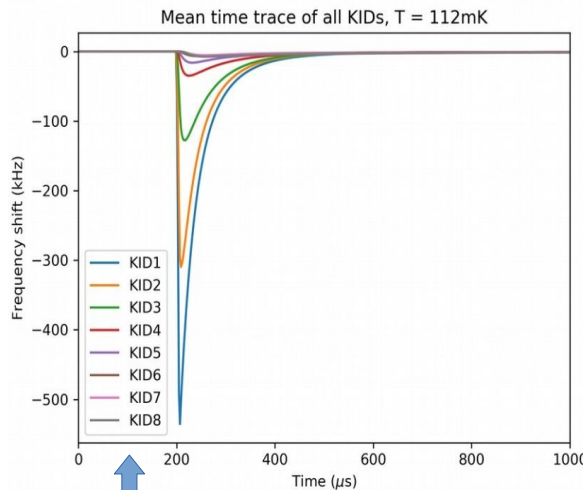
QuBits coherence (/KIDs glitches)

Sample results...

Swenson L. et al.,
 Appl. Phys. Lett. 96, 263511
 (2010)



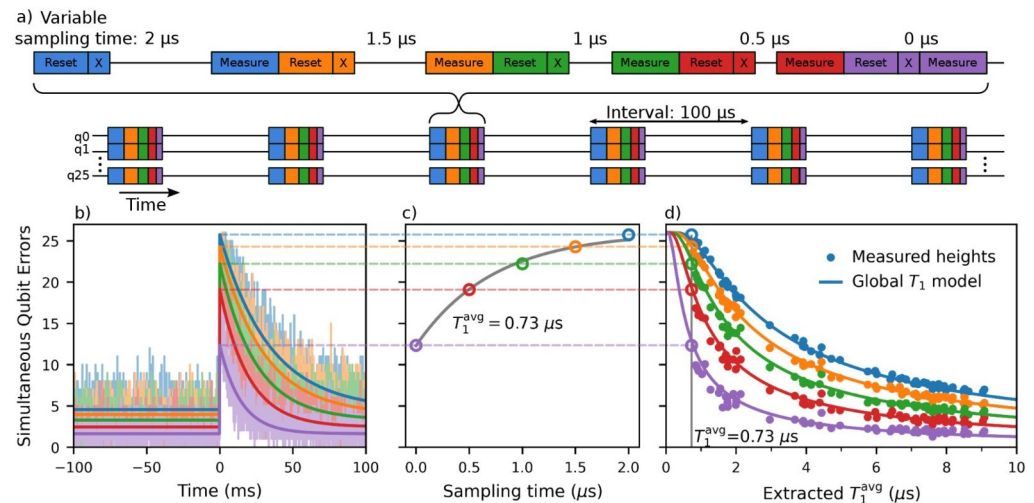
Catalano A. et al.,
 CNES RT report (2018)



