Kinetic Inductance Detectors for mm-wavelength radiation: the Grenoble GIS contribution

Sofia Savorgnano

La photodétection avec les semi-conducteurs
LPSC - June 3, 2024

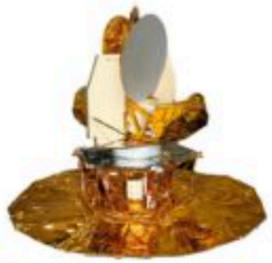
https://gis-kids.cnrs.fr/

THE CMB EXPERIMENTAL CONTEXT

Space based experiments

1st Generation (1989-1993) - COBE

2nd Generation (2001-2010) - WMAP



3rd Generation (2009-2014) - Planck

4th Generation (2030?)

LiteBIRD

Balloon experiments

Boomerang (1999-2003)
2 Flights

MAXIMA (1998-1999)
2 Flights

Archeops (2001-2002)
3 Flights

OLIMPO (2018)
1 Flight

Perspectives

3ISOU

Ground based experiments

CMB-S4
Next Generation CMB Experiment

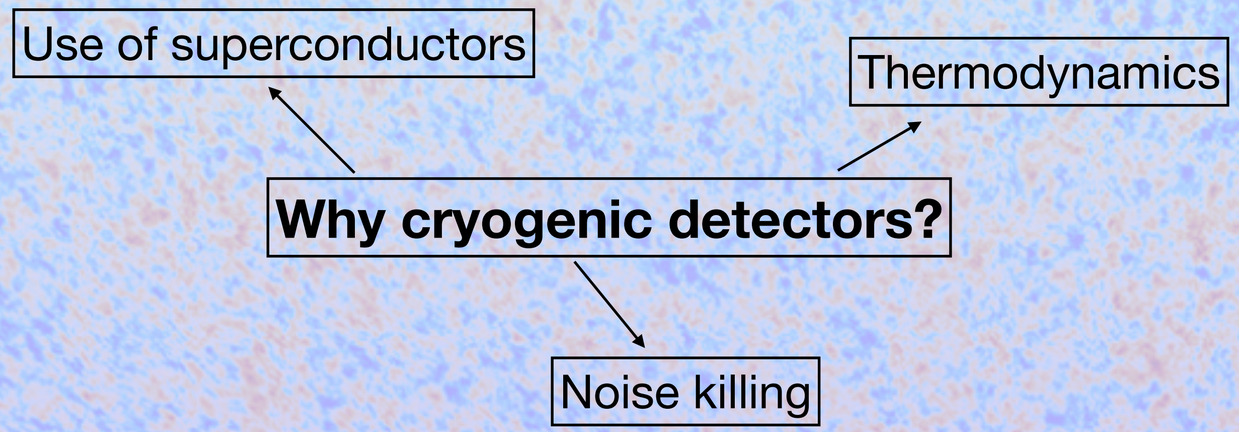
SIMONS OBSERVATORY
PARQUE ASTRONÓMICO ATACAMA, CHILE
22° 57' 31" S, 67° 47' 16" W
ELEVATION 5190m
www.simonsobservatory.org

OUR SCIENTIFIC INTEREST: Millimetre Wavelengths

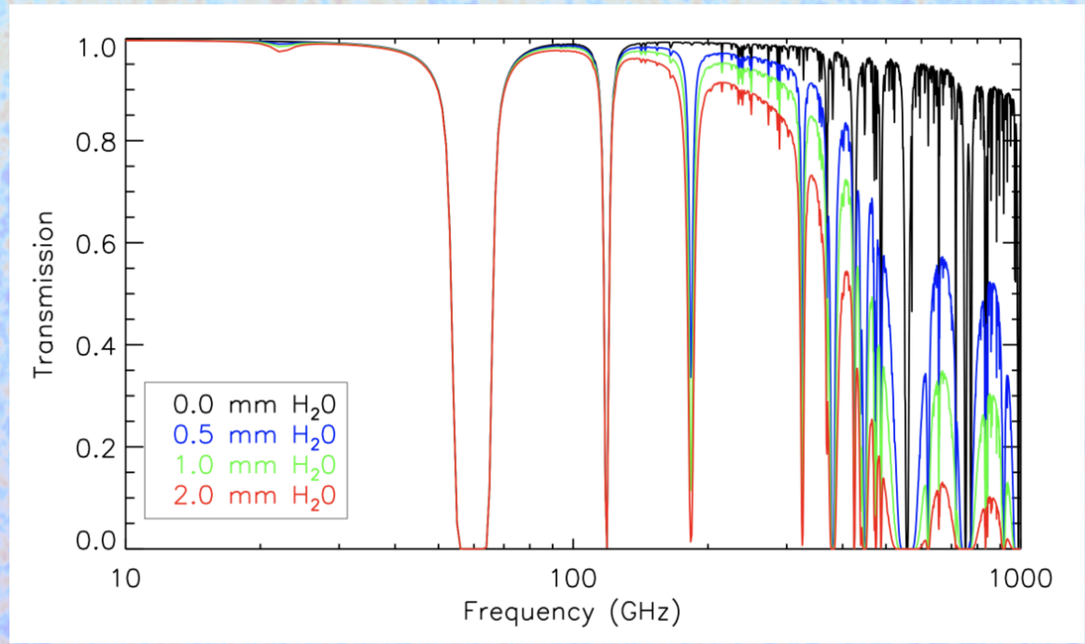
- Relatively recent branch of astronomy
- Only in the 70s the receivers became sensitive enough to detect the millimetre waves coming from space
- Since then this observing technique has become a key tool of investigating the Universe

Peculiar characteristics:

- High altitude observations or satellites
- Cryogenics detectors (like high impedance bolometers or **superconducting detectors**)

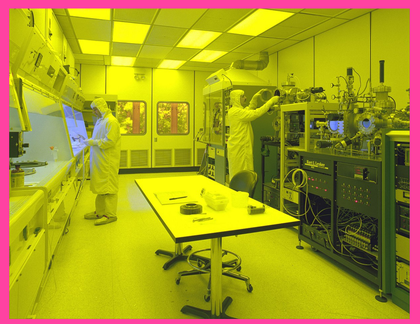


Atmosphere (for ground-based observations)

