



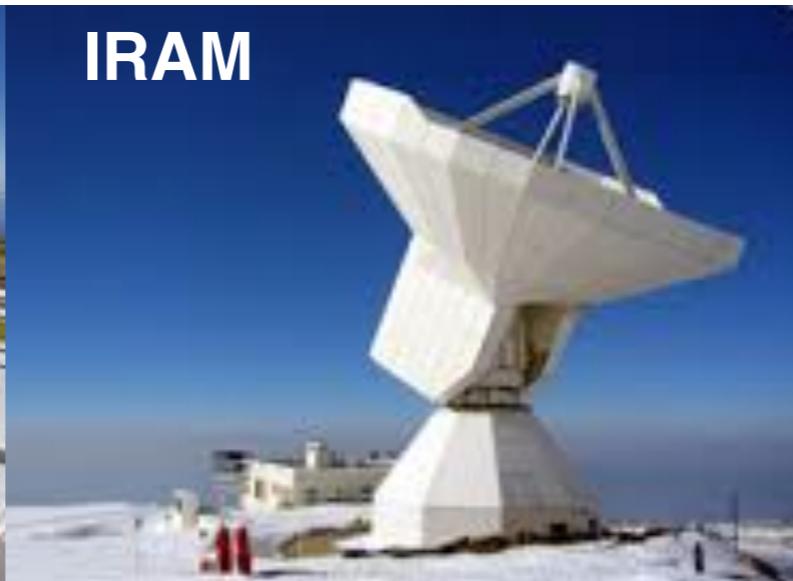
# ***Kinetic Inductance Detectors for millimeter and sub-millimeter cosmology***

GIS Grenoble Collaboration

**presentation prepared by A. Catalano and presented by F. Levy-Bertrand**



**Quijote**



**IRAM**



**APEX**

# The GIS Collaboration in Grenoble - *People*

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Alessandro MONFARDINI – Director of research  
Alain BENOIT – Director of research (Emeritus)  
Philippe CAMUS – Research engineer  
Martino CALVO – Research engineer  
Florence Lévy-Bertrand – Researcher  
\* \* Usasi CHOWDHURY PhD Student



Juan MACIAS-PEREZ – Director of research  
Andrea CATALANO – Researcher  
Olivier BOURRION – Research engineer  
Christophe HOARAU – Research engineer  
Julien BOUNMY – Research engineer  
Frédéric MAYET – Professor  
Laurence PEROTTO – Researcher  
\* Florian KERUZORE – PhD Student

## Funding:

- \* Labex FOCUS
- \* IRAM
- \* University
- \* CNRS



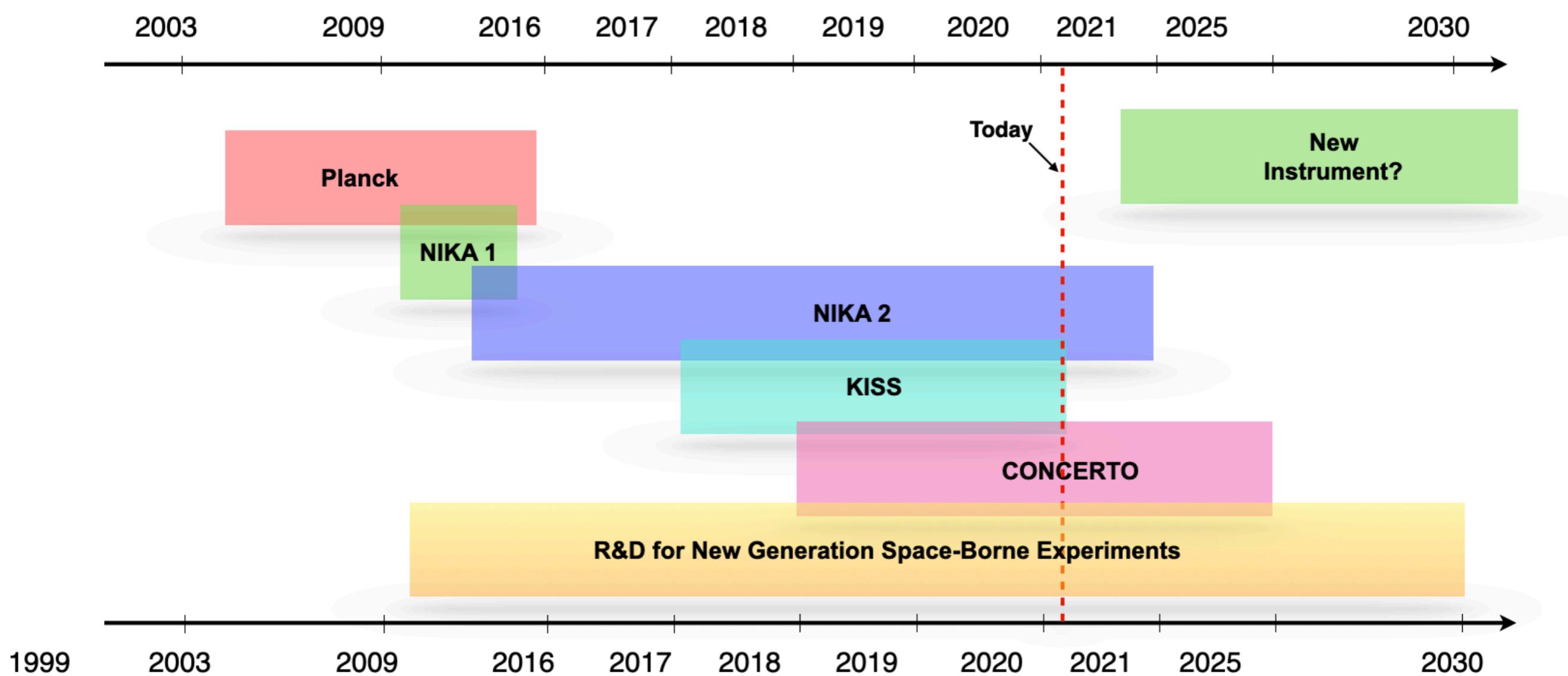
Karl SCHUSTER – Director  
Eduard DRIESSEN – Scientist  
Stefano BERTA - Scientist  
\* \* Johannes GOUPY – Research expert (CDD)