KID

QuBit

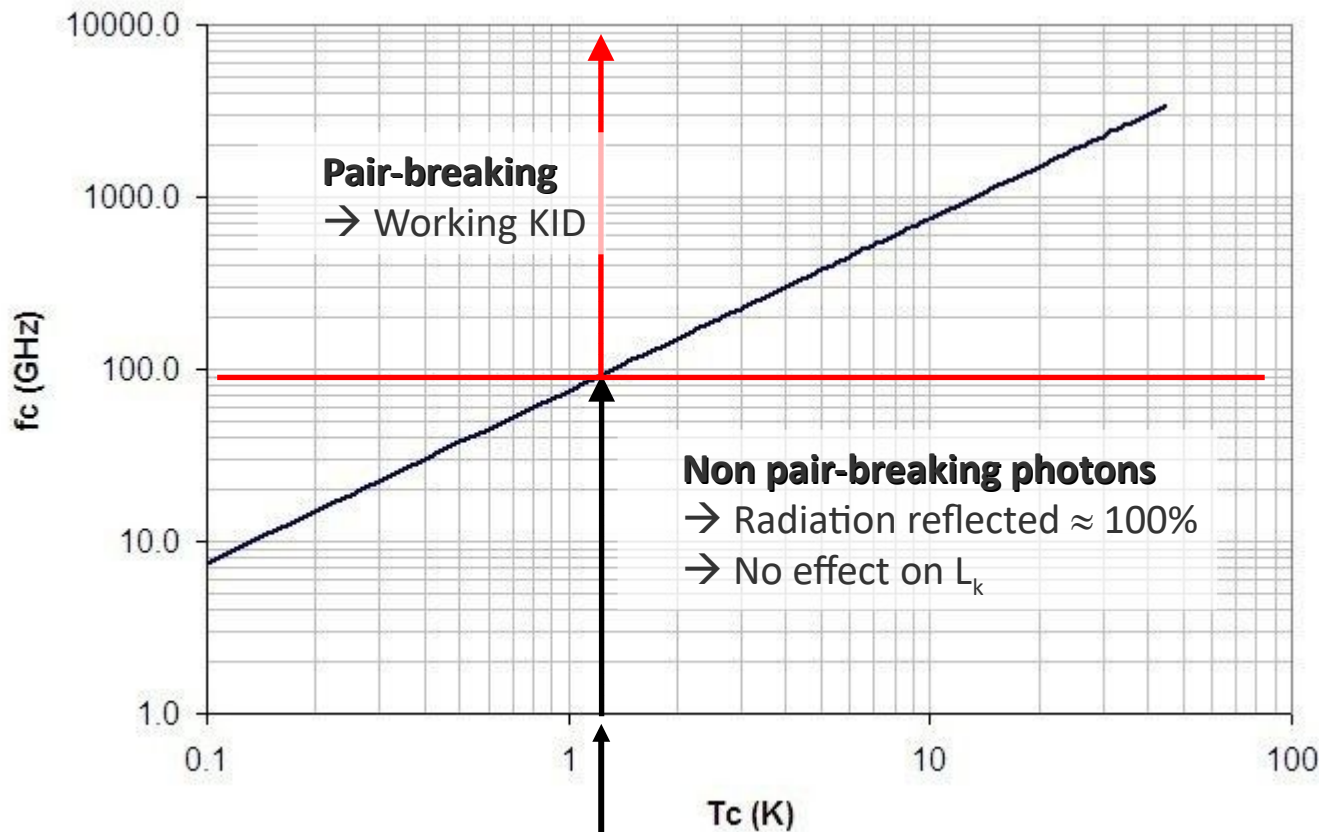
M. McEwen et al.,
 Nat. Phys. 18, 107-111 (2022)



KID response to light

Light can break Cooper Pairs, *if it has enough energy*

Some typical examples materials



Ti → $f_c \approx 40$ GHz

Al → $f_c \approx 100$ GHz

Re → $f_c \approx 130$ GHz

Ta → $f_c \approx 340$ GHz

Nb → $f_c \approx 700$ GHz

NbN → $f_c \approx 1.2$ THz

...

TiN_x → adjustable

Nb_xSi → adjustable

TiV_x → adjustable

Multilayers → adjustable

e.g. Al, our best friend !!