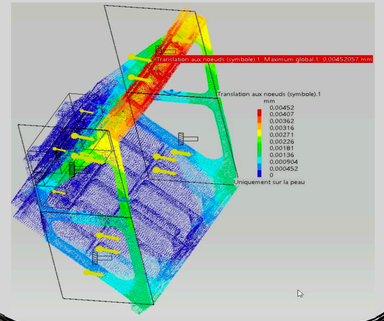


Cryogenics

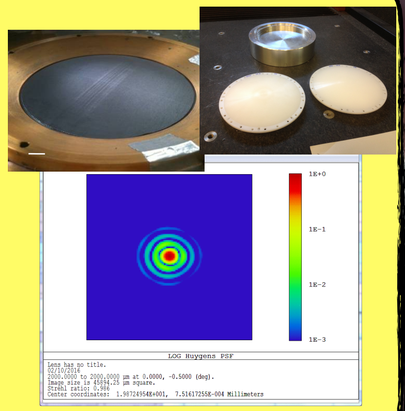
Fabrication



Mechanics

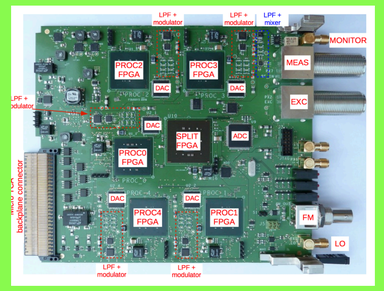


Optics

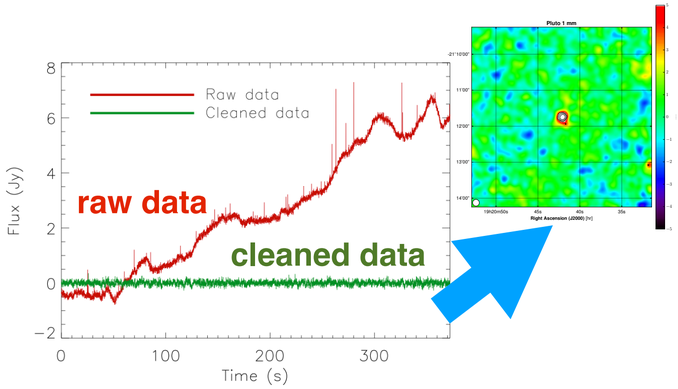


CORE TECHNOLOGY: KIDs

Electronics

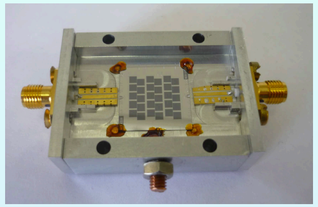


Data Acquisition-Pipeline



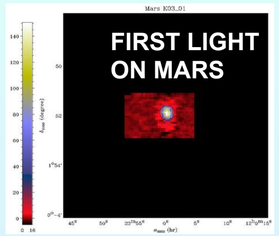
KIDs ARRAYS EVOLUTION

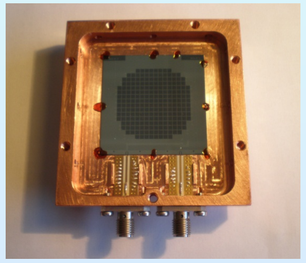
From 30 to 8000 pixels arrays



2009

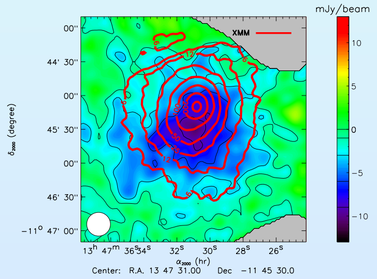
30 Pixels





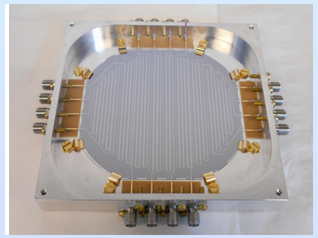
2010-2013

200 Pixels



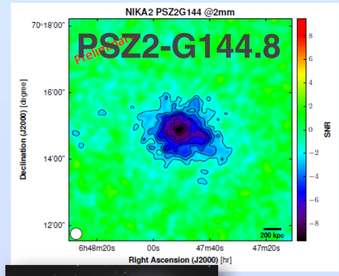
First SZ det. with KID

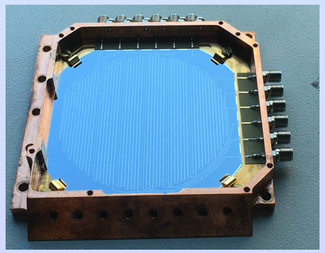
RXJ1347 (2012)



2014-2015

1000 Pixels





2015-Today

2000 Pixels

Today

8000 Pixels

2024-2030

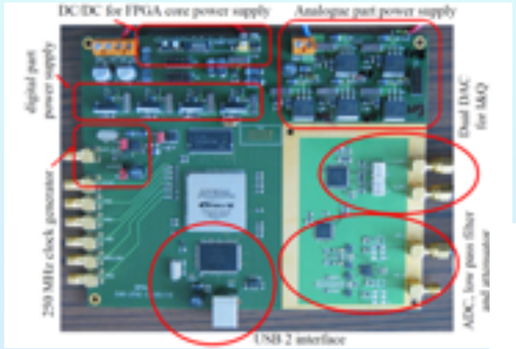
Prototype

For this we need:

- New evaporation machine
- Wafers of 200mm

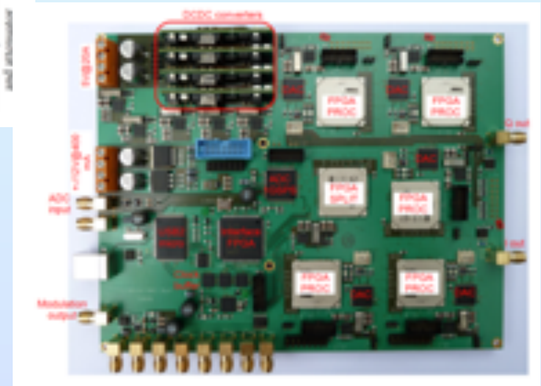
READOUT DEVELOPMENT

2011: NIKEL proto



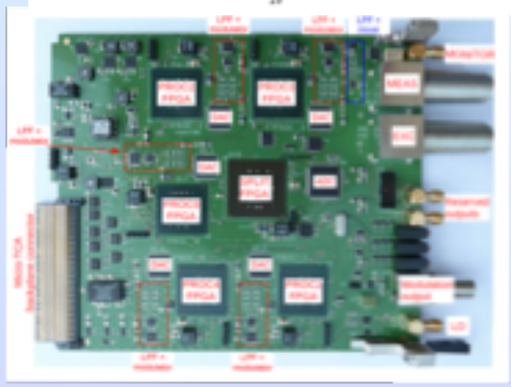
128 pixels
500 MHz bandwidth
external RF

2012: NIKEL (NIKA)



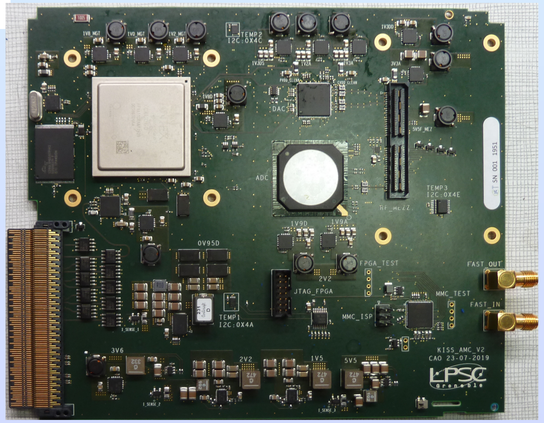
400 pixels
500 MHz bandwidth
external RF

2016: NIKEL AMC (NIKA2/KISS)



400 pixels
500 MHz bandwidth
RF in the board
Compact crate with up to 10 boards

2020: NIKEL AMC v2 (CONCERTO)

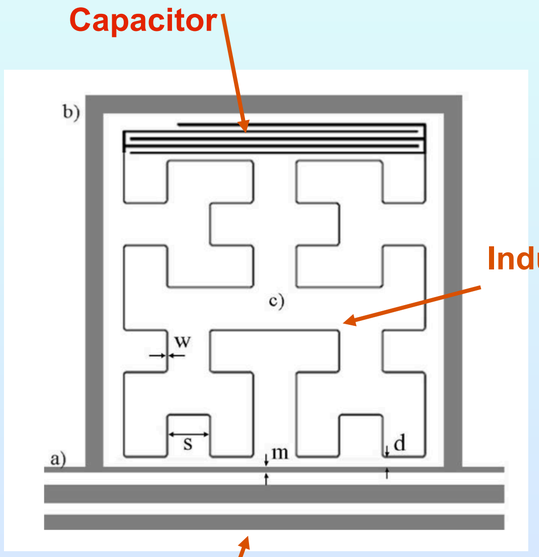


400 pixels
1 GHz bandwidth
30 watts power

[Bourrion+2011, 2012, 2016, 2022, Bounmy+2022]