François-Xavier DESERT – Astronomer / Director  
Nicolas PONTHIEU – Researcher



# Our R&D activities are driven by real instruments



Most of this work has been developed in a strong collaboration between  
**Institut Néel (INP), LPSC (IN2P3), IPAG (INSU) and IRAM**.  
These three labs together with IRAM are consolidating through a GIS  
(*Groupement d'Intérêt scientifique*).

# The KID Collaboration in Grenoble - *Science Drivers*

## CMB science and re-ionization...

Scientific Requirements	
<b>CMB B-Modes</b>	high sensitivity → low r values multi-frequency → foreground High Control Polarisation Systematics
<b>SZ Effect</b>	high resolution mapping of distant clusters spectroscopy measurements → mapping thermodynamic properties
<b>Re-ionisation</b>	measurements of molecules lines at high red-shift high sensitivity mapping large sky areas

# The KID Collaboration in Grenoble

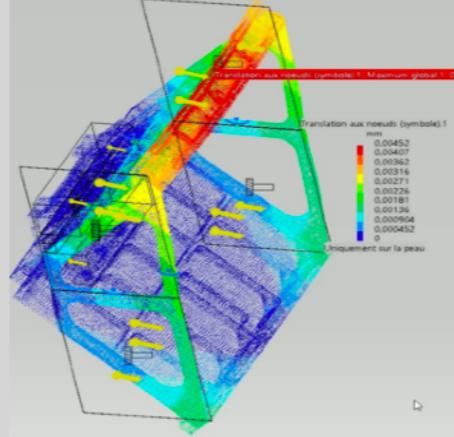
	Low Background (0.1-2pW)	High Background (5-70pW)
Low Frequencies (60-120 GHz)	Space Qualification	KISS
CMB frequencies (120-350 GHz)	Space Qualification	NIKA1/NIKA2/KISS/ CONCERTO
High Frequencies (350-1500 GHz)	Space Qualification	—

Extend KIDs range of application in terms of frequency coverage and dynamic range.

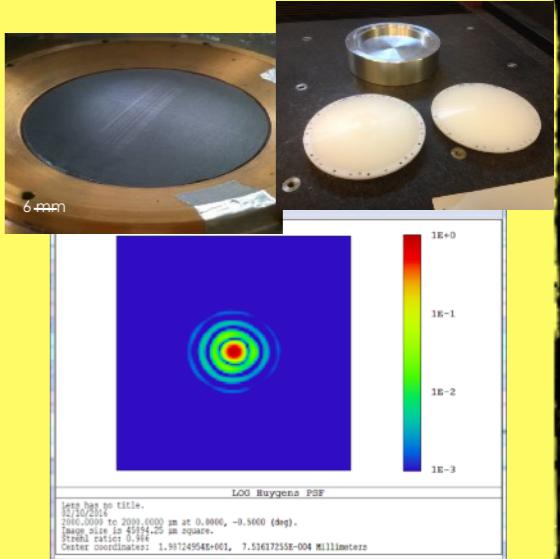
## Cryogenics



## Mechanics

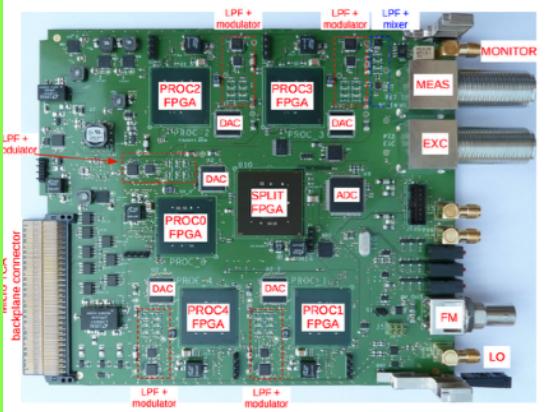


## Optics

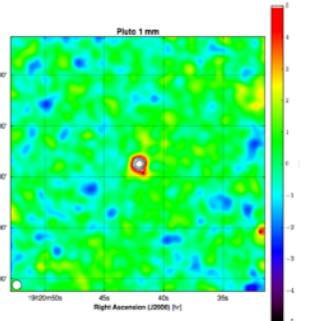
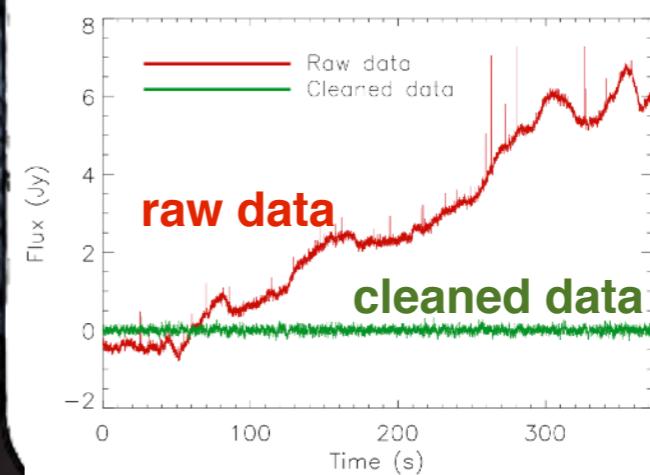


