Observations of the Early Universe at millimetre wavelengths: the Grenoble GIS contribution

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

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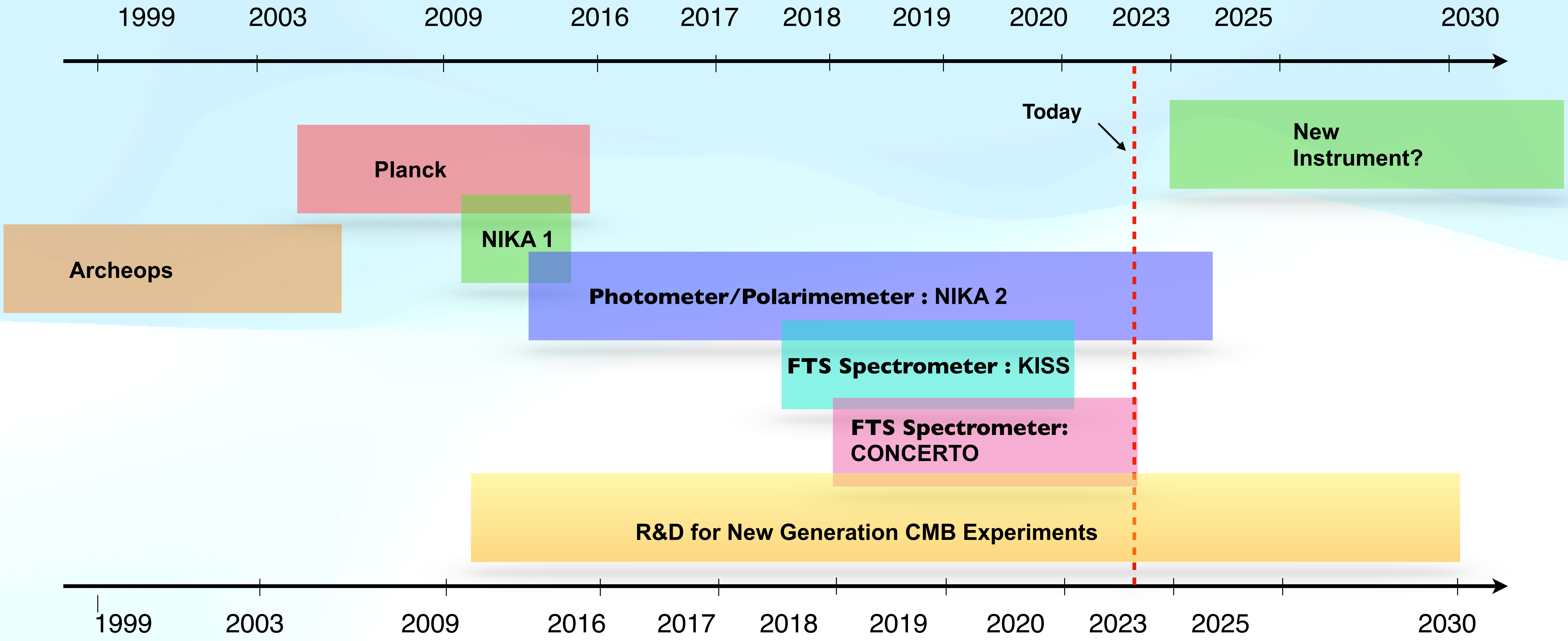
GDR - Nantes

A RESEARCH CENTRED ON THE INSTRUMENT



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?)

Balloon experiments

Boomerang (1999-2003)
2 Flights

MAXIMA (1998-1999)
2 Flights

Archeops (2001-2002)
3 Flights

OLIMPO (2018)
1 Flight

Perspectives

Ground based experiments

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)

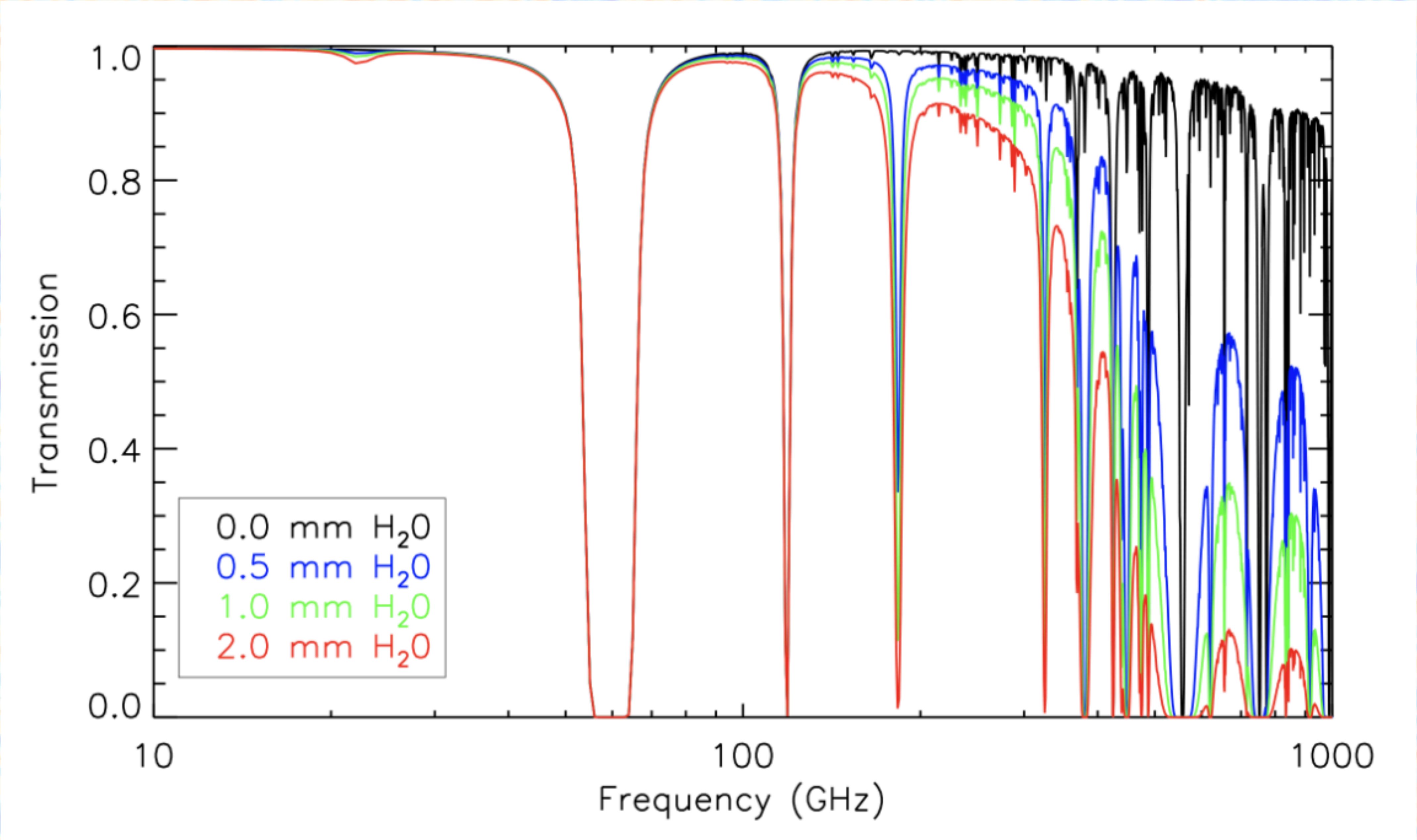
Use of superconductors

Thermodynamics

Why cryogenic detectors?

Noise killing

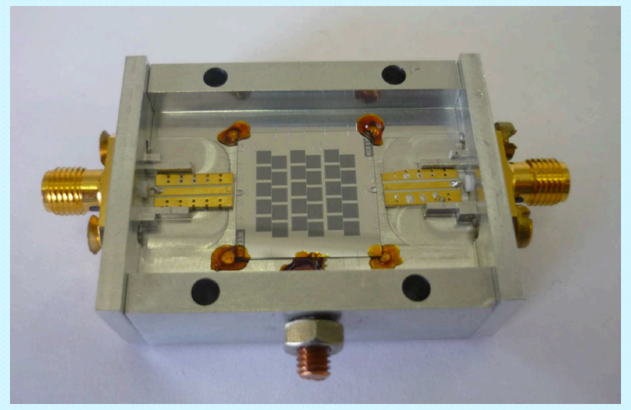
Atmosphere (for ground-based observations)




Cryogenics
Fabrication
Mechanics
Optics
CORE TECHNOLOGY: KIDs
Electronics
PROC2 FPGA
PROC3 FPGA
DAC
MEAS
MONITOR
EXC
SPLIT FPGA
ADC
PROC0 FPGA
PROC4 FPGA
PROC1 FPGA
FM
LO
Data Acquisition-Pipeline
Raw data
Cleaned data
raw data
cleaned data
Flux (Jy)
Time (s)
0
100
200
300
−2
0
2
4
6
8

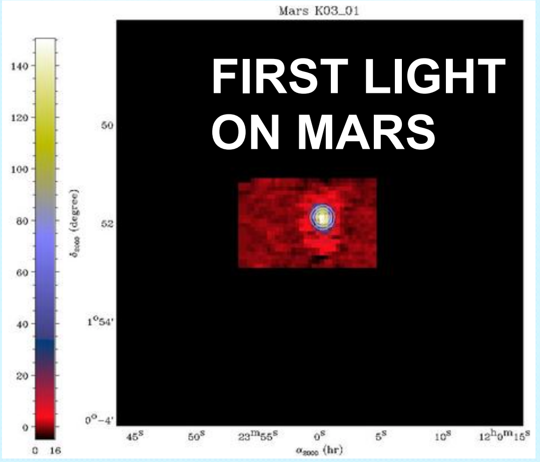
KIDs EVOLUTION

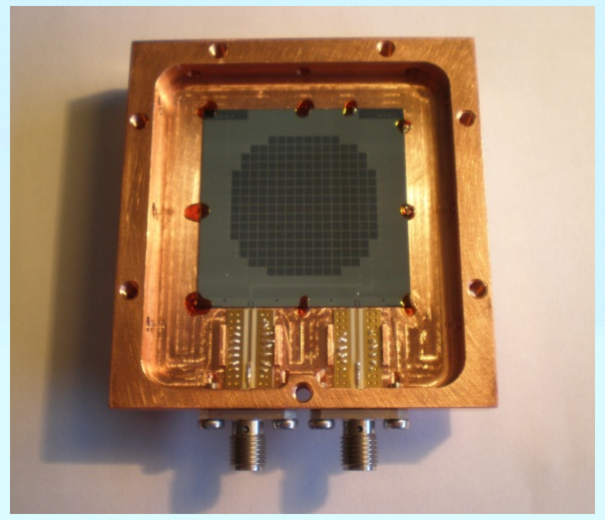
KIDs have been validated in several bands