WORKING PRINCIPLE

The incoming photons break Cooper pairs (supercurrent carriers) in a superconducting LC resonator → measurable signals

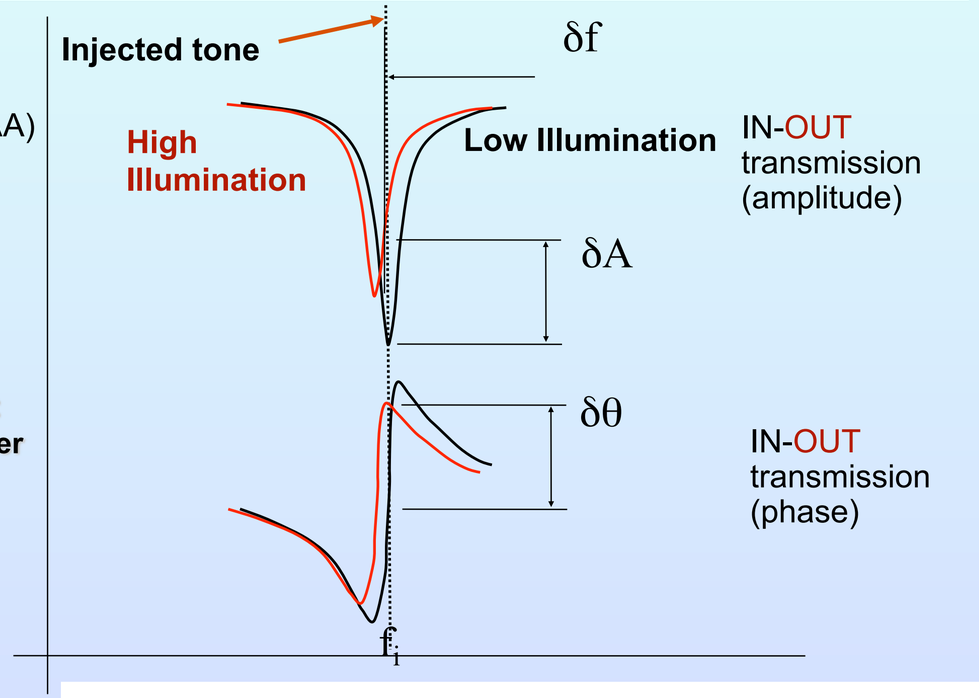


Dark, T << T_c

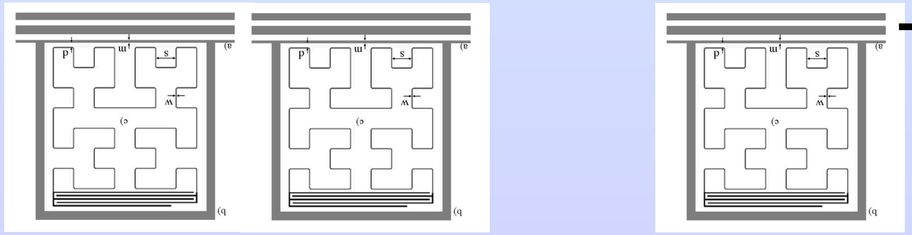
Light: **increase in R**
Change in amplitude (ΔA) and phase

$\delta f \propto \delta L_K \propto \delta P$

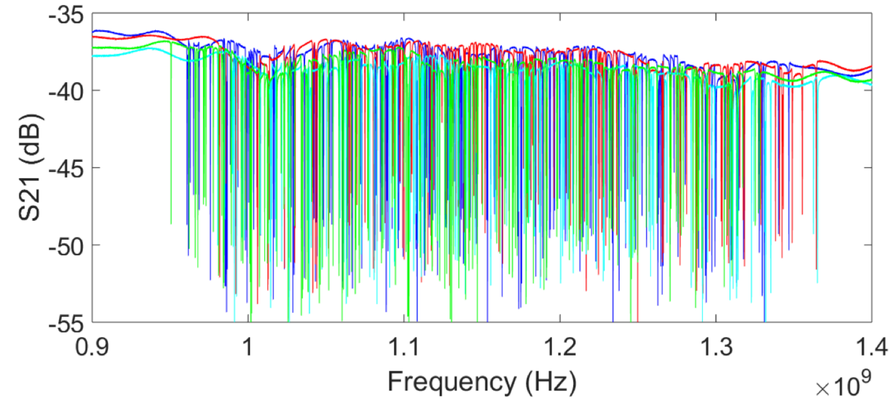
δf = frequency shift
δP = incoming power