## The KID Collaboration

### Electronics



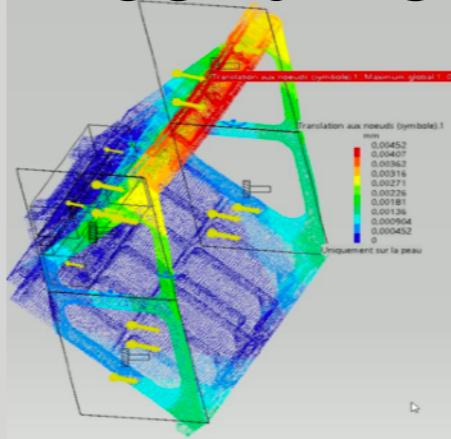
## Data Acquisition-Pipeline



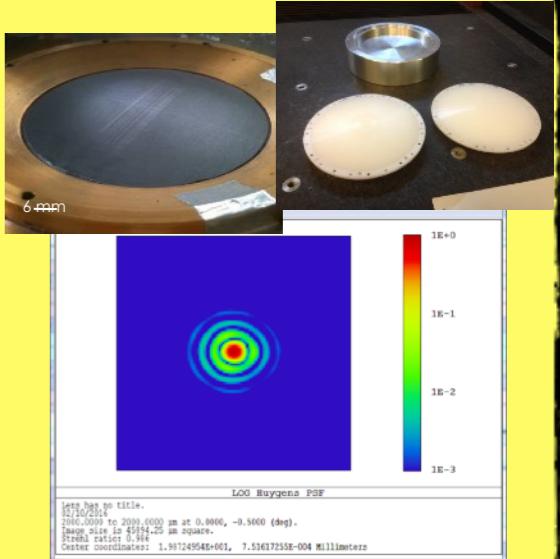
## Cryogenics



## Mechanics

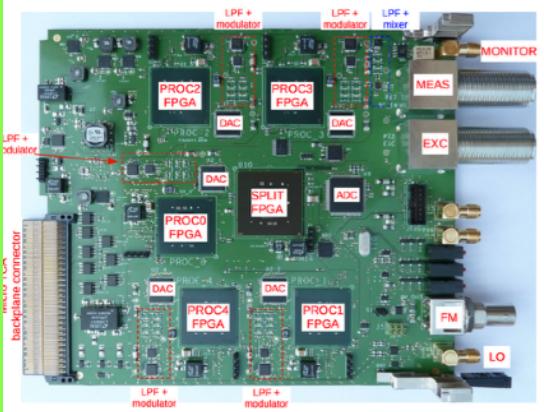


## Optics

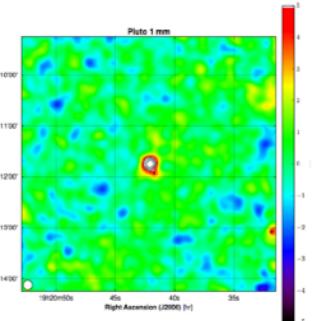
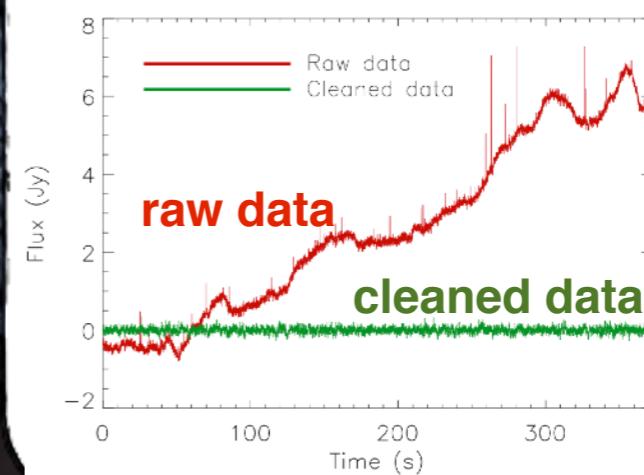