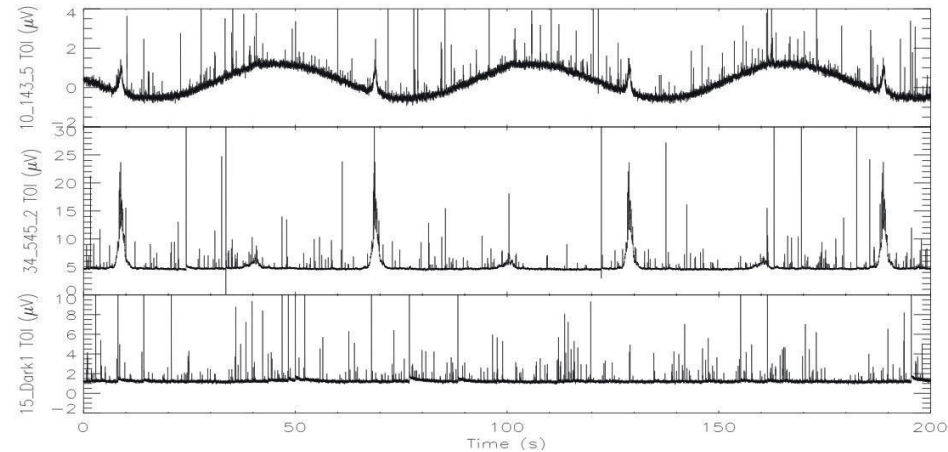
Cosmic Rays effect on KID



Space-based missions are exposed to an intense flux of high-energy particles, known as Cosmic Rays (CR)

CR can reach focal plane giving an unwanted *glitch*, masking the scientific signal

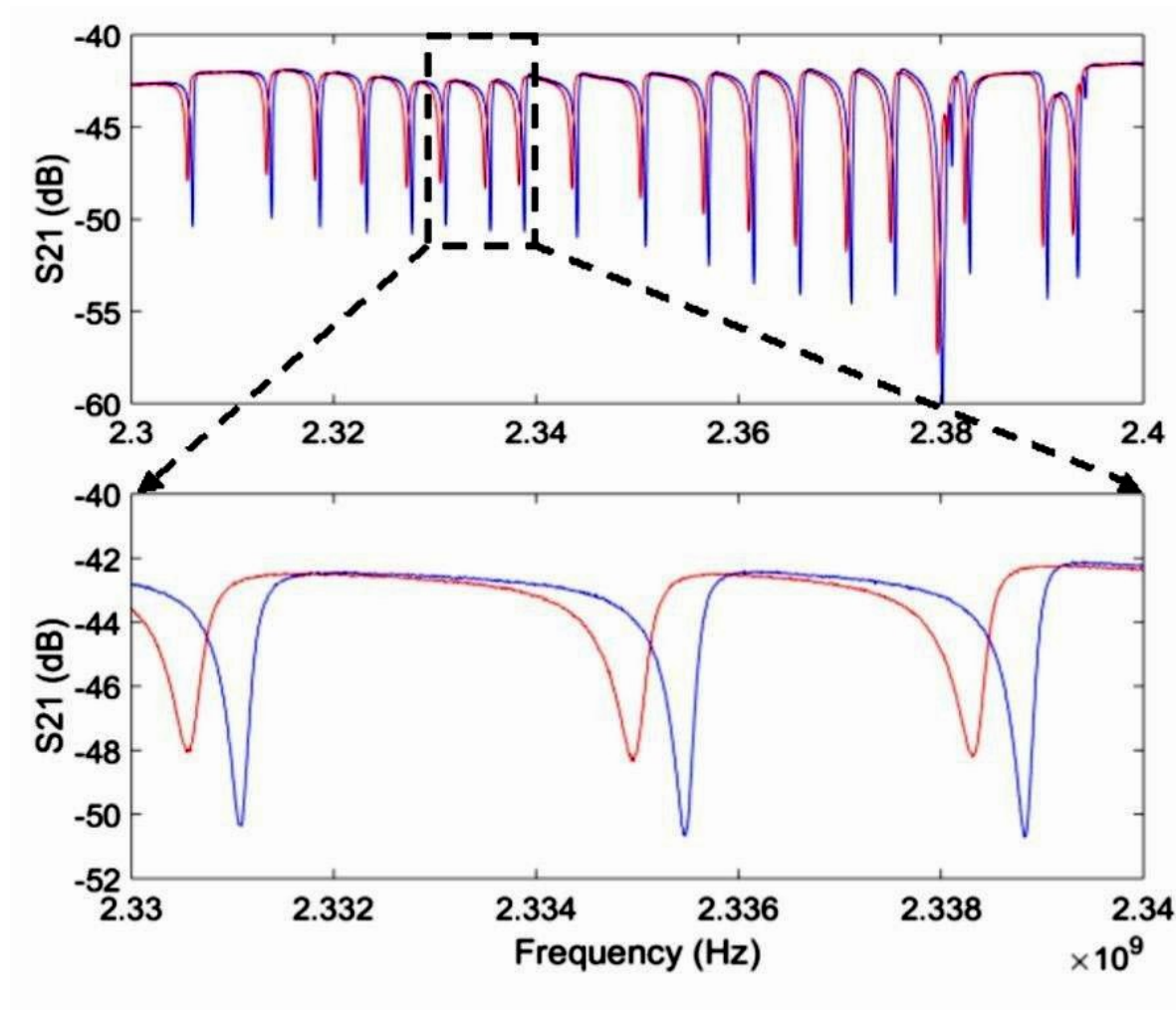
Planck:
≈ 20% of data loss!