IN → f_o f_1 ..... f_{n-1} → OUT

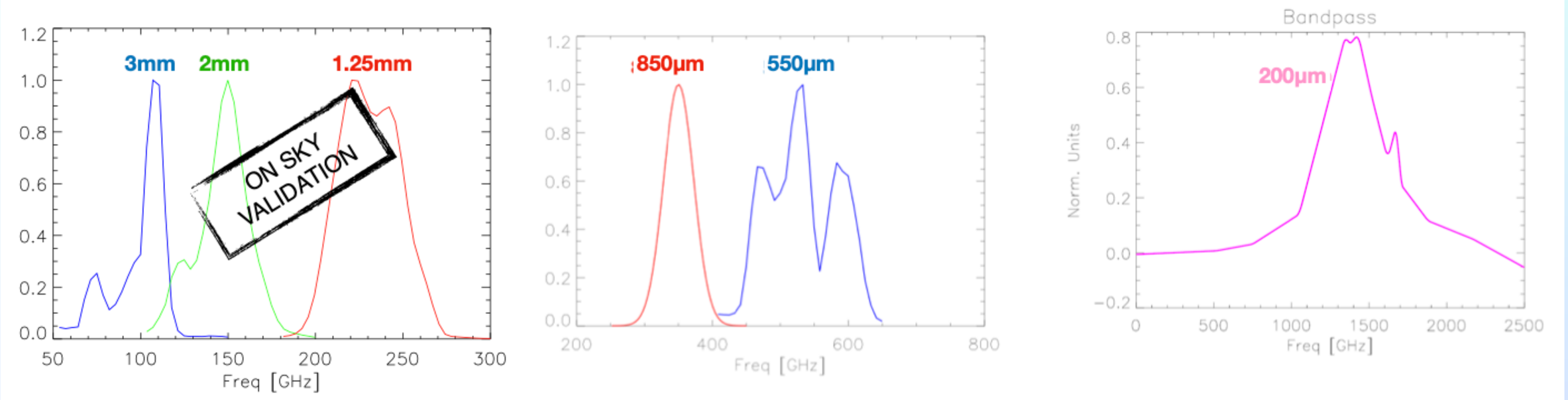


400 pixels are connected to a single transmission line



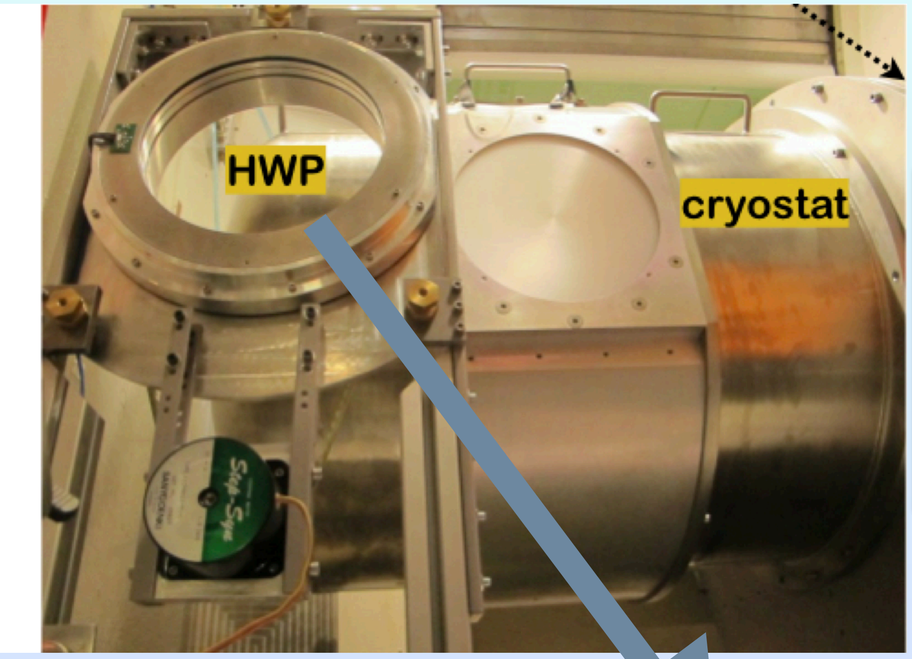
MAIN ADVANTAGES of KIDs

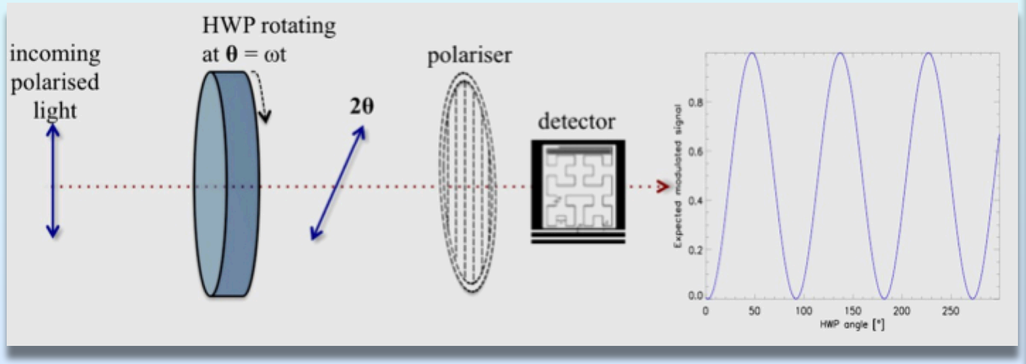
Catalano et al, 2020

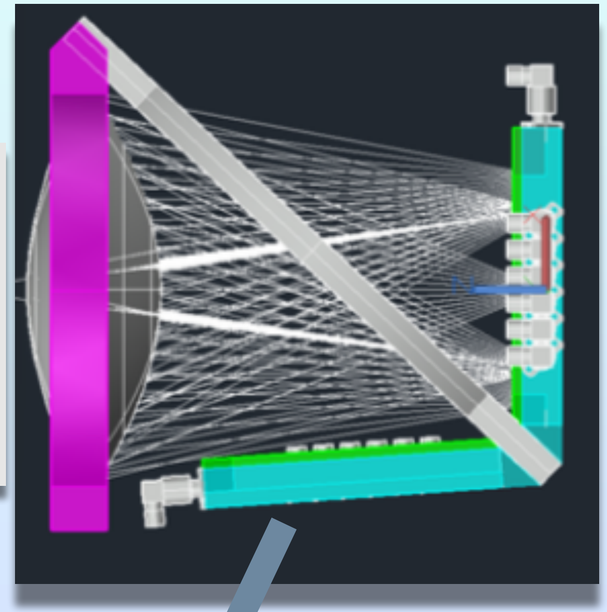


- **Photon noise detectors in 6 bands** (for ground based or space based typical optical loads)
- **Few tens of μs time constant**
- About **x10 less impact of cosmic rays** for space application (not thermal detectors and fast time constant)
- Very **low sensitivity to the base temperature fluctuations**

LEKIDs USED FOR POLARIMETRY







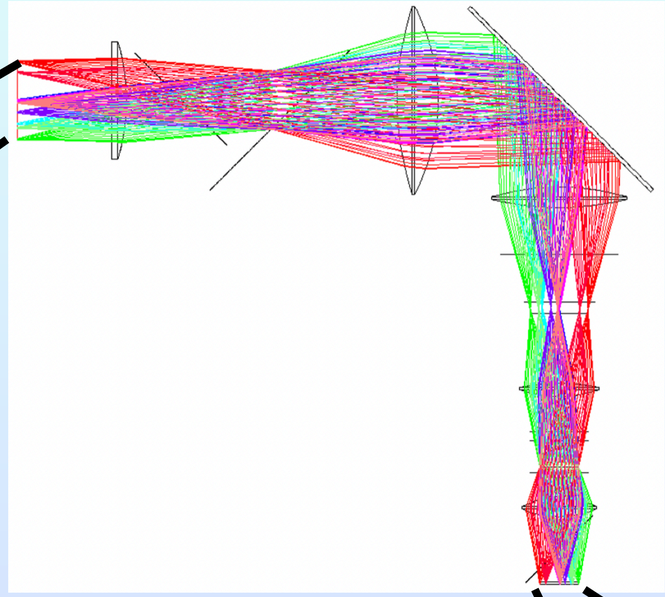
HWP: Half Wave Plate

- Optical element that dephases polarization
- Made of birefringent material
- Continuous rotations allows simultaneous observations of all polarization directions

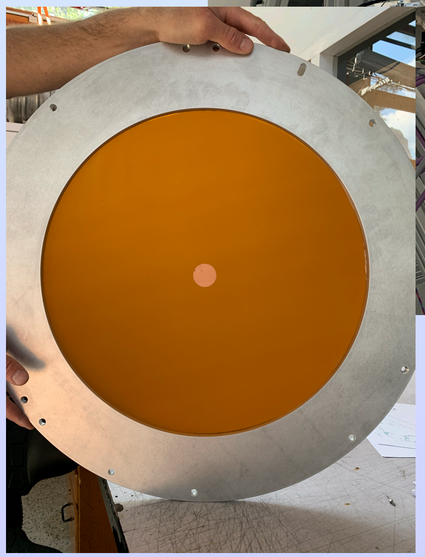
Filled array LEKIDs

- Cover all focal plane with sensitive detectors
- Loss of incident radiation is minimal
- High multiplexing

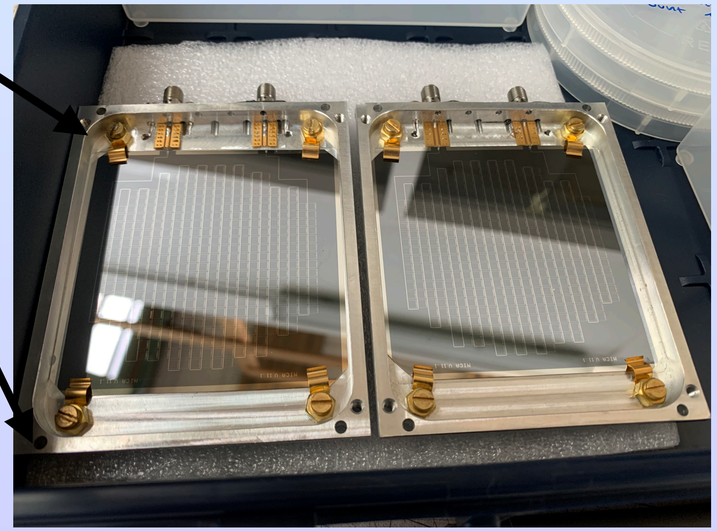
LEKIDs for CMB POLARIZATION: IN-LAB PROOF OF CONCEPT



PolarKID R&D Project:
Can we use LEKIDs in a filled array configuration to measure polarization?