2009

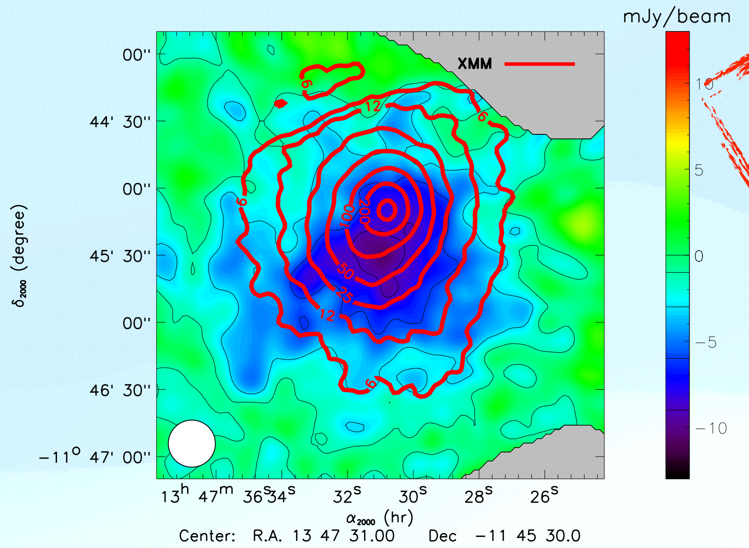
30 Pixels





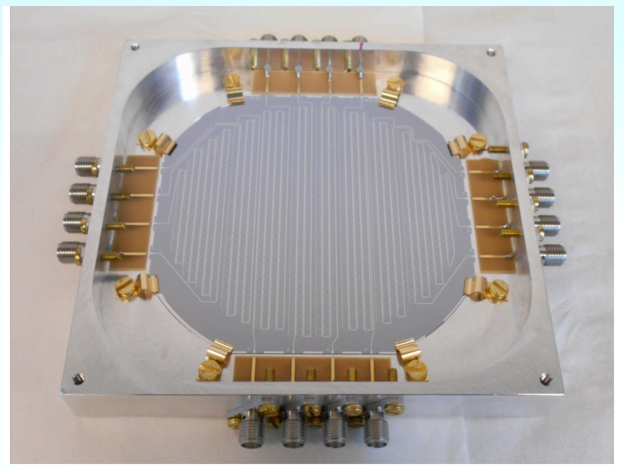
2010-2013

200 Pixels



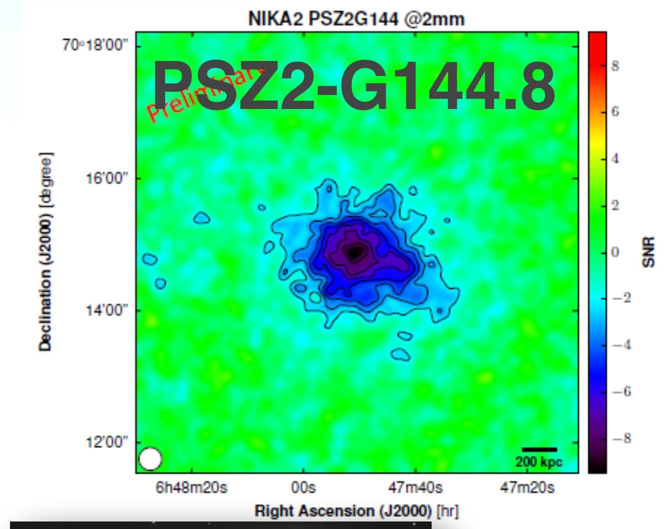
First SZ det. with KID

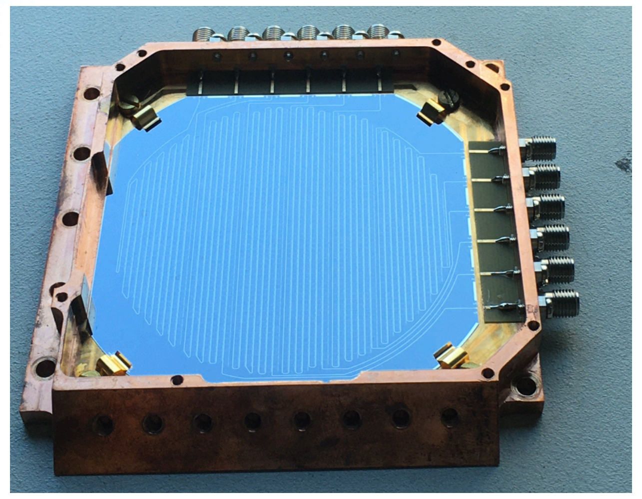
RXJ1347 (2012)



2014-2015

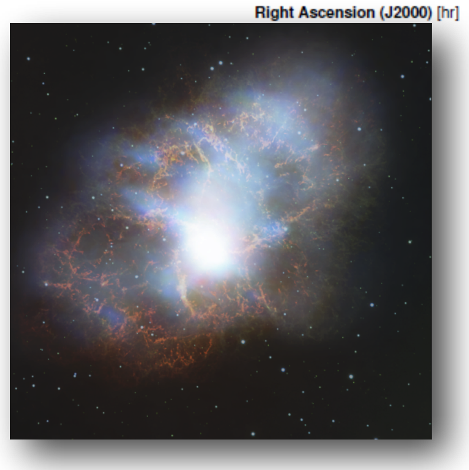
1000 Pixels





2015-Today

2000 Pixels



Today

8000 Pixels

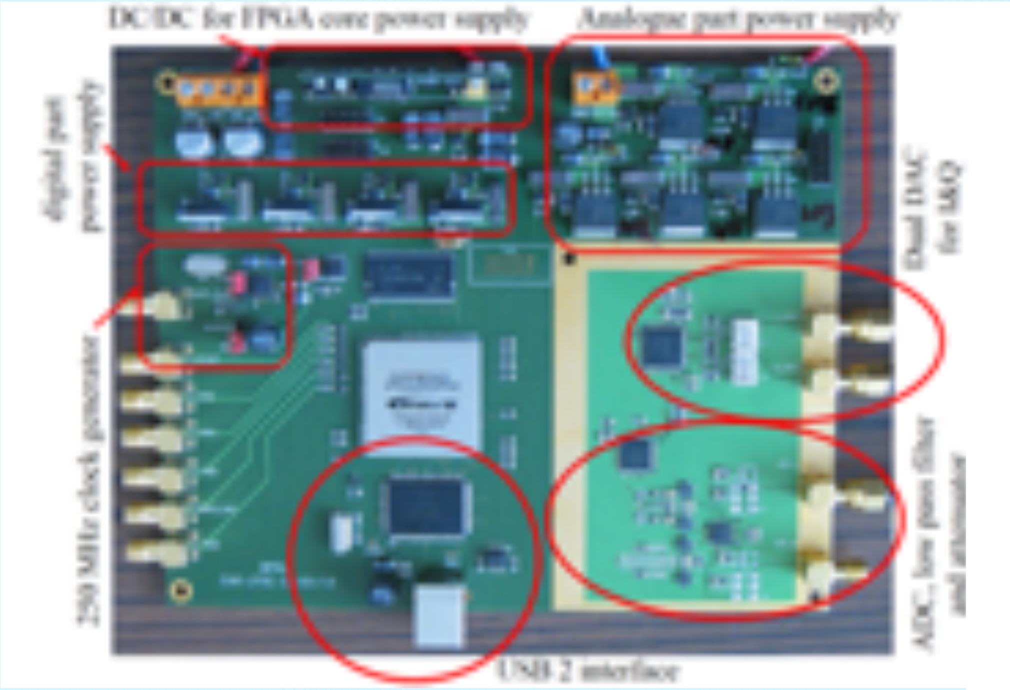
2023-2030

Prototype

- New evaporation machine
- Up to 20 cm wafer

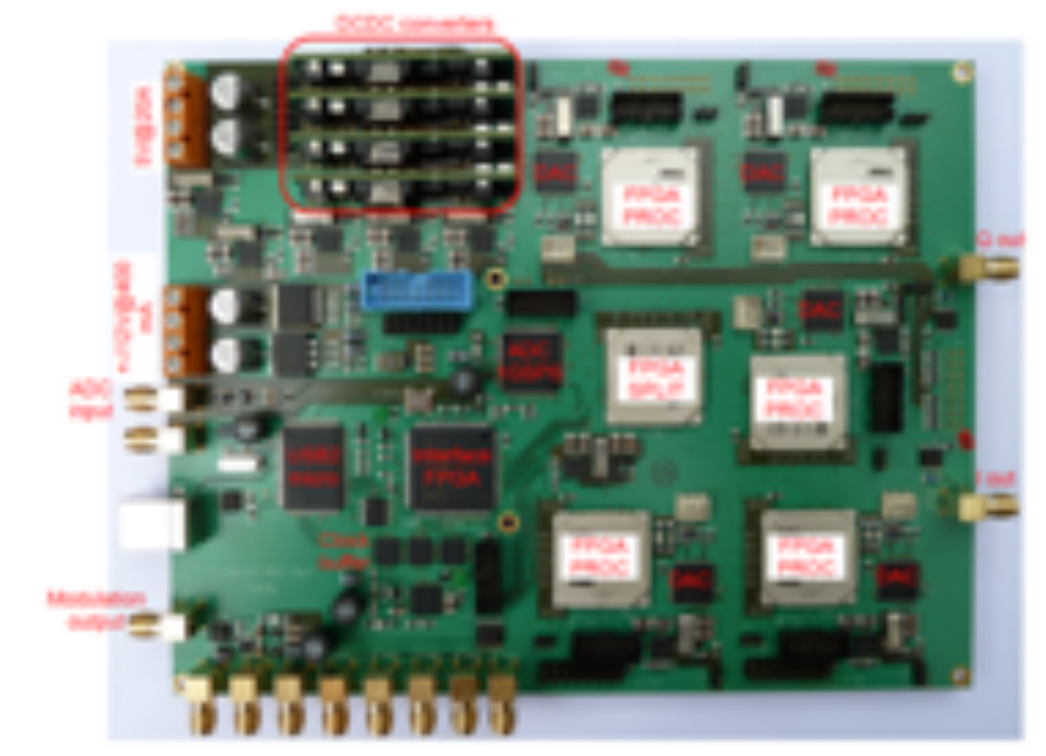
READOUT DEVELOPMENT

2011: NIKEL proto



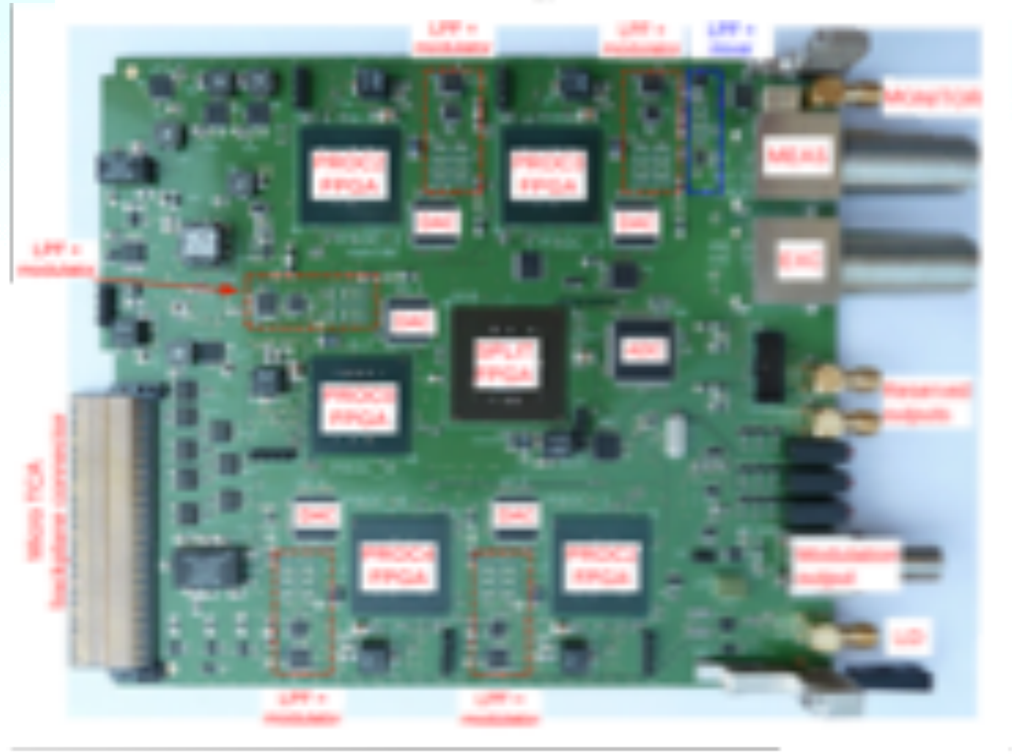
128 pixels
500 MHz bandwidth
external RF

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)