## The KID Collaboration

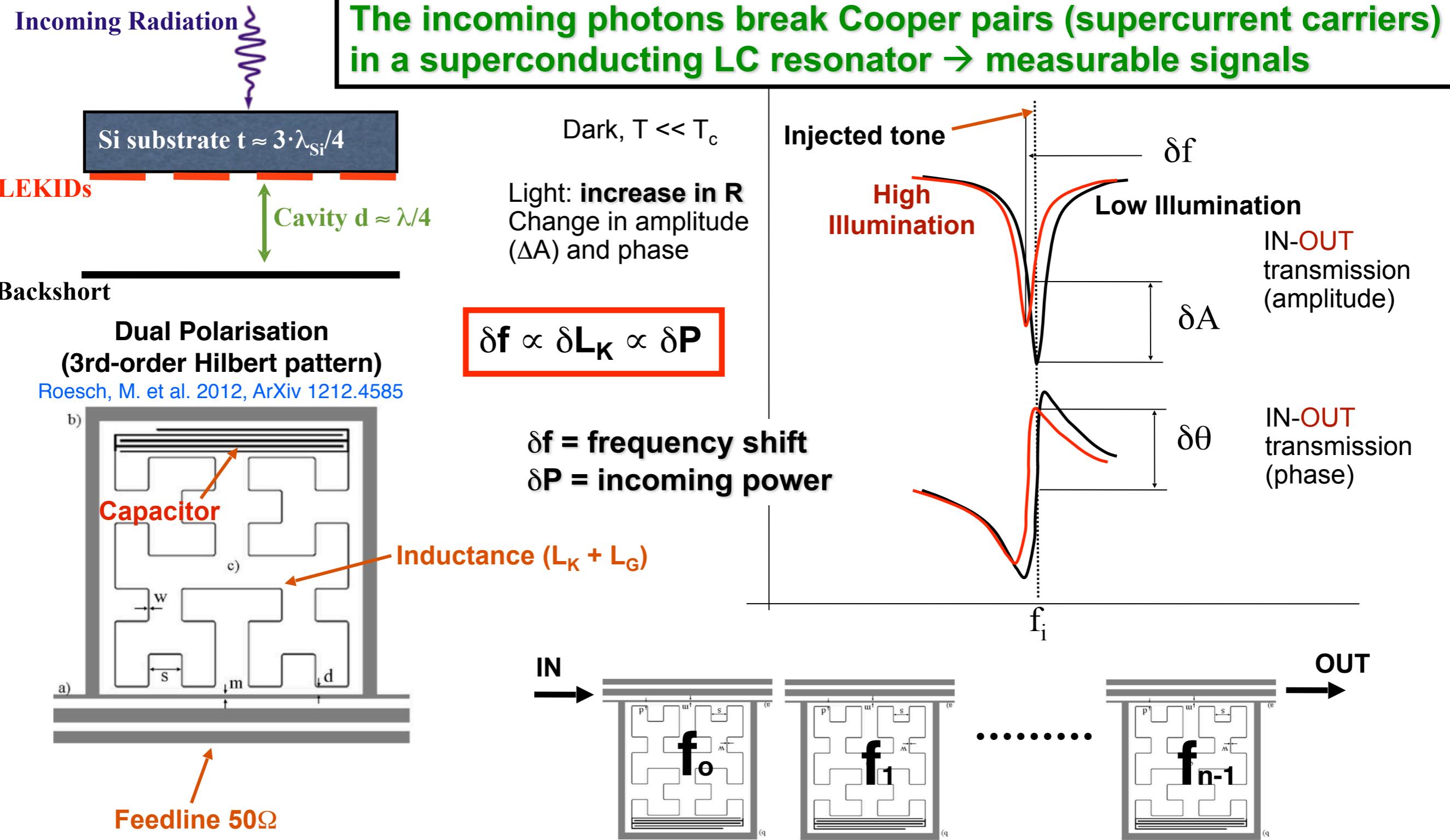
### Electronics



### Data Acquisition-Pipeline



# The Kinetic Inductance Detectors



# KID Technology

## Large efficiency due to simple fabrication process

Standard process for Al KIDs array on Si wafer:

- Fabrication of one array in few days
- Criticality : no defect on the feed line and low number of bad pixels



Evaporate a thin layer (18nm) of aluminium on a 4 inch silicon mono crystalline and high purity ( $> 1000\Omega\cdot\text{cm}$ ) wafer