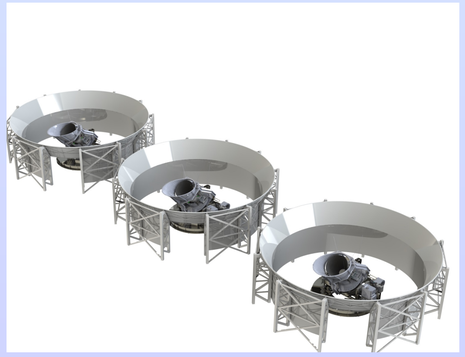
Polarization orientation:
Source VS detected
→
The difference gives the **systematic effects contribution**



FUTURE PERSPECTIVES

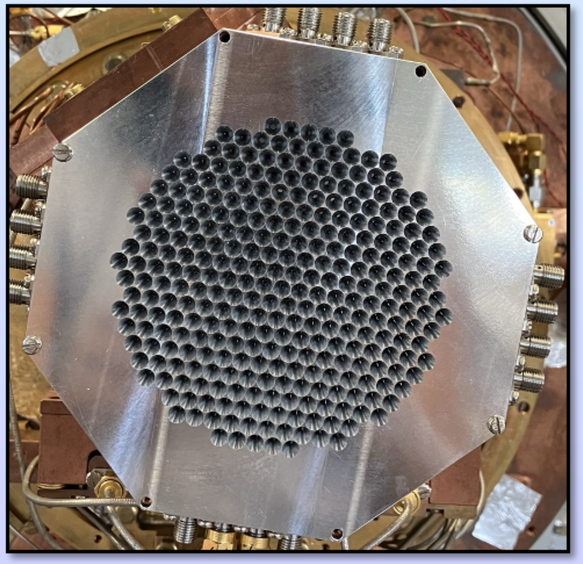
KIDs for CMB

- Fabrication of 30k pixels arrays
- New instrument to be added to SO Small Aperture Telescopes
- First on-sky validation of LEKIDs in a filled array configuration for CMB polarization



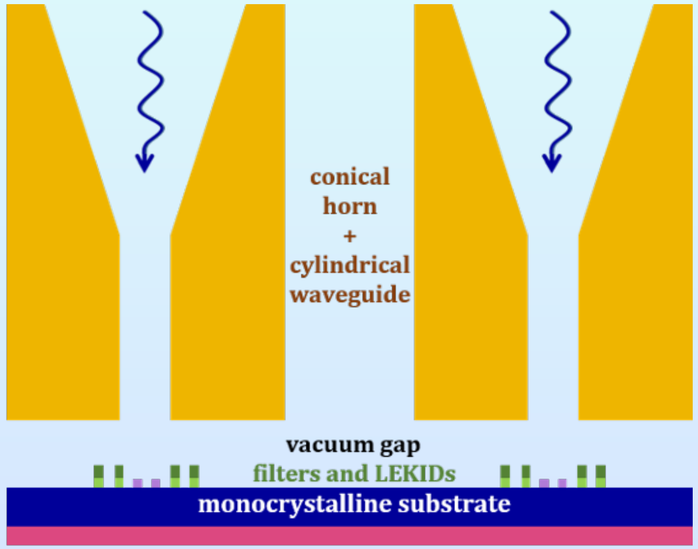
KIDs for spectroscopy

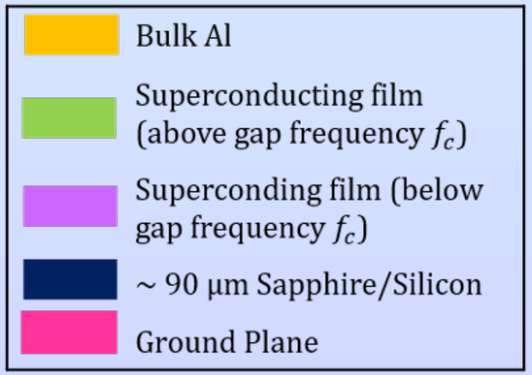
- Future cosmological challenge: spectral distortions of CMB
- Brand-new technology for KIDs
- More suitable for large fields of view

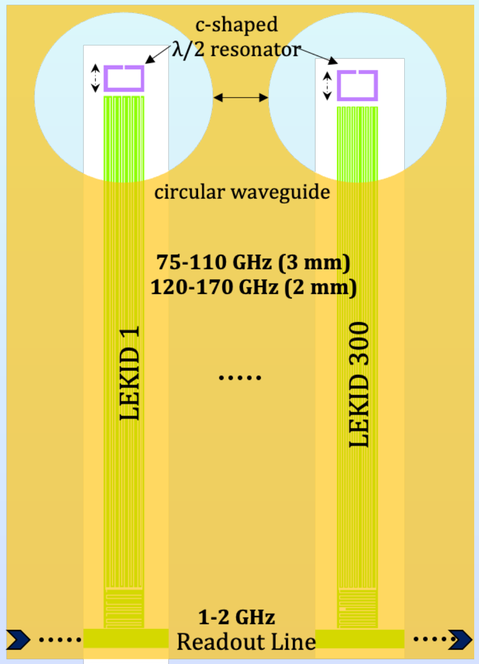


Overview of a 300 spectral channels HYPKID for 2 mm

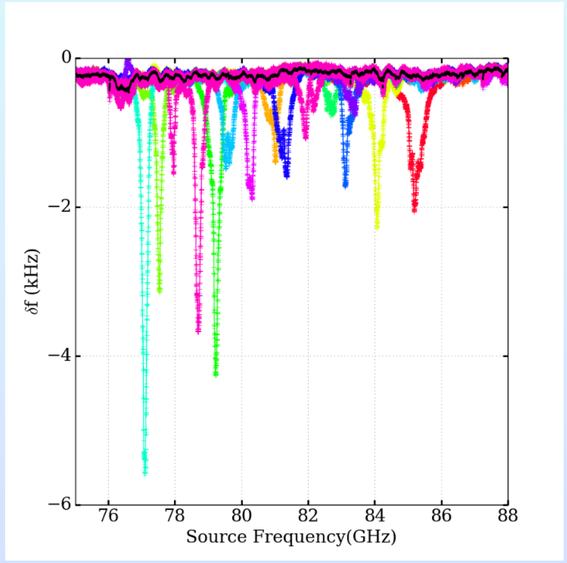
HYPER-SPECTRAL DEVICES based on LEKIDs







HYPKID 3mm wave source



R = 200-400

- Designed for 3D Line Intensity Mapping (LIM)
- Device is polarization sensitive → spectral-polarimetry
- Prototype showed resolving power $R = \lambda/\Delta\lambda$ = 800

Based on the work by **U. Chowdhury**: *A millimetre-wave superconducting hyper-spectral device,* RASTAI 2, 552-556, August 2023