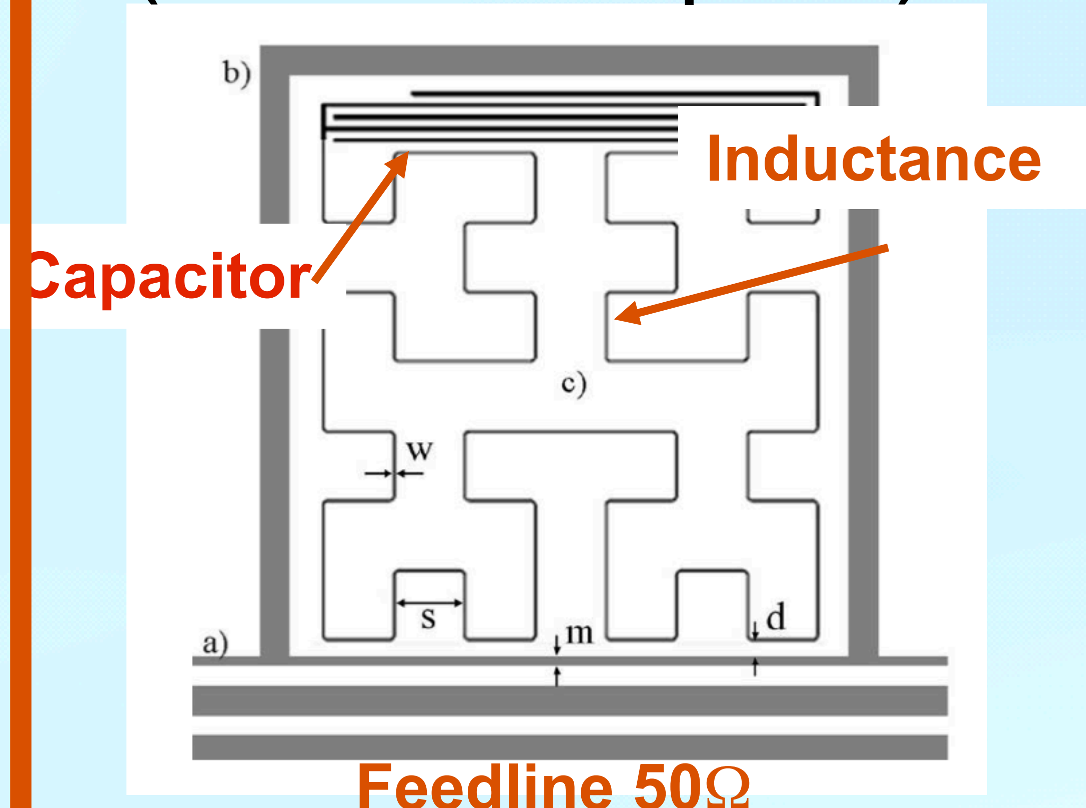
400 pixels
1 GHz bandwidth
30 watts power

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

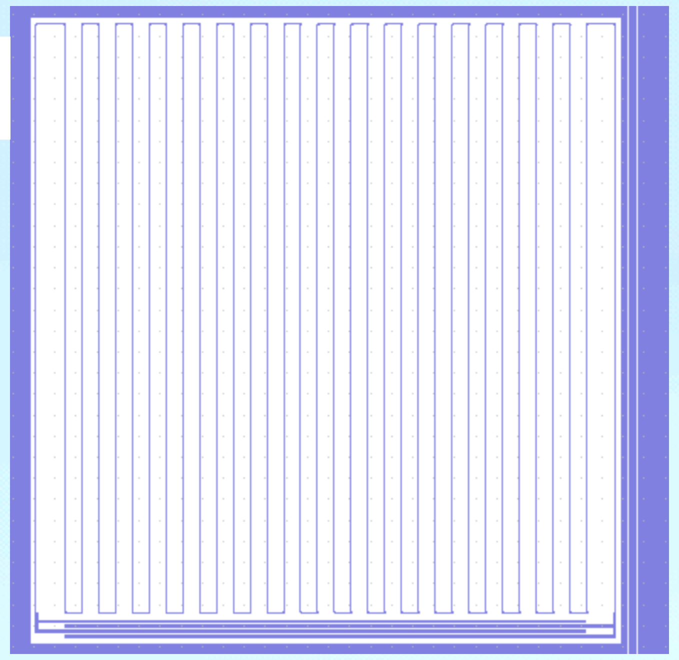
PHOTOMETERS and POLARIMETERS

Lumped Element KID

Dual Polarisation
(3rd-order Hilbert pattern)