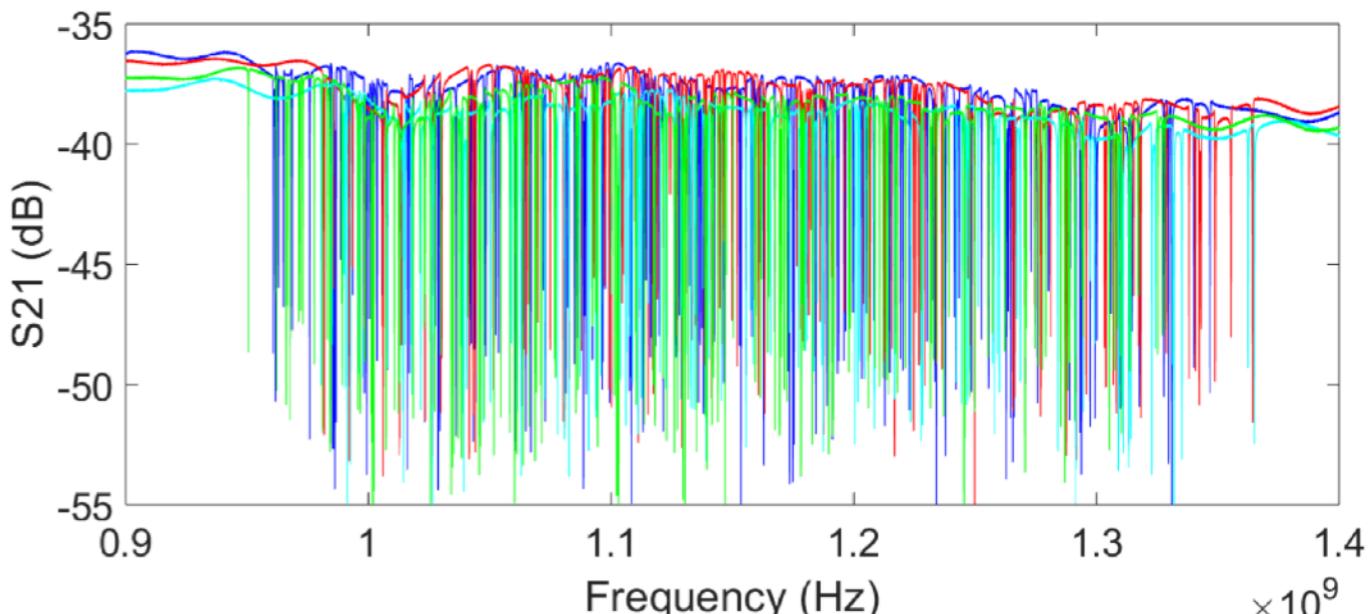


Draw the patterns with optical lithography and the mask



Etch the aluminium layer with wet attack and strip the resin

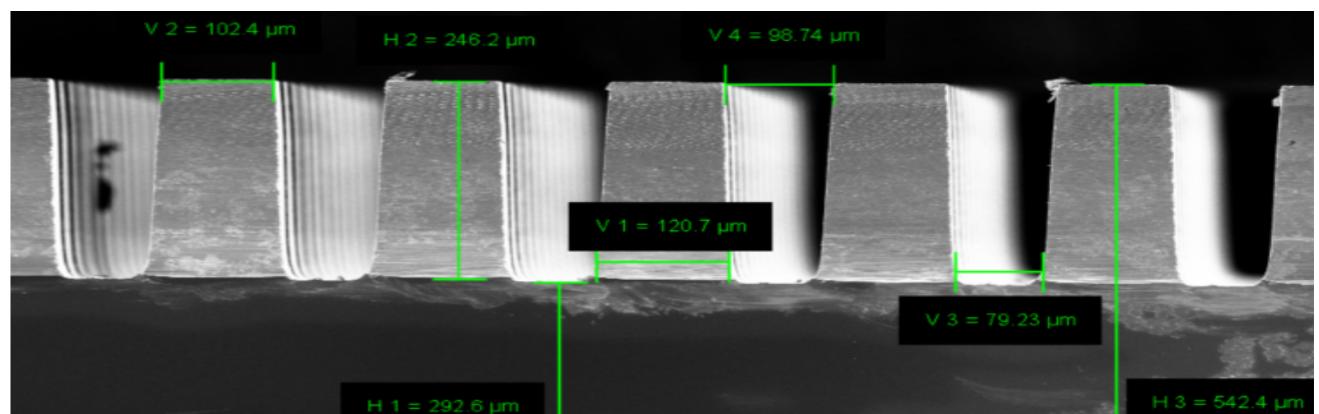
After these critical steps realized in clean room, arrays are diced and mounted in dedicated holders and connected by micro-bonding



Optical adaptation layer on the bottom of the array to increase the absorption

- Reduce the Si density at 30% by dicing
- Adapted the effective index ( $n$ )

$$n_{\text{vide}} = 1 < n_{\text{adapt}} \sim 2 < n_{\text{Si}} \sim 3.4$$



# KID State-of-the-Art

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## USA:

- **Astrophysical applications:** Caltech, Santa Barbara, Goddard, NIST, Arizona, Columbia (NYC), etc... (cameras & REU)
- **Quantum Information Science :** Yale, Santa Barbara, ....

## Europe:

- **Cameras:** NIKA , AMKID, OLIMPO (from 100 to 900 GHz)
- **R&D Collaboration :** France, Italy, Spain, UK, Netherlands
- **KID-REU :** NIKEI, NIXA, FFTS-Bonn, SRON

## France:

- **Grenoble (Néel-LPSC-IRAM-IPAG):** NIKA project, R&T CNES
- **CSNSM :** Material development for low frequency channel - **APC :** Antenna-coupled