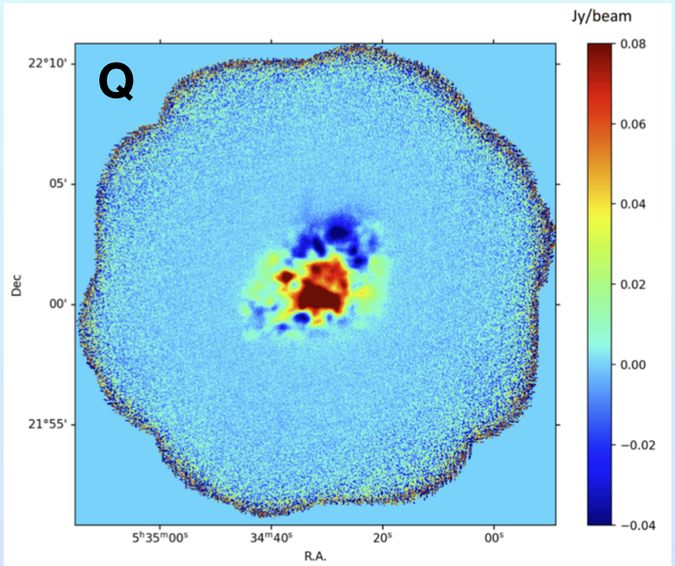
CONCLUSIONS AND PROSPECTS

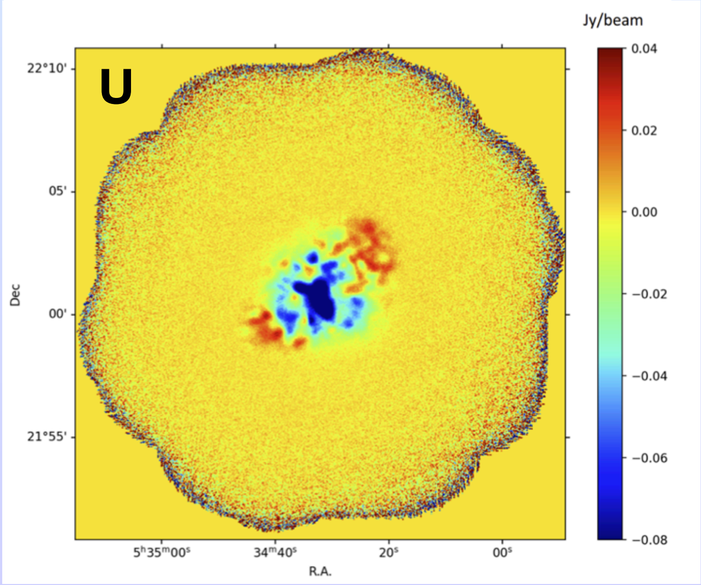
- ✓ The **PolarKID project** aims at proving that LEKIDs used in a filled array configuration can assure precisions suitable for cosmological polarization experiments
- ✓ GIS LEKID technology has today a **TRL** high enough to be used for the next generation of CMB experiments (French SAT for SO)
- ✓ **Hyper-spectral technology** with LEKIDs seems promising for very large fields of view (eg. Line Intensity Mapping)
- ✓ Overall, **French KIDs technology** represents the **state-of-the-art** worldwide for mm and sub-mm astrophysics

MERCI !

OBSERVATIONS IN POLARIMETRY: the CRAB NEBULA

Stokes Q and U maps
of the Crab nebula observed at 260 GHz

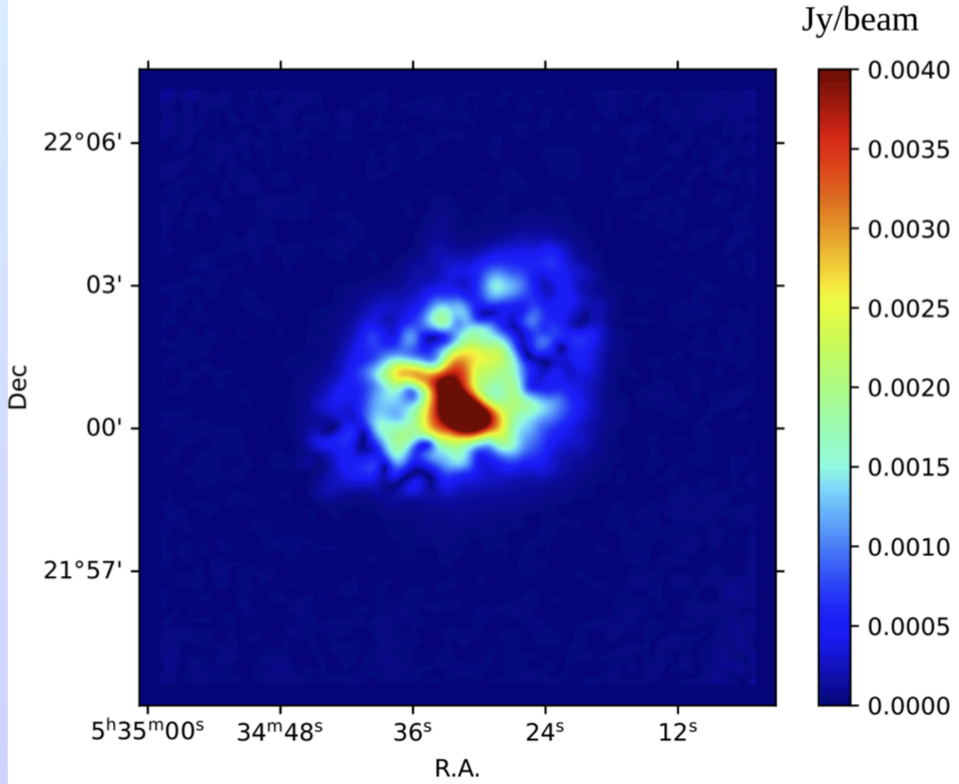




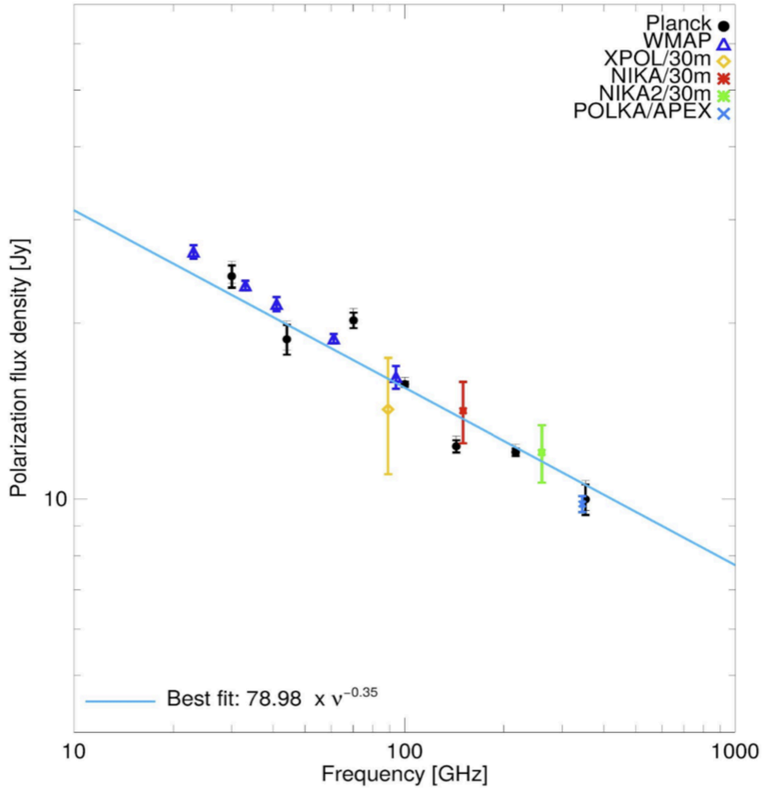
- **Final Sensitivity:** $\sim 20\ mJ\sqrt{s}$ **(better than photometric sensitivity)**
- **Polarisation leakage : < 1% (mainly due to the telescope)**
- **Error on the polarisation angle reconstruction :** $\pm 0.5°$