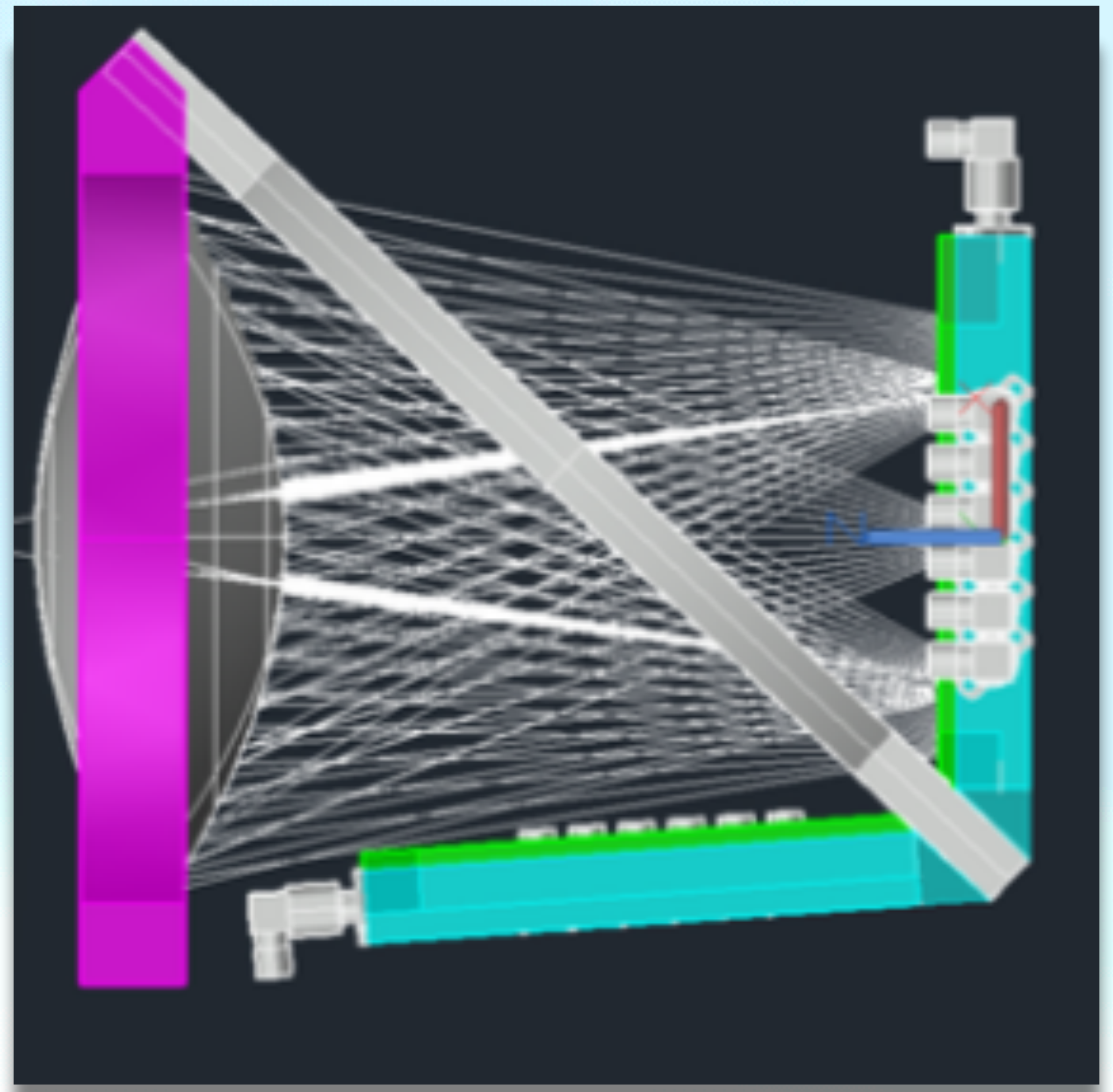


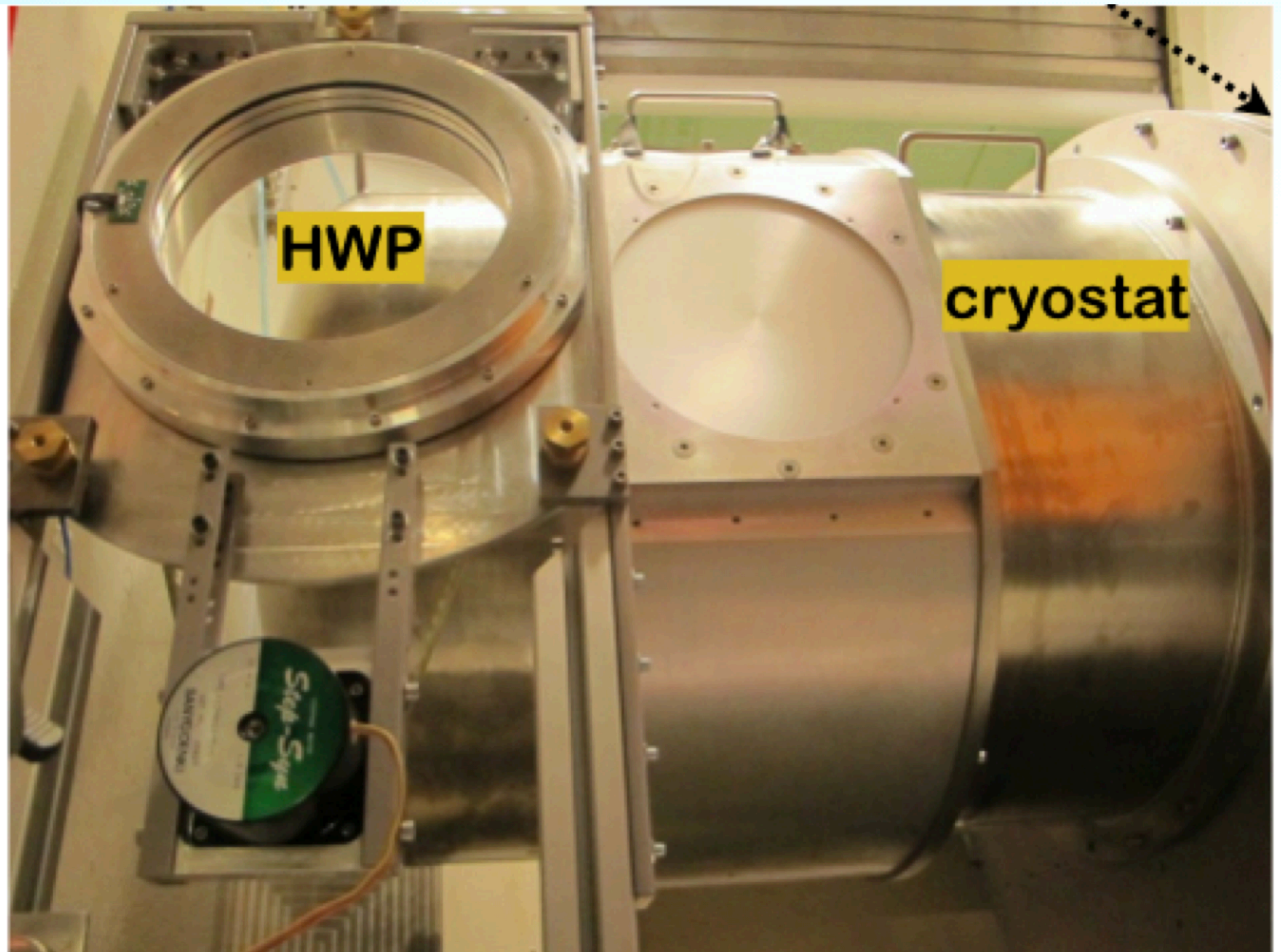
Single Polarisation

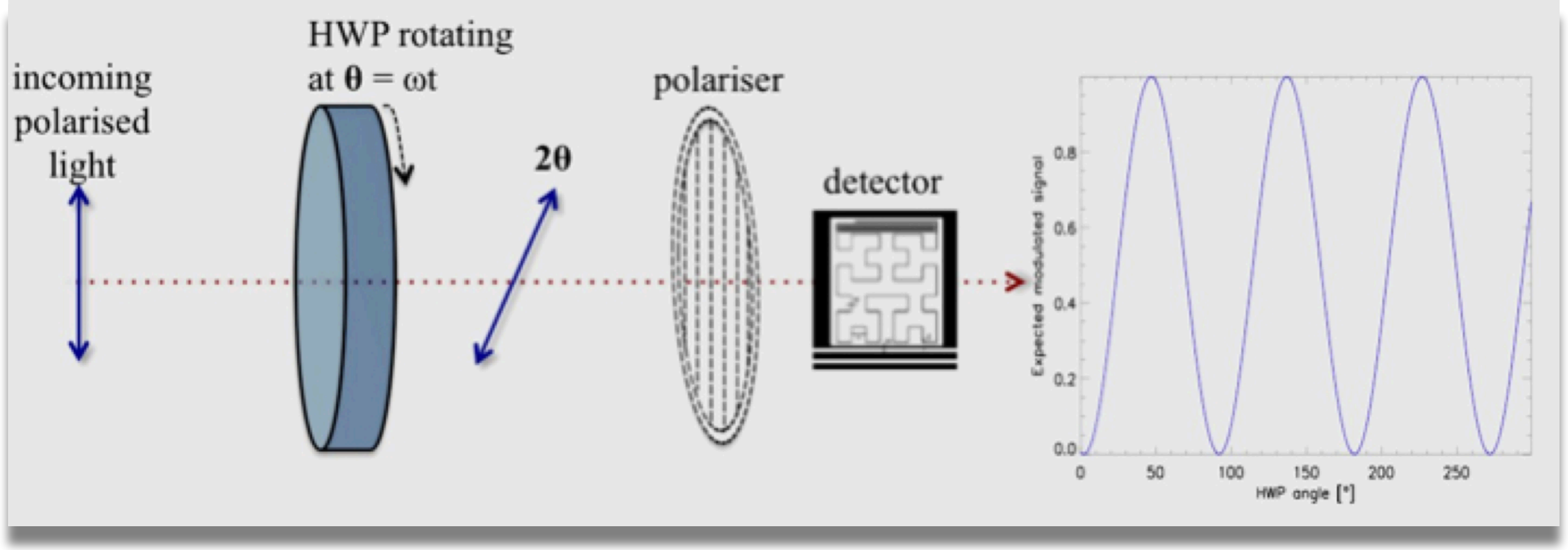


Filled arrays LEKID:

- Large filling factor
- Very high quantum efficiency in a 30% mm-band
- Easy to fabricate



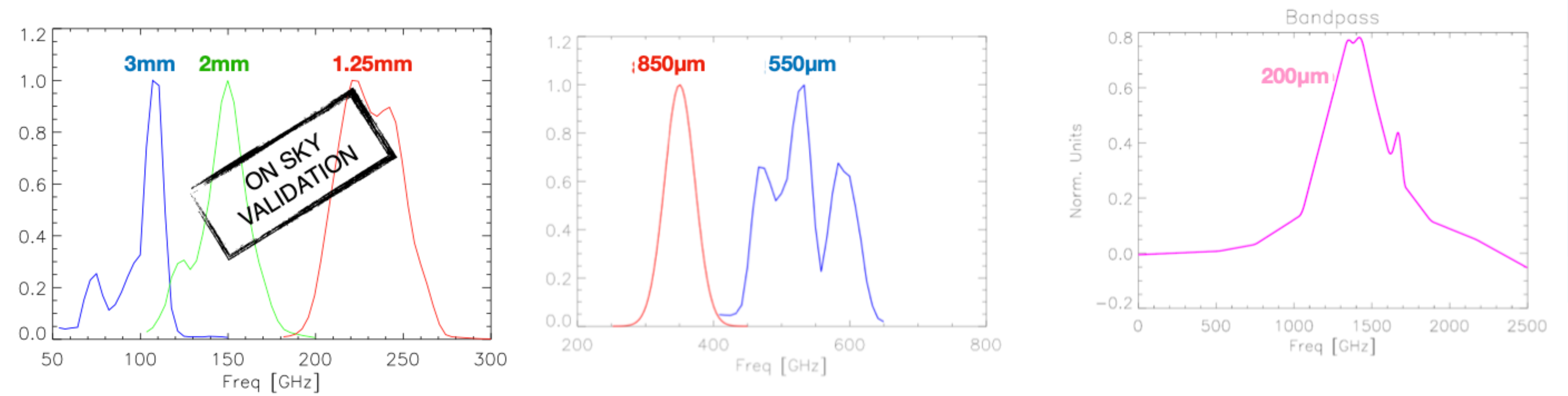




Continuous rotation of an HWP permits quasi-simultaneous observations of I,Q,U Stokes parameters

BANDS COVERAGE and SENSITIVITY

Catalano et al, 2020

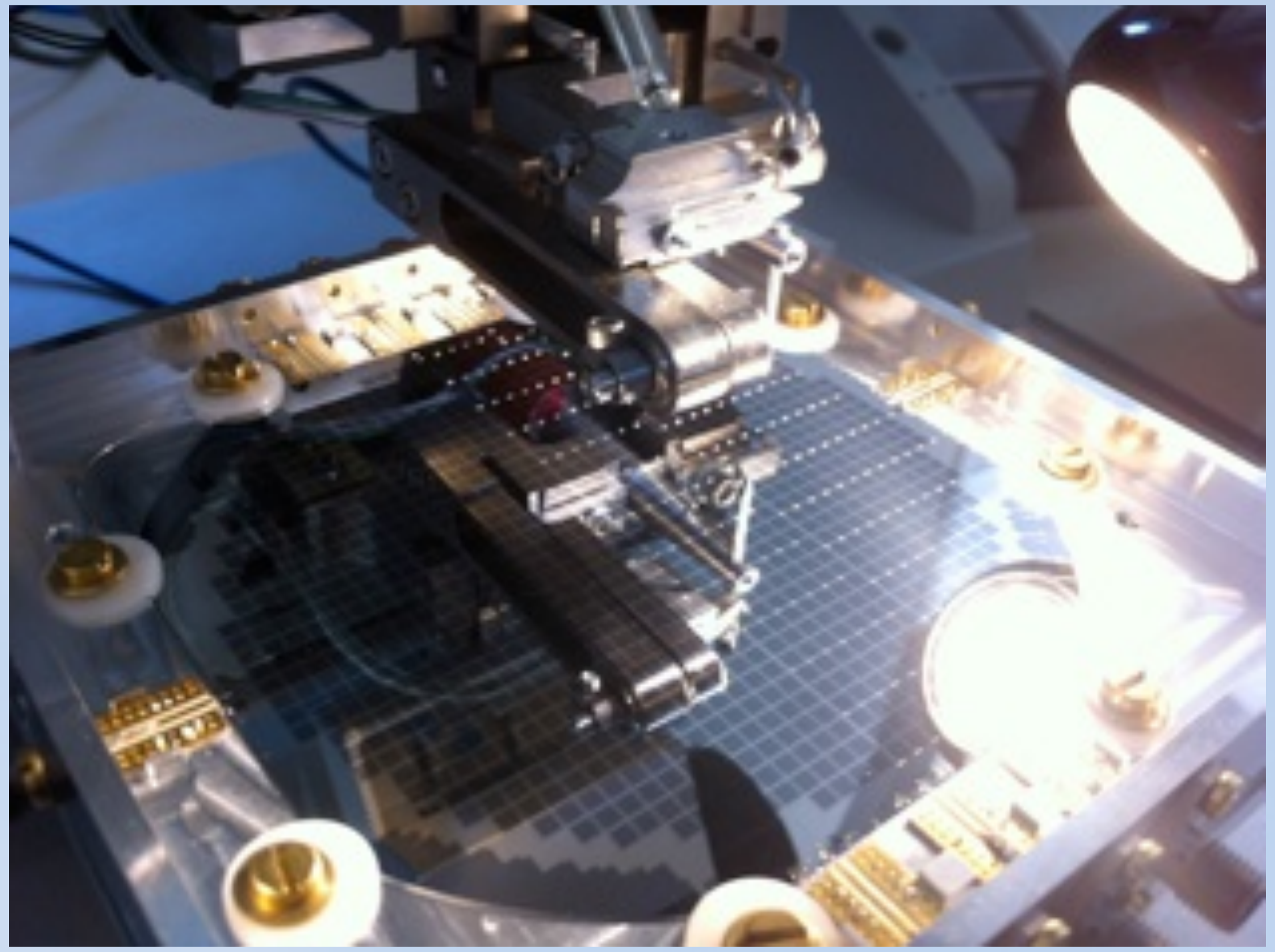


- **Photon noise detectors in 6 bands** (for ground based or space based typical optical loads)
- **Few tens of μs time constant**
- About **x10 less impact of cosmic rays** for space application (not thermal detectors and fast time constant)
- Very **low sensitivity to the base temperature fluctuations**

The New IRAM KIDs Arrays (NIKA2) Project

← The NIKA2 cryostat

The 2mm matrix →



Instrumental performances ↓

	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

Scientific targets:

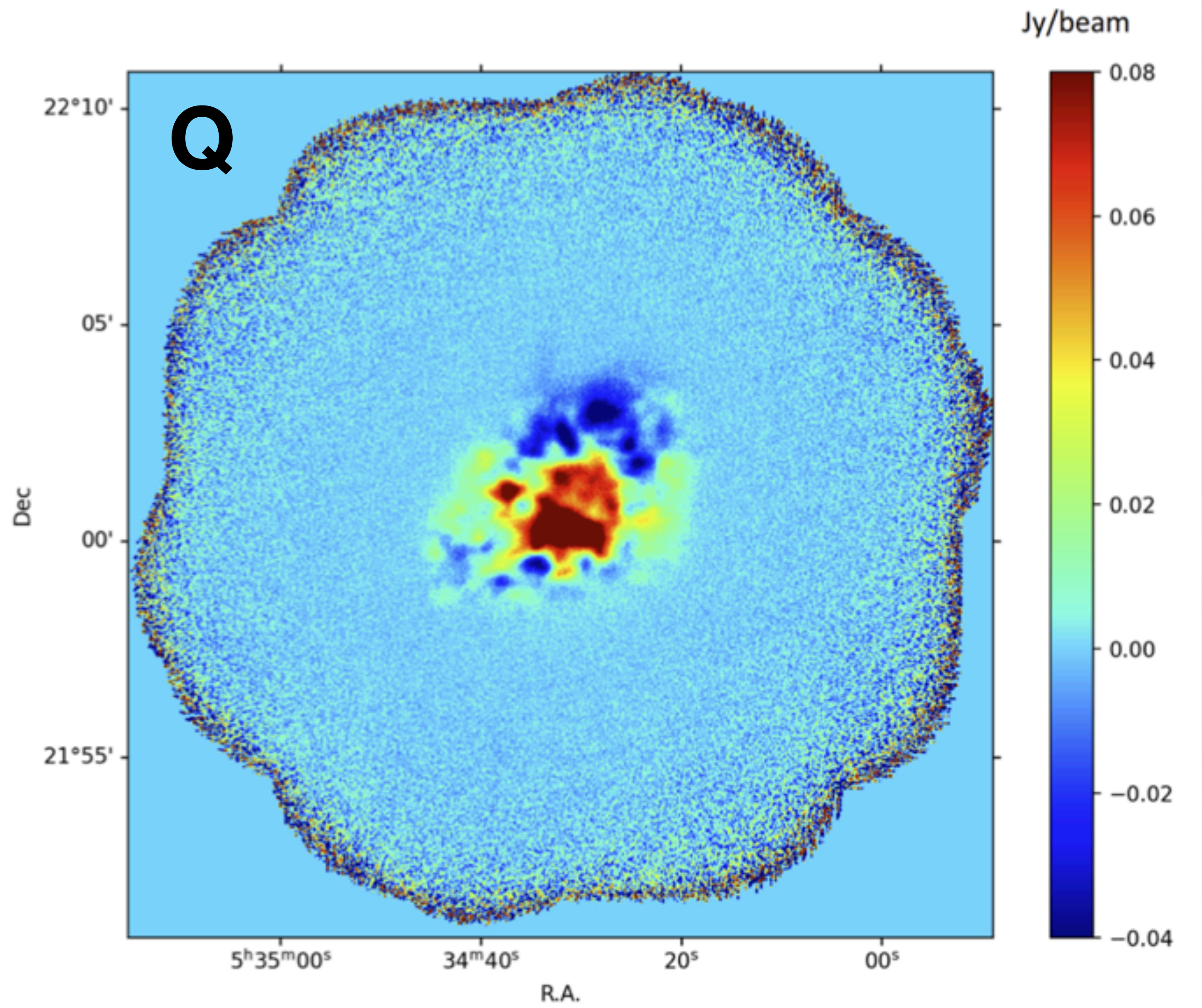
- SZ effect through galaxy clusters
- Maps of the inter stellar medium
- Magnetic fields and star formation in **polarisation**
- …