# From 30 to 8000 pixels

2009

30 pixels



Roach (Berkley) REU

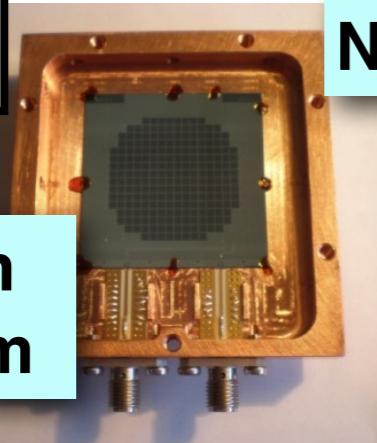


FIRST LIGHT  
ON MARS

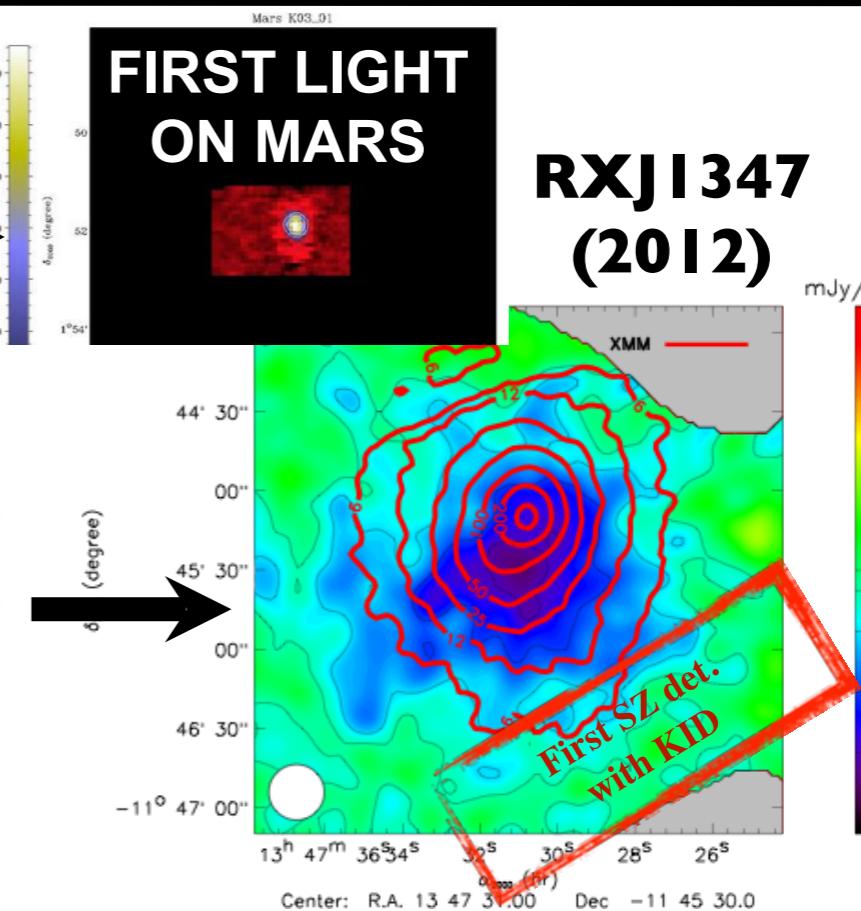
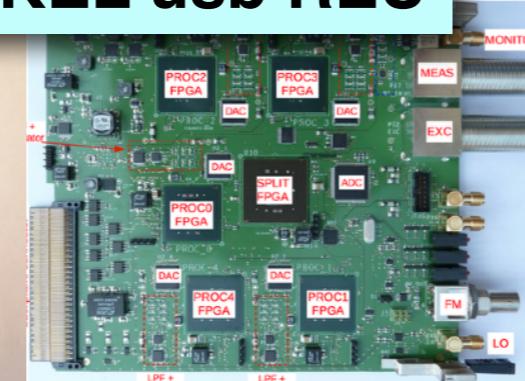
RXJ1347  
(2012)

2010-2013

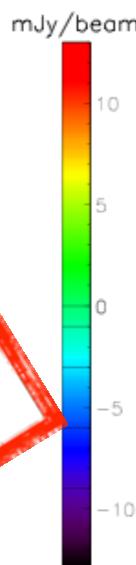
190 pixels @ 1mm  
125 pixels @ 2mm



NIKEI usb REU

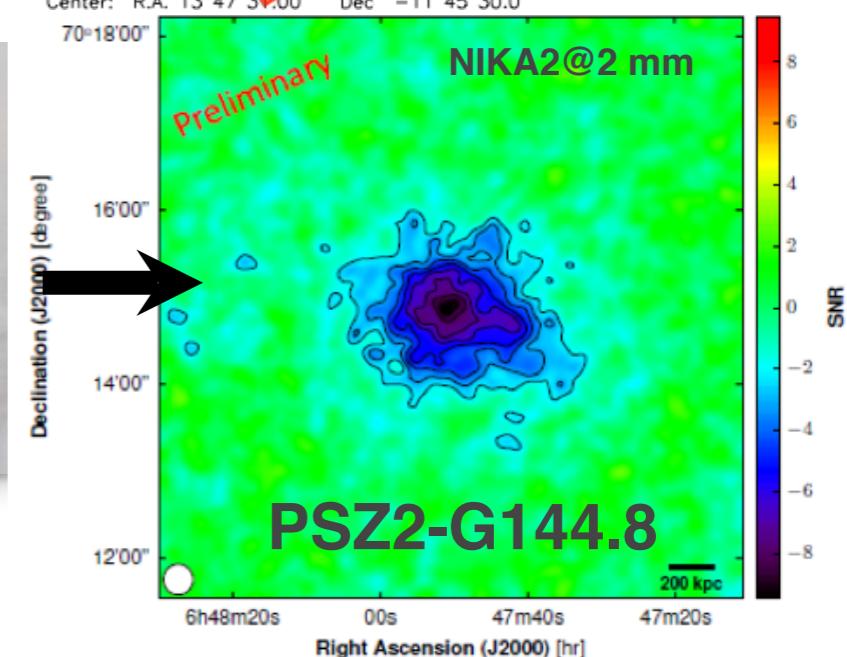
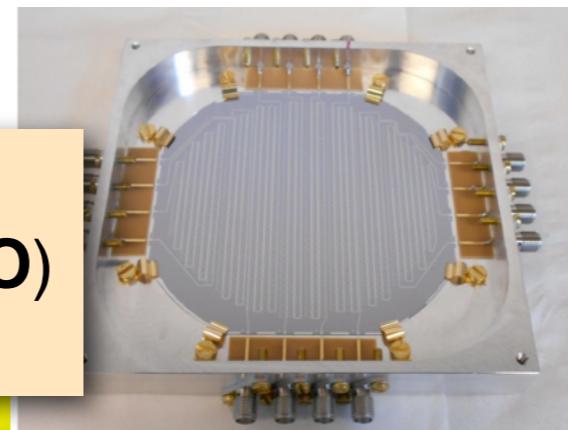


44° 30''  
00''  
46° 30''  
-11° 47' 00''  
13h 47m 36s 34s  
Center: R.A. 13 47 36.34 Dec -11 45 30.0  
First SZ det.  
with KID



2014-2020

1140 x 2 pixels (NIKA2)  
2142 x 2 pixels (CONCERTO)  
NIKEI AMC



Dec 16'00'' 14'00'' 12'00''

Right Ascension (J2000) [hr]