The effect of long range 'ballistic' phonons was larger than expected

KID could help a lot!

Astro-KID activities in Grenoble



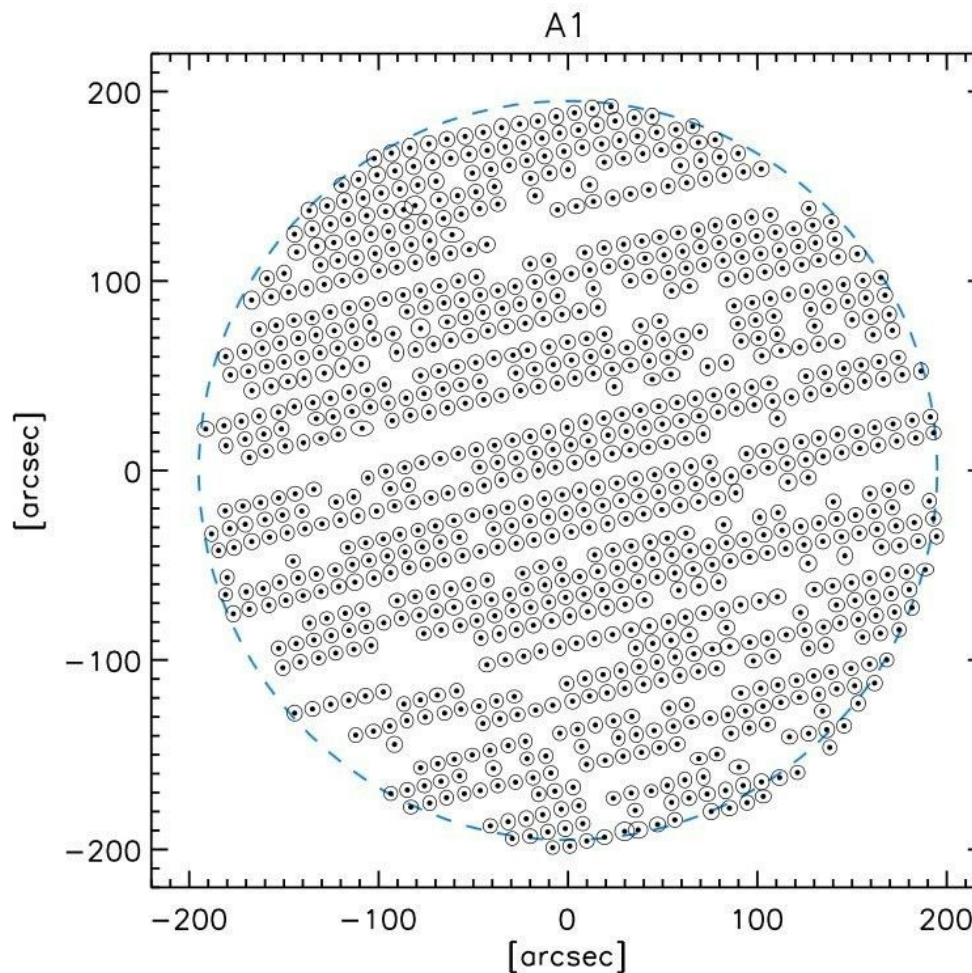
Astro-KID activities in Grenoble

Footprint of a NIKA2 1mm array:

Yield 70% to 90%!