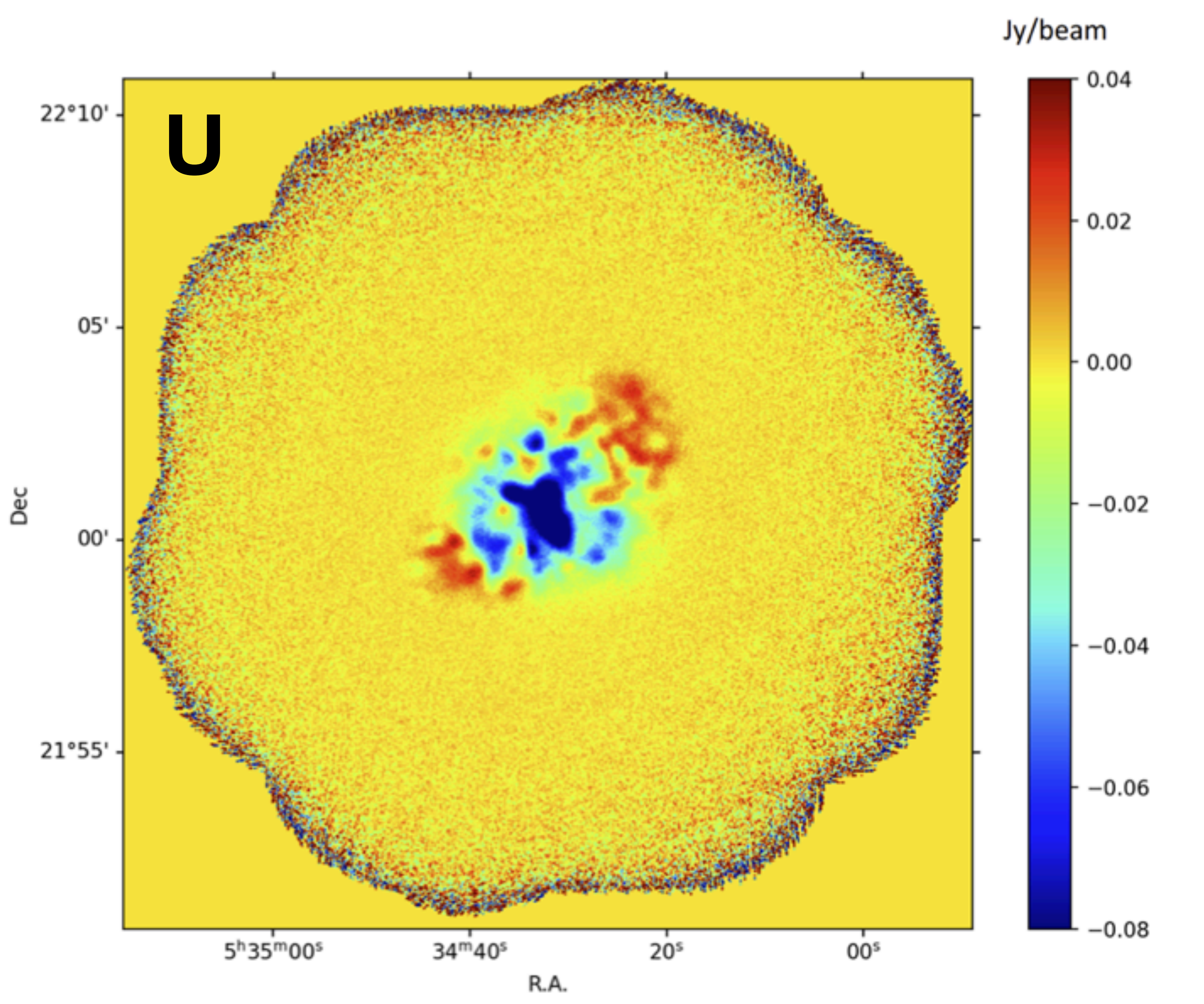
KID/Readout Development - Polarisation

- **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 : $\pm 0.5°$**

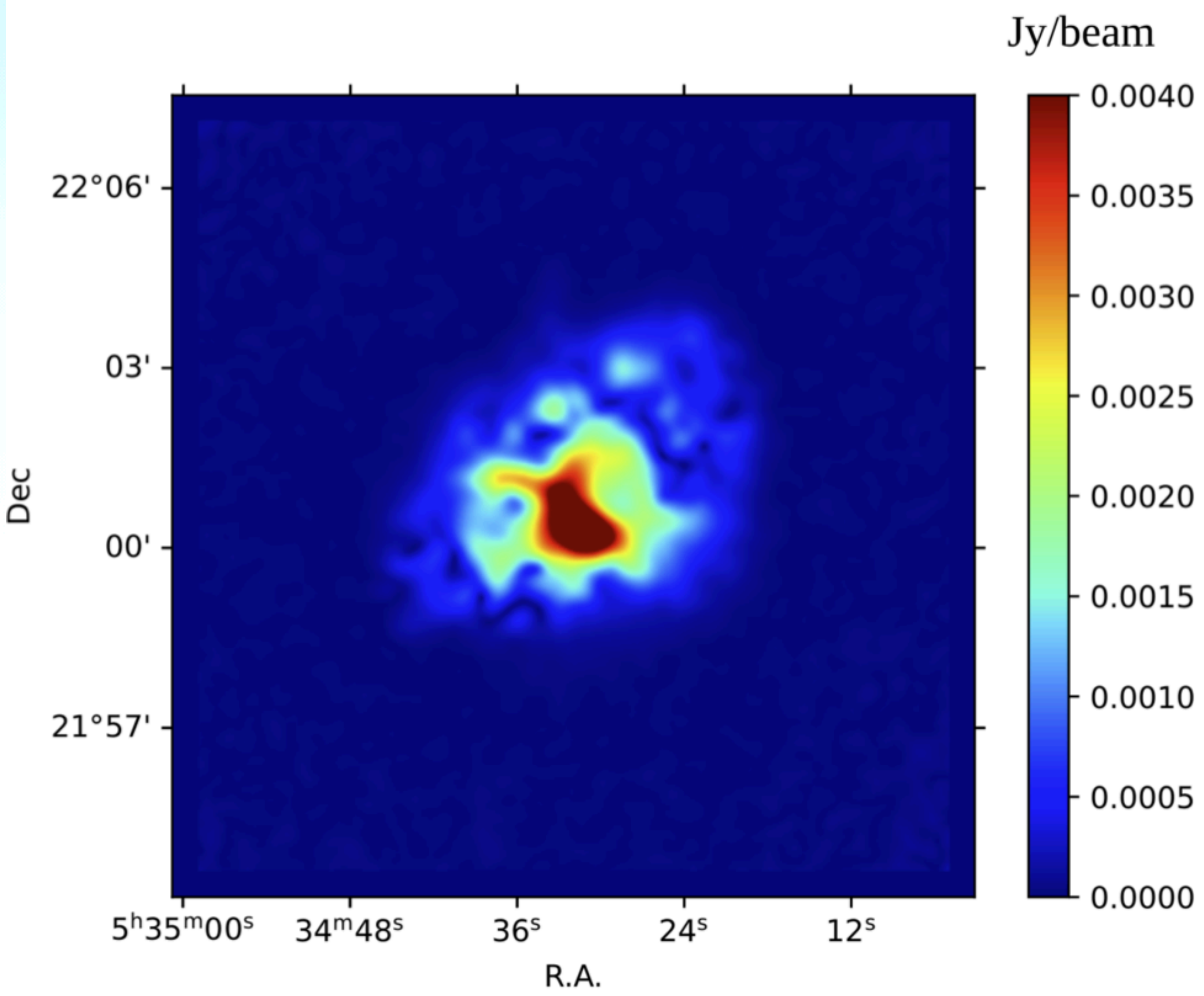
Ritacco et al, 2021

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

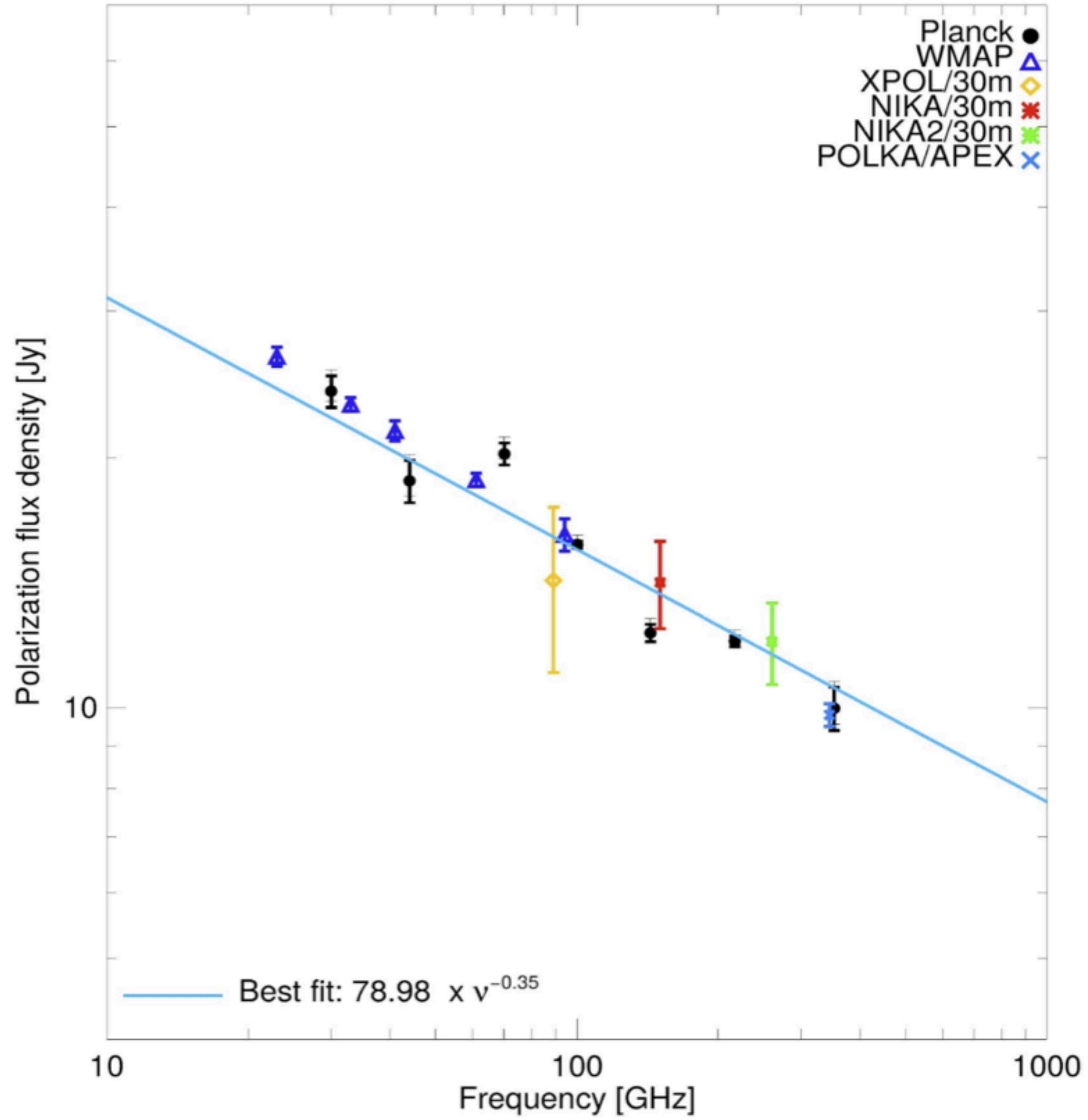




NIKA2 polarised intensity map

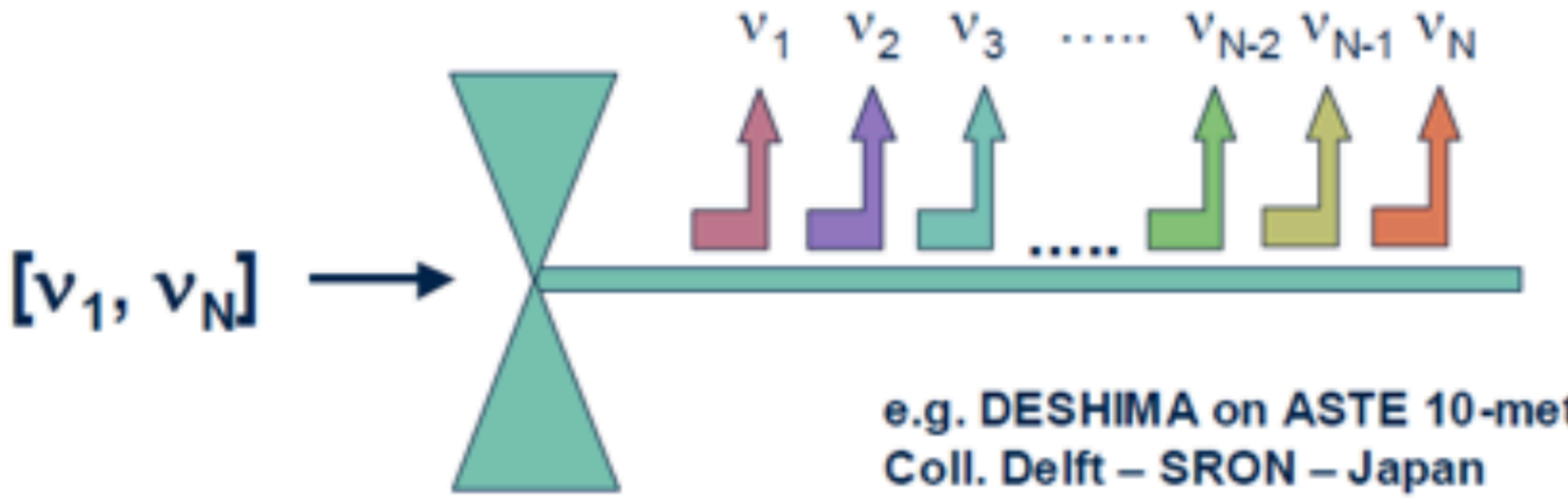


Spectral energy distribution



MULTI PURPOSE SPECTROMETERS

ON-CHIP