PSZ2-G144.8

SNR

8

6

4

2

0

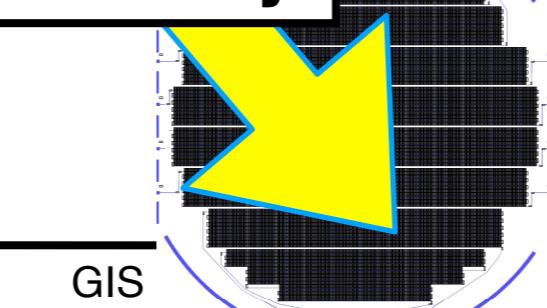
-2

-4

-6

-8

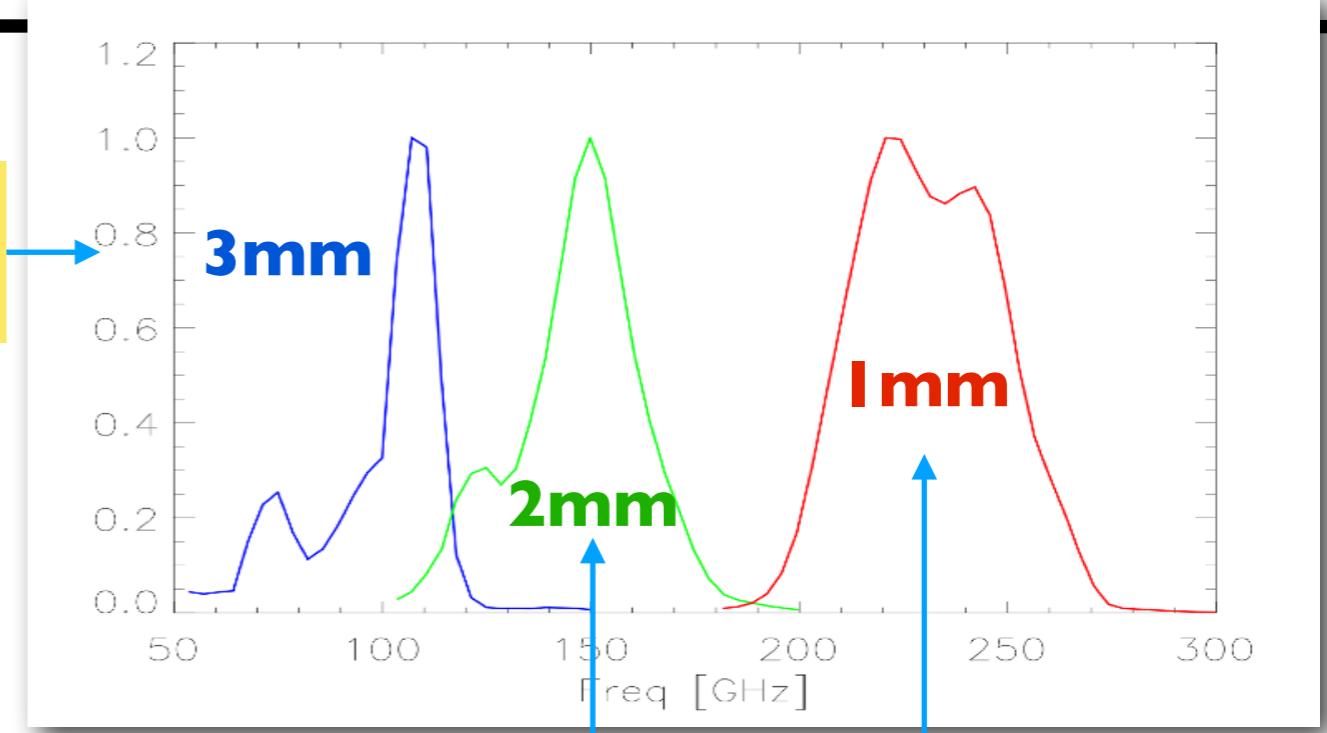
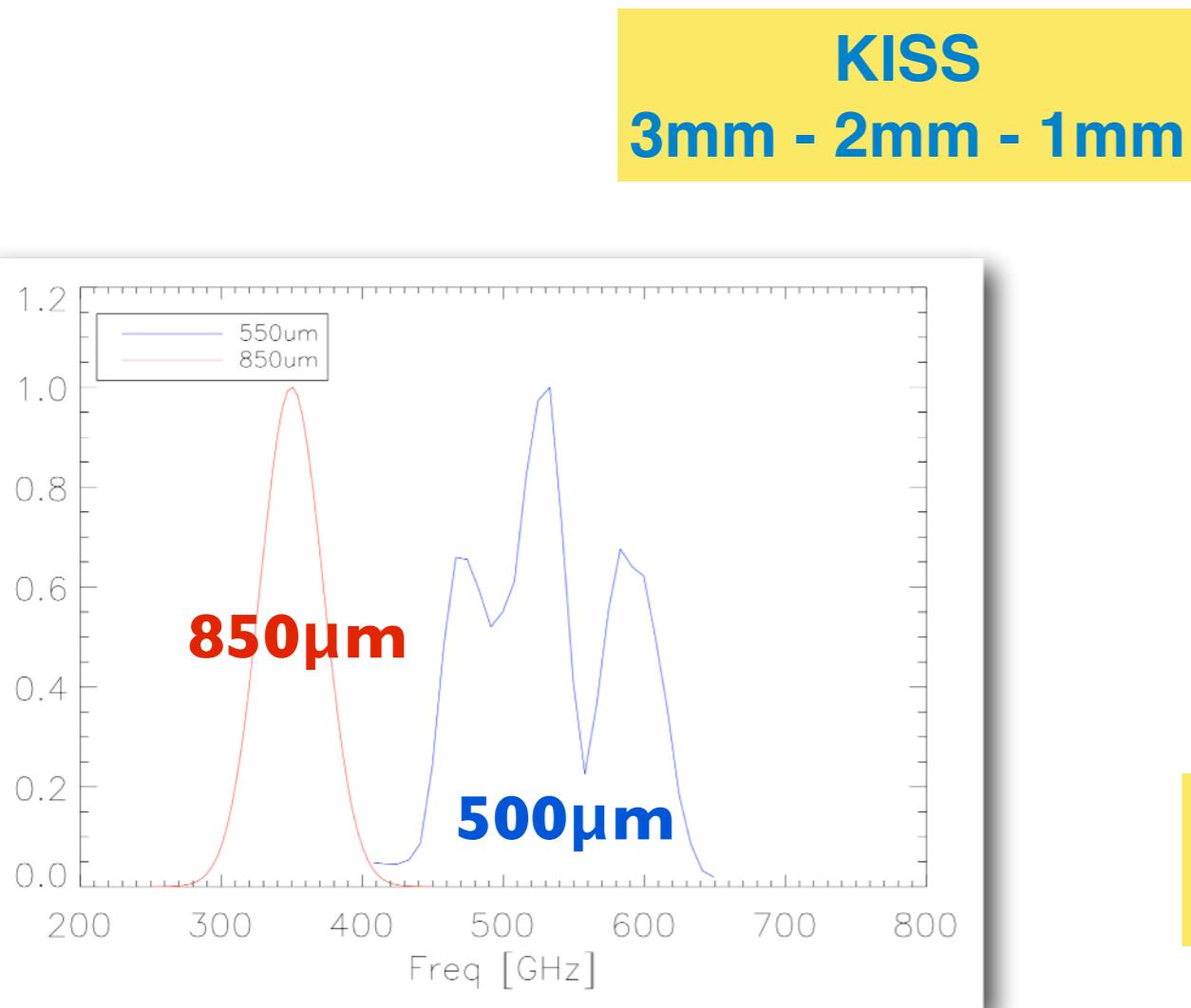
2020-Today