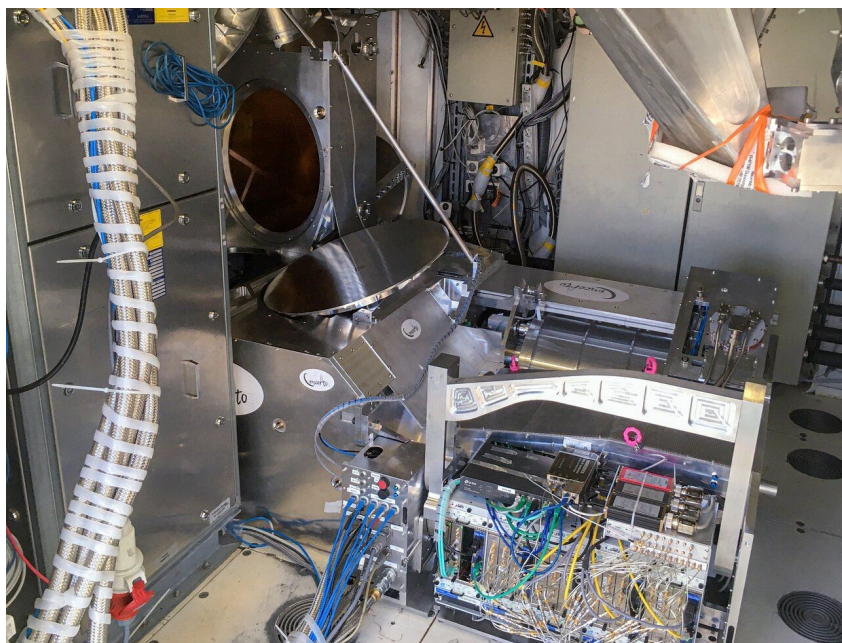
Used

Existing pixels



See Adam et al, A&A 609, A115 (2018) (arXiv: 1707.00908)

- CONCERTO : spectrometer dedicated to mapping CII lines
- **Science data taking ongoing, installation last April (!!)**