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

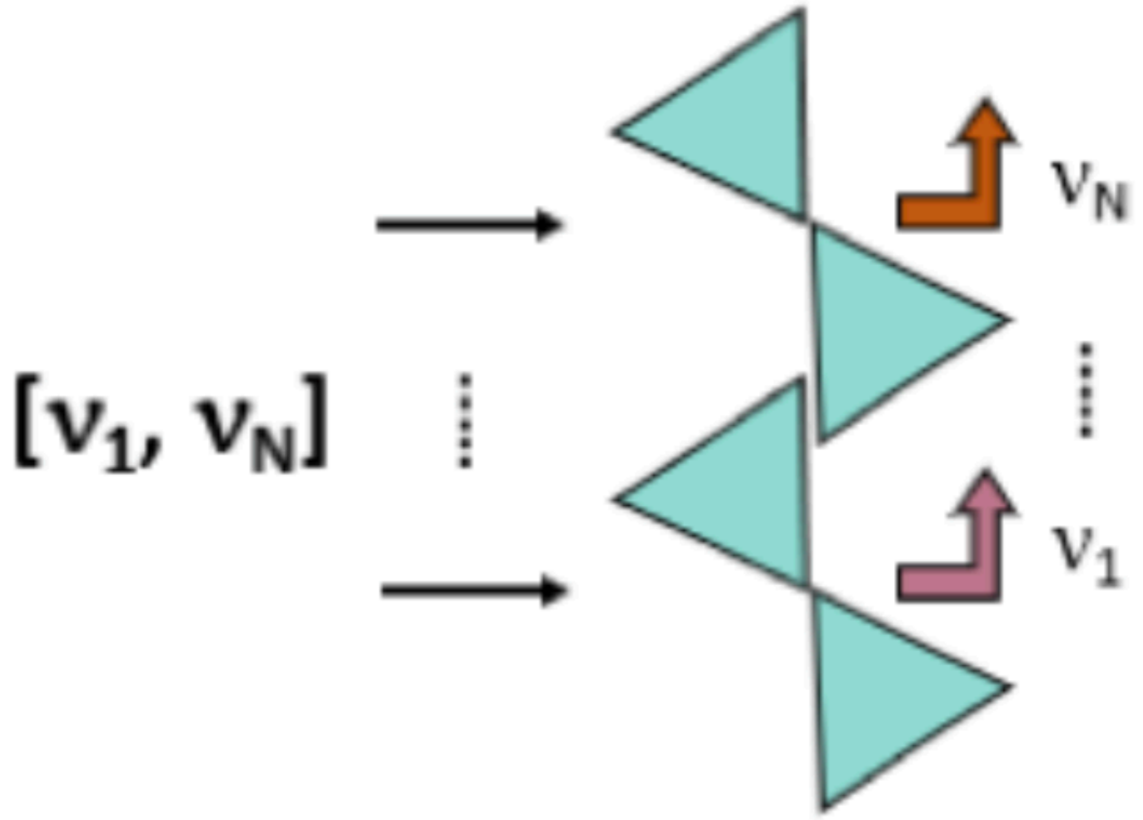
BETTER FOR **SMALL NUMBER OF BEAMS (FOV)** AND **R=100 ÷ 1000**

INTERFEROMETER

e.g. CONCERTO on APEX

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

HYPERSPECTRAL



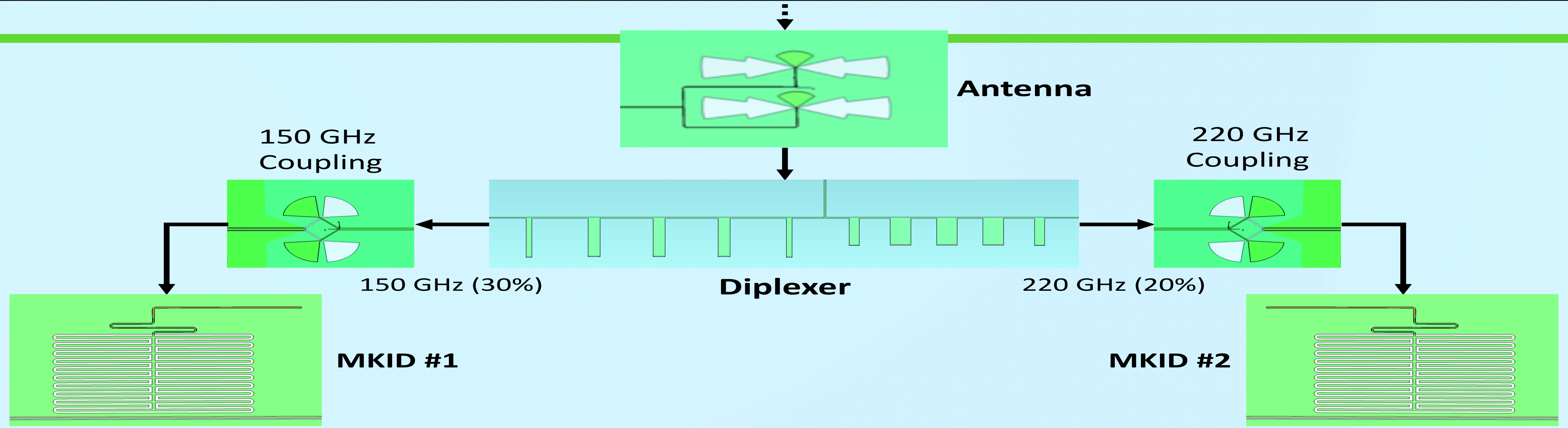
FABRY-PEROT ≡ HYPERSPECTRAL

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

MULTI PURPOSE SPECTROMETERS

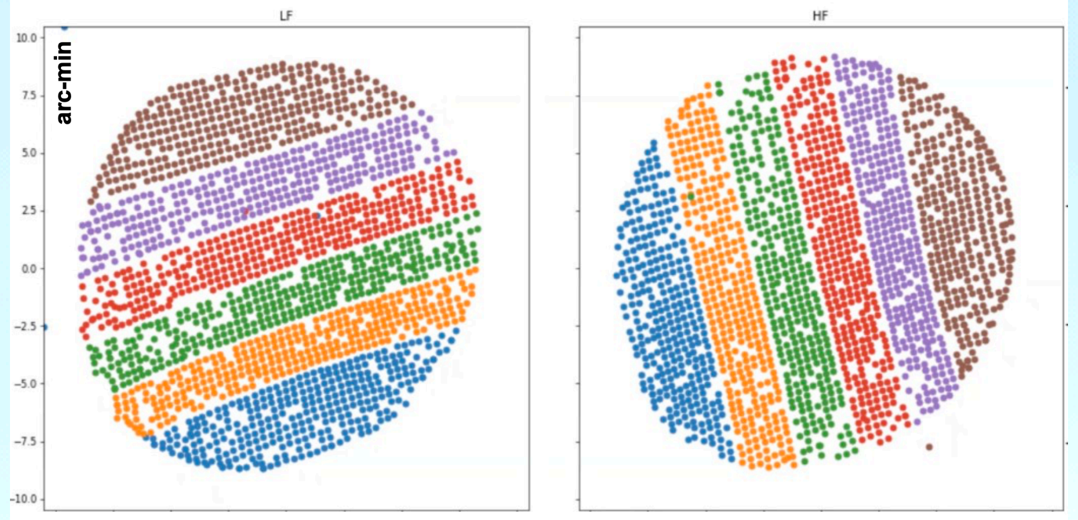
ON-CHIP - APC + GISKID (R&D)