Ritacco et al, 2021

NIKA2 polarised intensity map



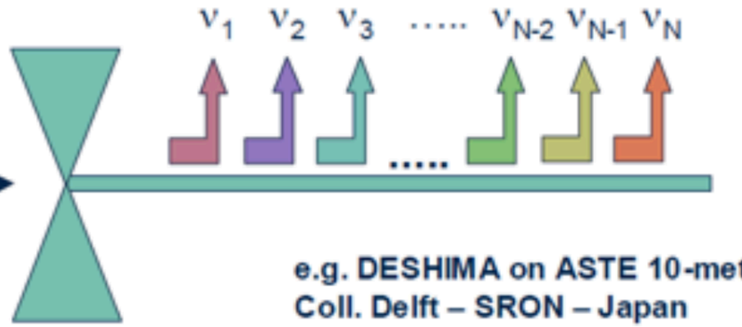
Spectral energy distribution



MULTI PURPOSE SPECTROMETERS

ON-CHIP

$[\nu_1, \nu_N]$

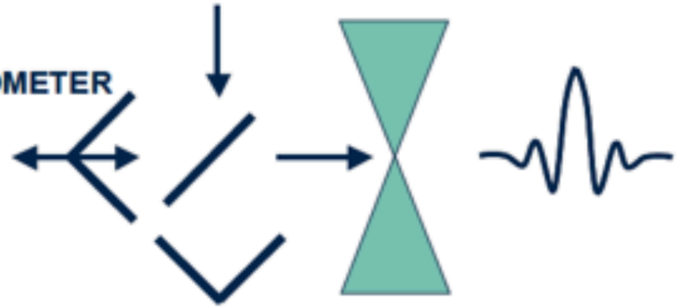


e.g. DESHIMA on ASTE 10-meters telescope
Coll. Delft – SRON – Japan
OR SuperSpec US coll.

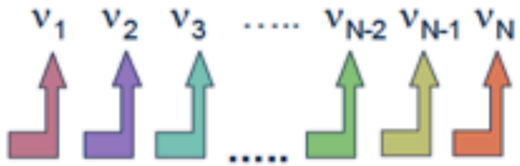
BETTER FOR
SMALL NUMBER OF BEAMS (FOV)
AND
R=100 ÷ 1000

$[\nu_1, \nu_N]$

INTERFEROMETER



FFT

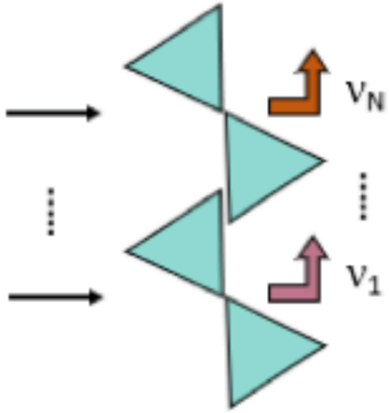


e.g. CONCERTO on APEX

BETTER FOR
MEDIUM NUMBER OF BEAMS (FOV)
AND
R = 10 ÷ 100

HYPERSPECTRAL

$[\nu_1, \nu_N]$



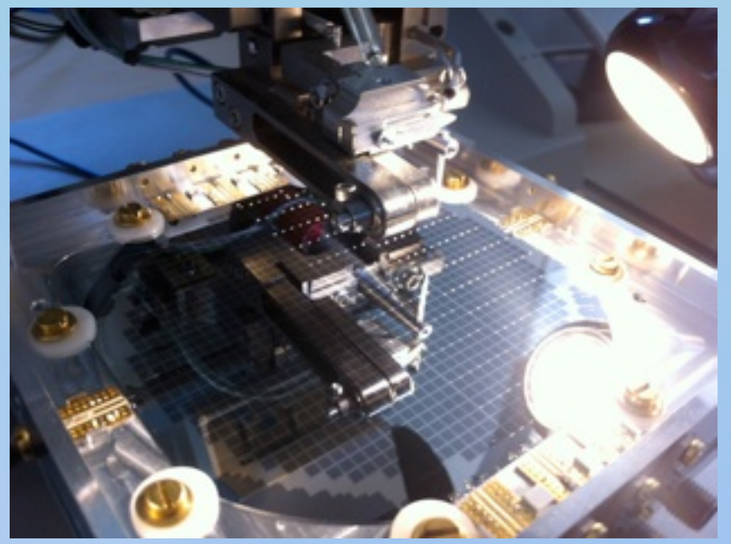
FABRY-PEROT ≡ HYPERSPECTRAL

BETTER FOR
VERY LARGE NUMBER OF BEAMS (FOV)
AND
R = 100 ÷ 1000

The **N**ew **I**RAM **K**IDs **A**rrays (NIKA2) Project

← The NIKA2 cryostat

The 2mm matrix →



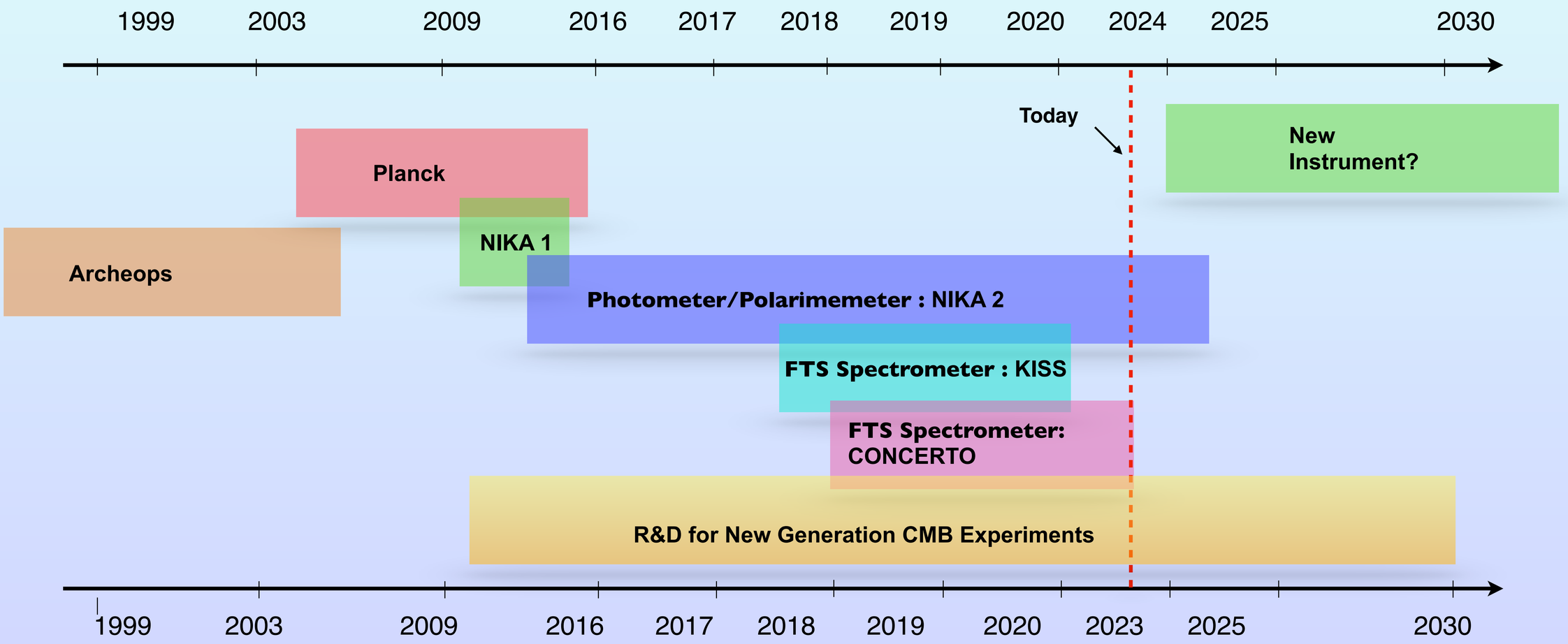
Instrumental performances ↓

Scientific targets:

- SZ effect through galaxy clusters
- Maps of the inter stellar medium
- Magnetic fields and star formation in **polarisation**
- …

	260 GHz	160 GHz
beam (FWHM)	11”	17”
FOV (diameter)	6.5’	6.5’
# of detectors	2 x 1140	616
Sensitivity	30 mJy.s	9 mJy.s
Polarisation	YES	NO

A RESEARCH CENTRED ON THE INSTRUMENT



KIDs FABRICATION PROCESS

CLEAN ROOM

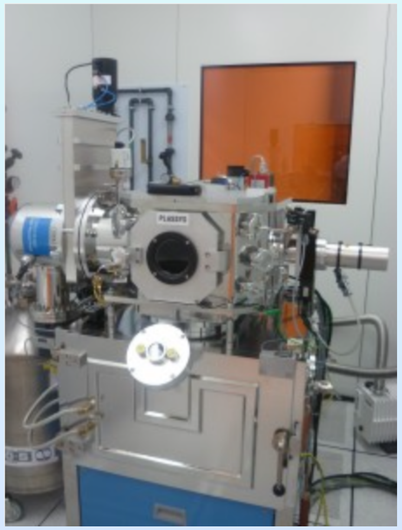
Evaporate a thin layer of **aluminium** on a 4 inch **silicon** mono crystalline and high purity (> 1000 Ωcm) **wafer**

Impress the pattern through a **mask** with **optical lithography**

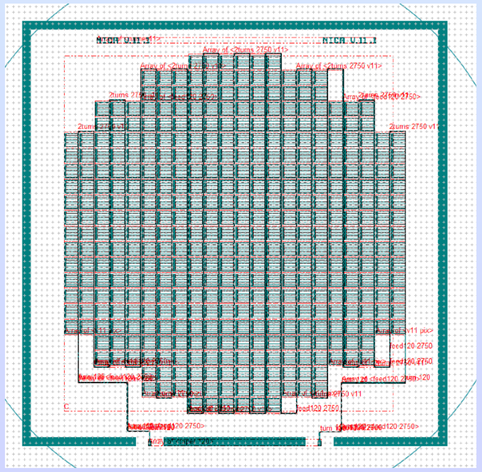
Etch the layer with wet attack and strip the resin

LAB

- Dicing of the array
- Mount on dedicated holders
- Micro bonding connection



Plassys evaporator in the PTA clean room in Grenoble



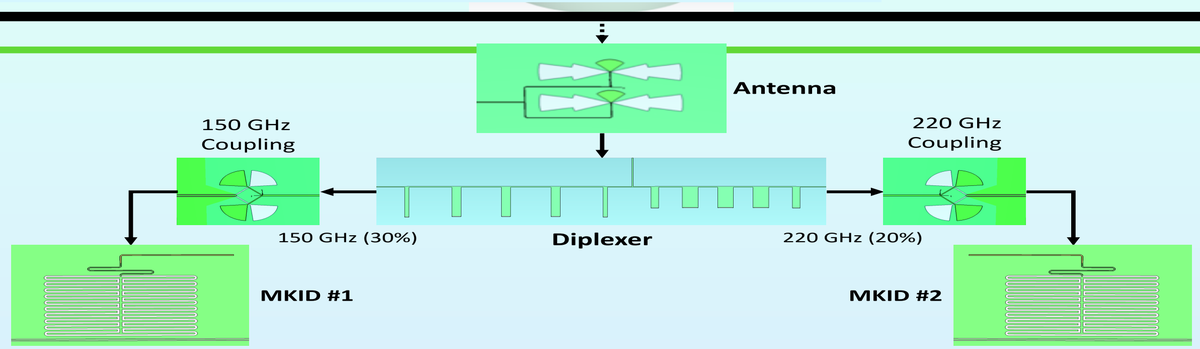
Mask design for 1mm matrix by A. Monfardini

- Fast and simple process
- **Need** no defects on the feedline
- **Need** low number of bad pixels

MULTI PURPOSE SPECTROMETERS

ON-CHIP - APC + GISKID (R&D)

- **Total bandwidth:** Center 184.75 GHz, 60% (Range: 127.5 – 242 GHz)
- **Sub-bands:** 150 GHz, 30% (127.5 – 172.5 GHz) & 220 GHz, 20% (198 – 242 GHz)
- **Polarisation-sensitive:** Linear
- **Return loss:** (S11) < -10 dB (> 90% power transmitted)
- **Far field:** Symmetrical, side lobes < -20 dB
- **Cross-polarisation** < -15dB at 2 sub-bands 150 & 220GHz

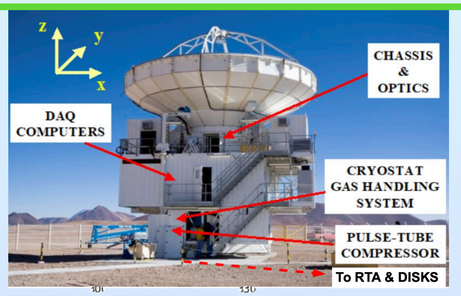


FTS (CONCERTO) - GISKID

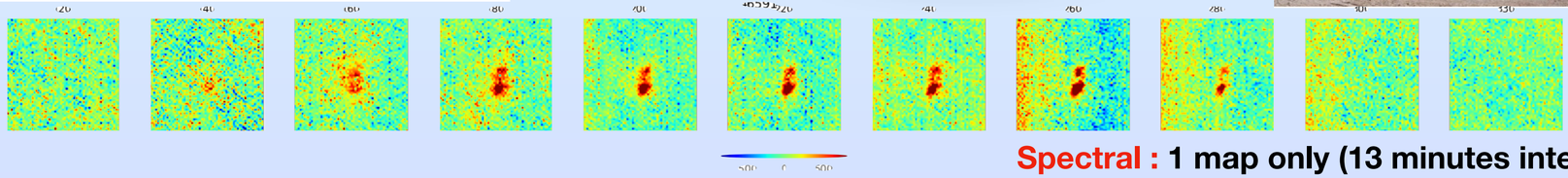
Fundings : ERC Advanced Grant
Duration of operation: April 2021 - May 2023
P.I. : G. Lagache (LAM) / A. Monfardini (IN)

Focal Plane Geometry
> 90 % Functional pixels

ORION



- 1200 hours observations of the CII-emission line at high redshift
- 50 hours SZ signal from galaxy cluster



Spectral : 1 map only (13 minutes integration)

HYPERSPECTRAL - GISKID (R&D)

- Direct coupling of the horn with the resonant filter
- Horn micro-strip transition removed
- Very interesting for low resolution spectra on-chip
- NEP very raw: 1.10^-17 W/sqrt(Hz)