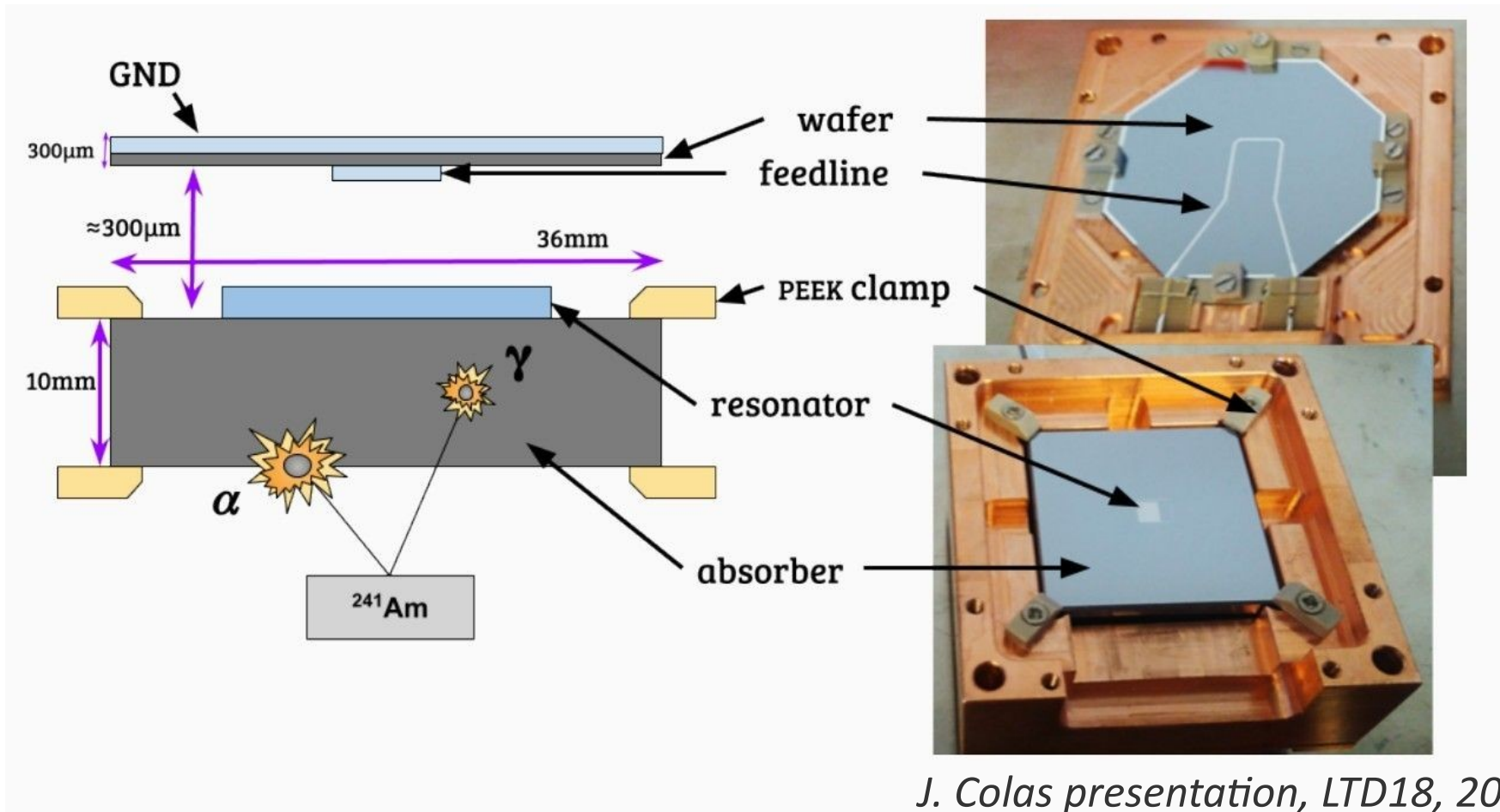


WiFi-KIDs !

Developed in the framework of **RICOCHET** project

RICOCHET
A Coherent Neutrino Scattering Program

KID used with 'wireless' readout → maximized phonon sensing!



J. Colas presentation, LTD18, 2019

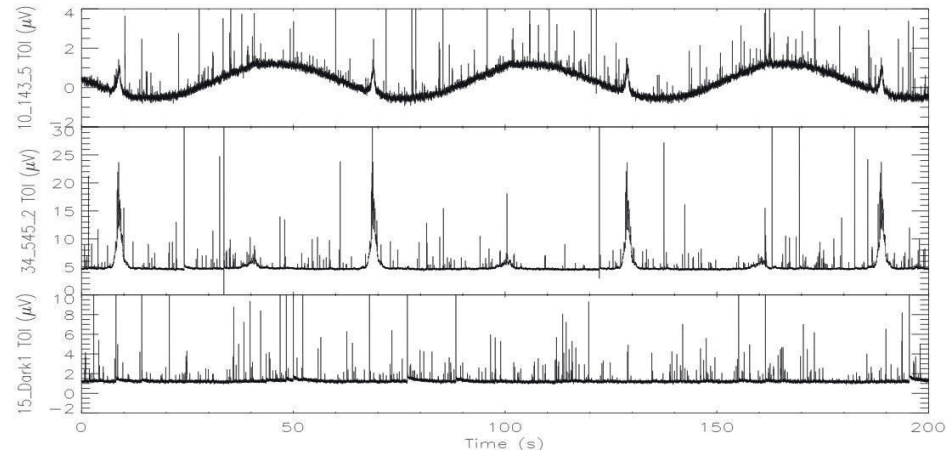
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