- **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

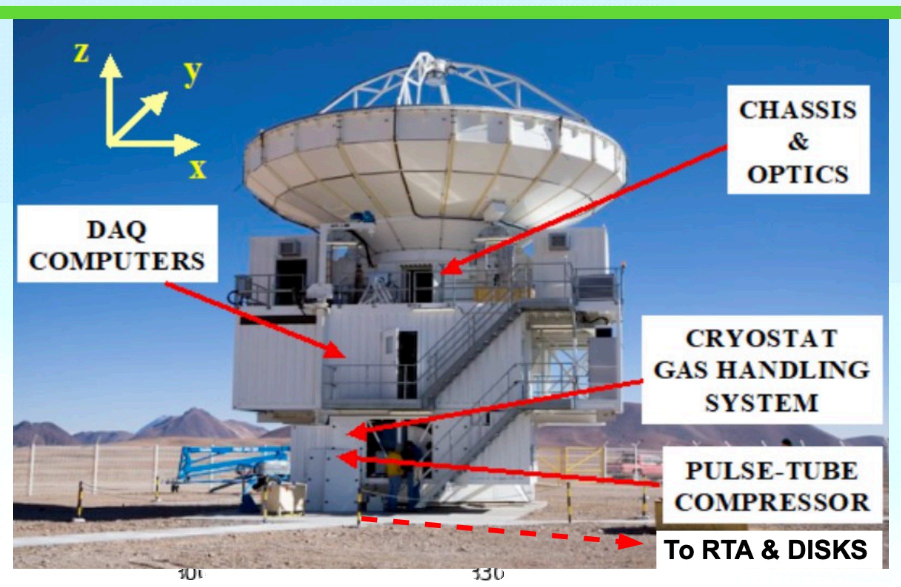
Fundings : ERC Advanced Grant
Duration of operation: April 2021 - May 2023
P.I. : G. Lagache (LAM) / A. Monfardini (IN)



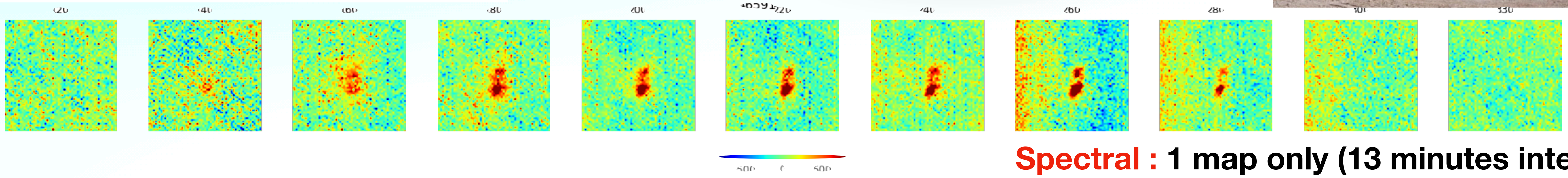
Focal Plane Geometry

> 90 % Functional pixels

ORION



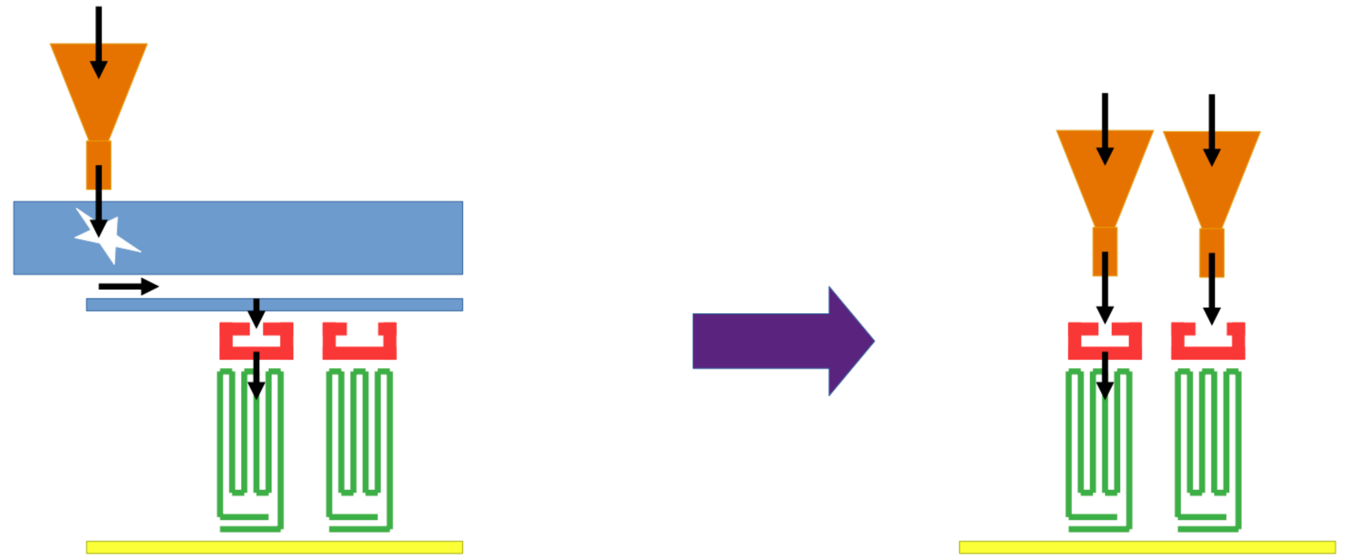
- 1200 hours observations of the CII-emission line at high redshift
- 50 hours SZ signal from galaxy cluster

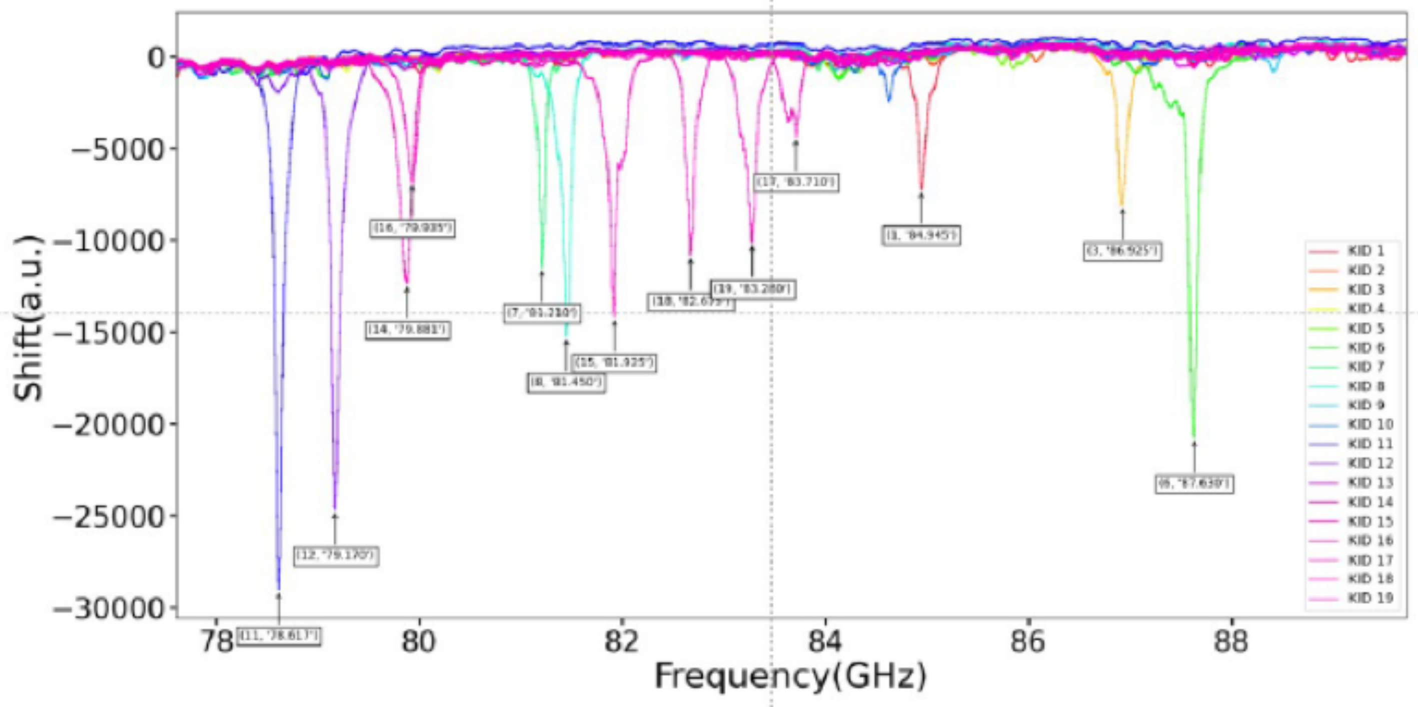


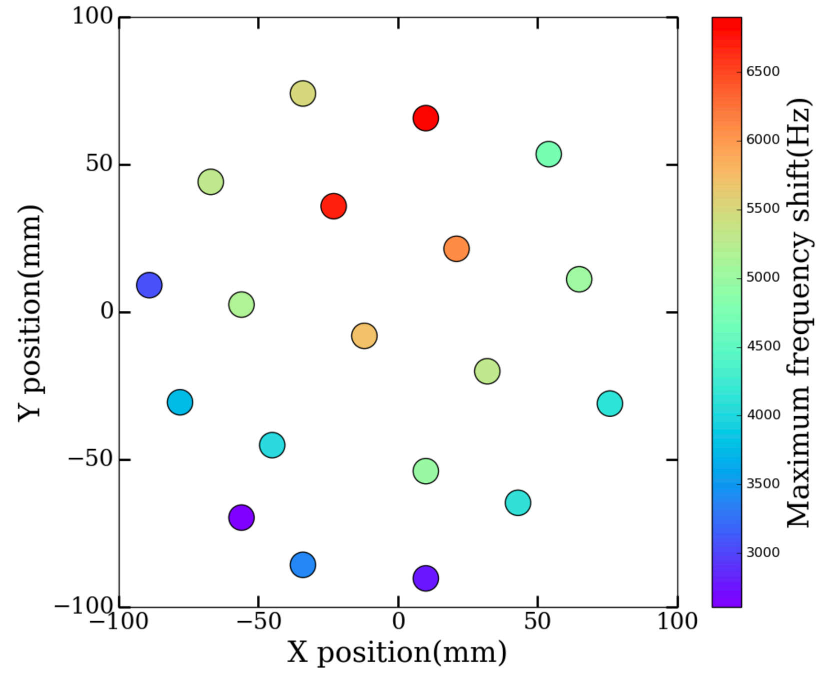
Spectral : 1 map only (13 minutes integration)

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)



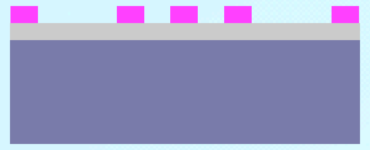




KIDs FABRICATION PROCESS

CLEAN ROOM

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



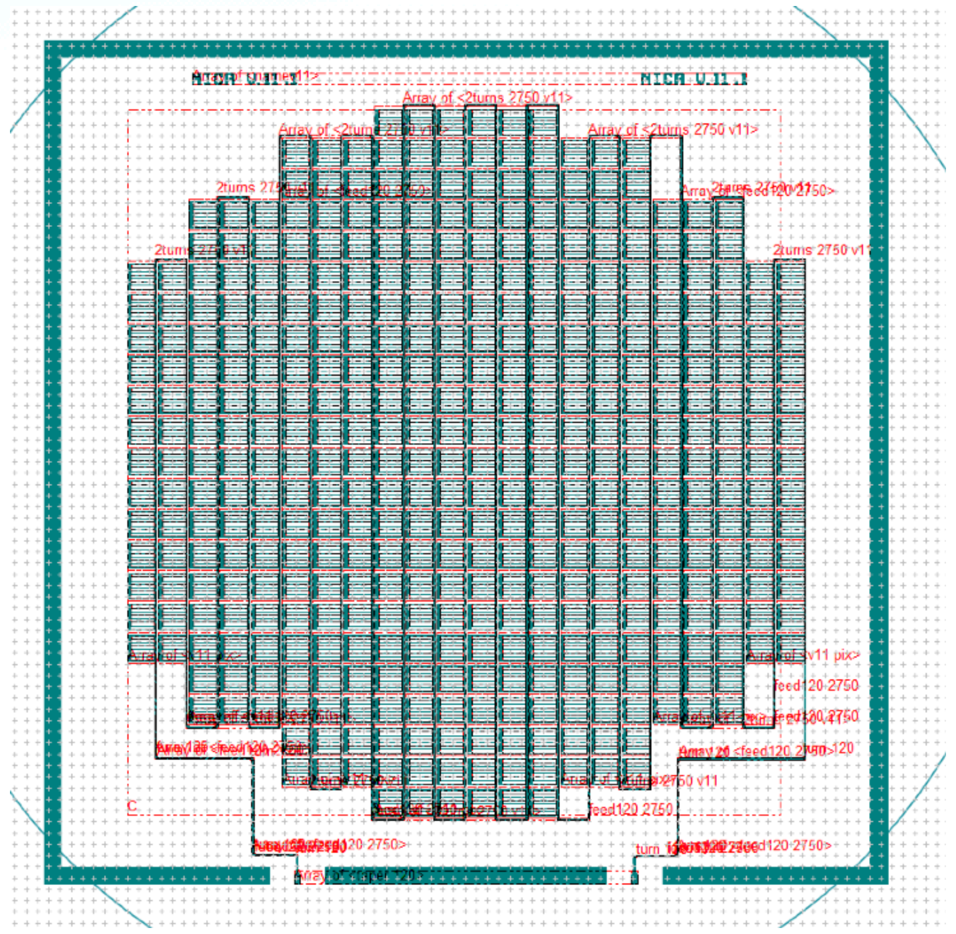
Impress the pattern through a **mask** with **optical lithography**

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

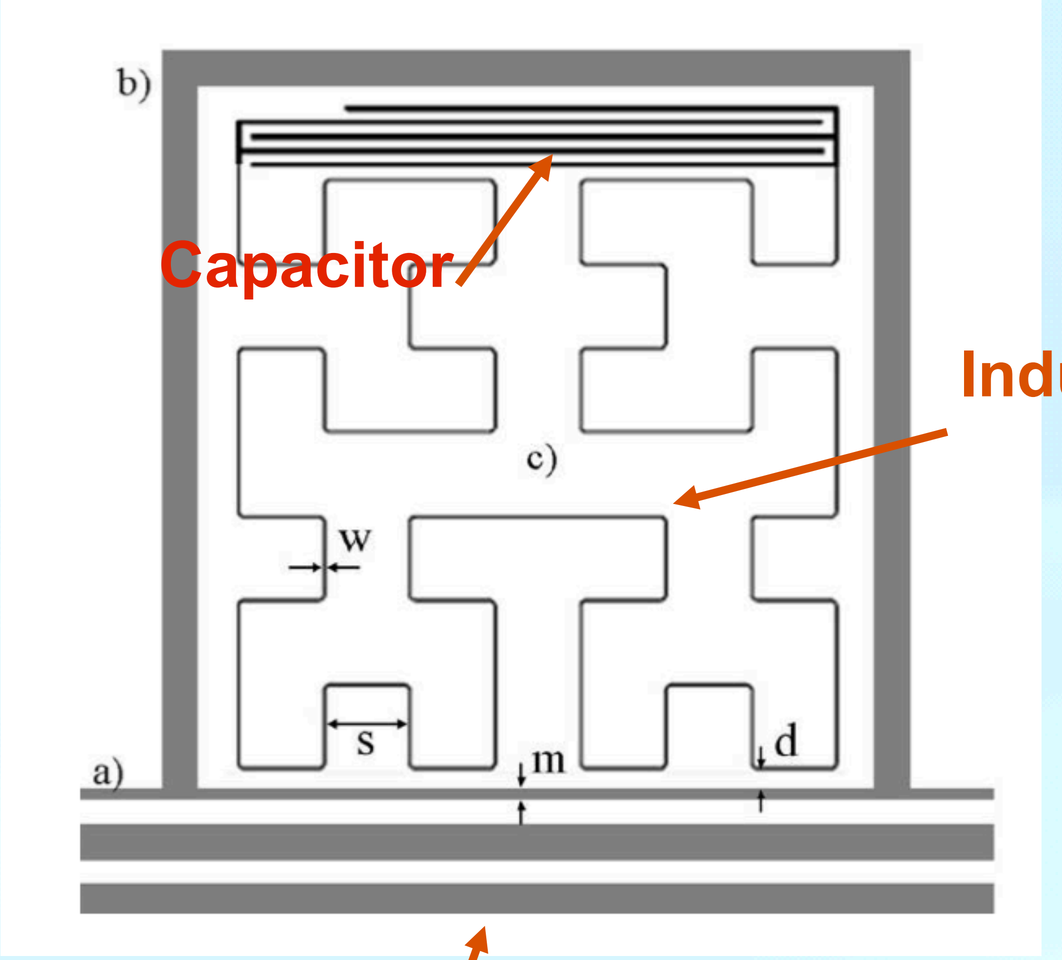
CONCLUSIONS AND PROSPECTS

- GIS LEKID technology has today a **TRL** high enough to be used for the next generation of CMB experiments
- **Sensitivity** for photometers and polarimetry applications is **in line with predictions**
- FTS spectroscopy analysis with **CONCERTO** is in progress, **first results** are coming out soon
- **On-chip spectroscopy** with KIDs seems promising for very large fields of view (ex. Line Intensity Mapping)
- Overall, **French KIDs technology** represents the **state-of-the-art** worldwide for mm and sub-mm astrophysics

MERCI !

The **K**inetic **I**nductance **D**etectors

Dual Polarisation
(3rd-order Hilbert pattern)
Roesch, M. et al. 2012, ArXiv 1212.4585



Inductance ($L_K + L_G$)

Feedline 50Ω

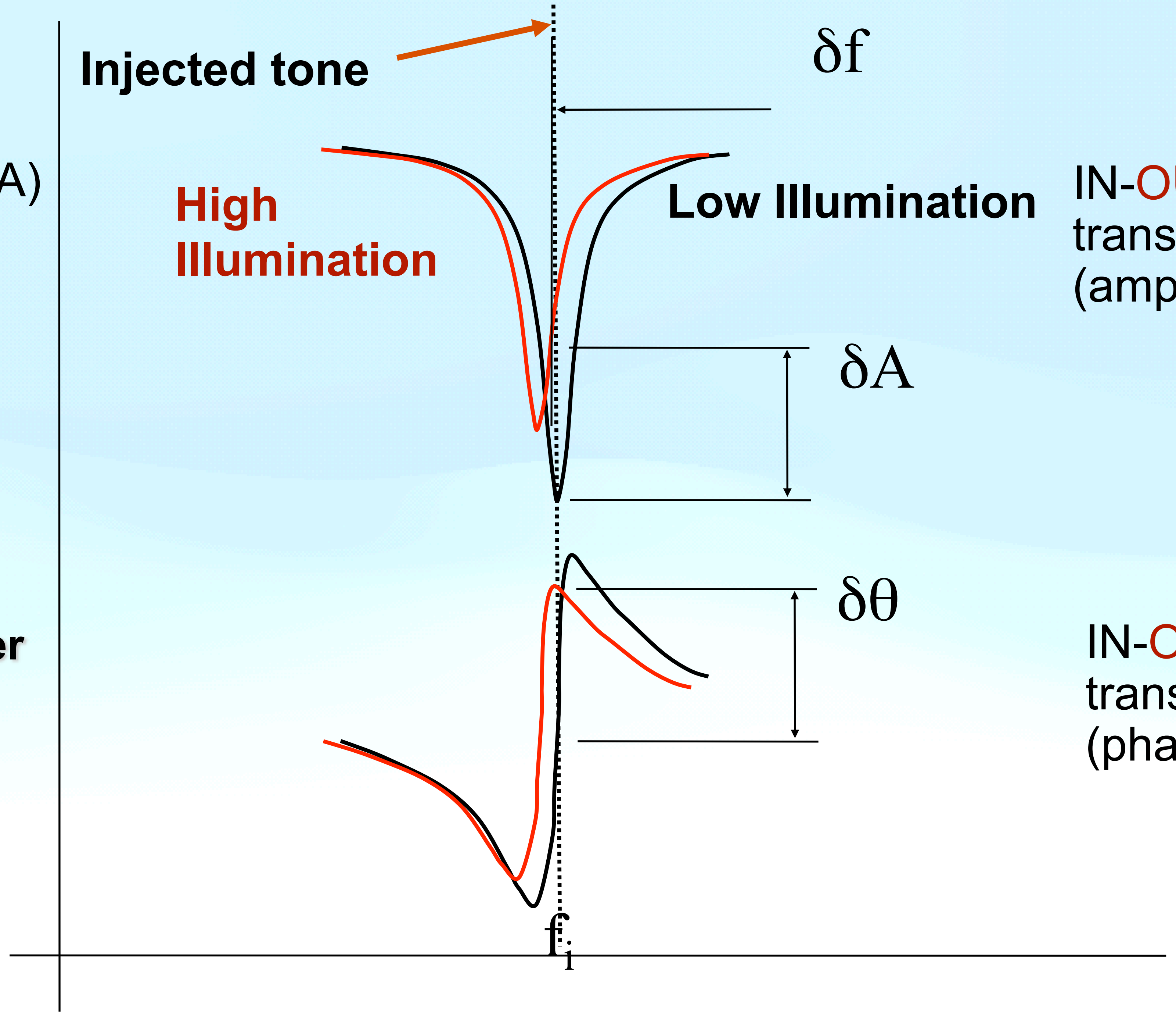
The incoming photons break Cooper pairs (supercurrent carriers) in a superconducting LC resonator → measurable signals

Dark, $T << T_c$

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

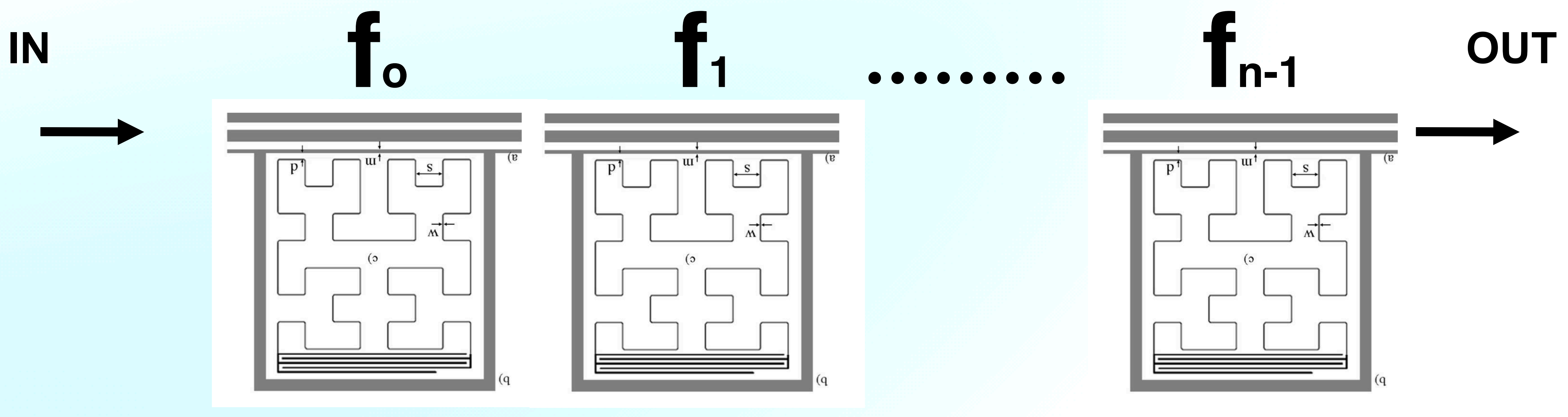
$\delta f \propto \delta L_K \propto \delta P$

δf = frequency shift
δP = incoming power



IN-OUT transmission (amplitude)

IN-OUT transmission (phase)



400 pixels are connected to a single transmission line