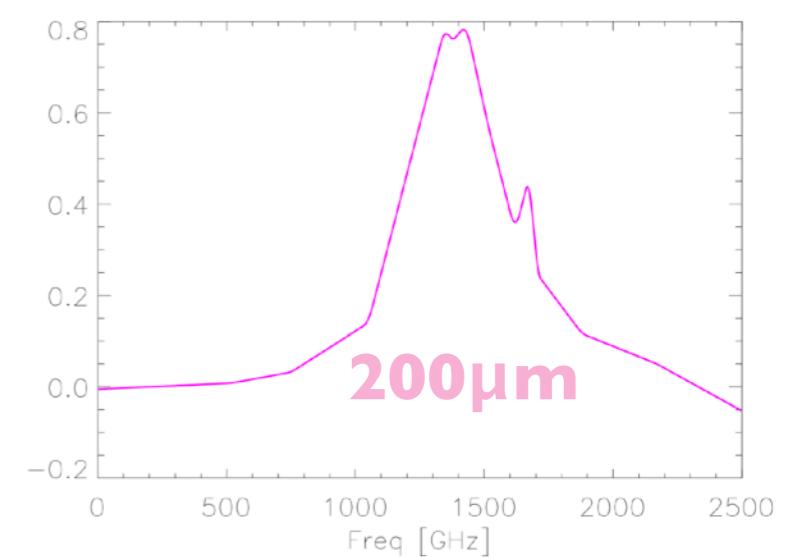
GIS

Prototype 8000 pixels

# Maturity in terms of Spectral Response



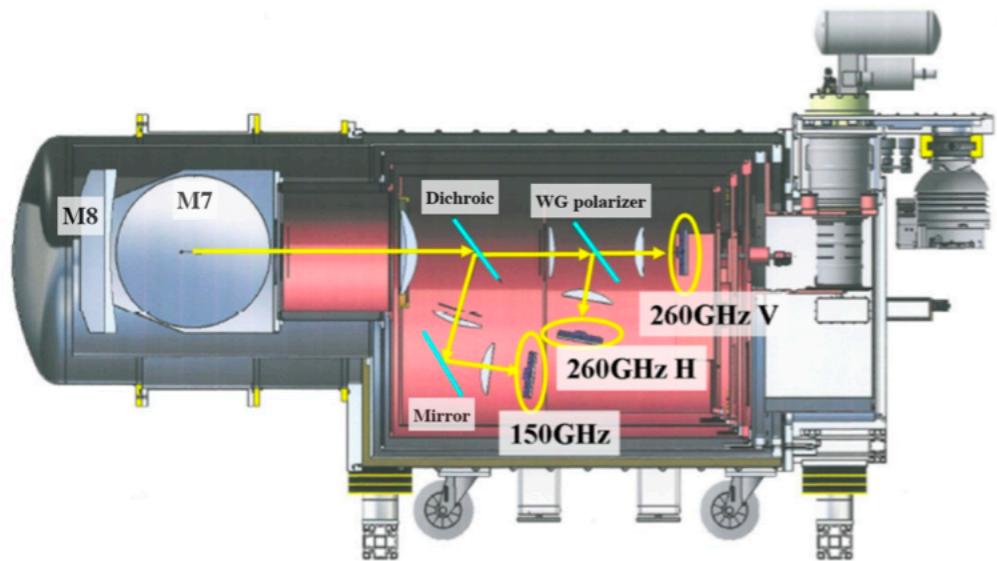
Demonstrators for Space  
3mm - 2mm - 1mm - 850 μm - 500 μm - 200 μm



# Maturity in terms of Sensitivity : Ground

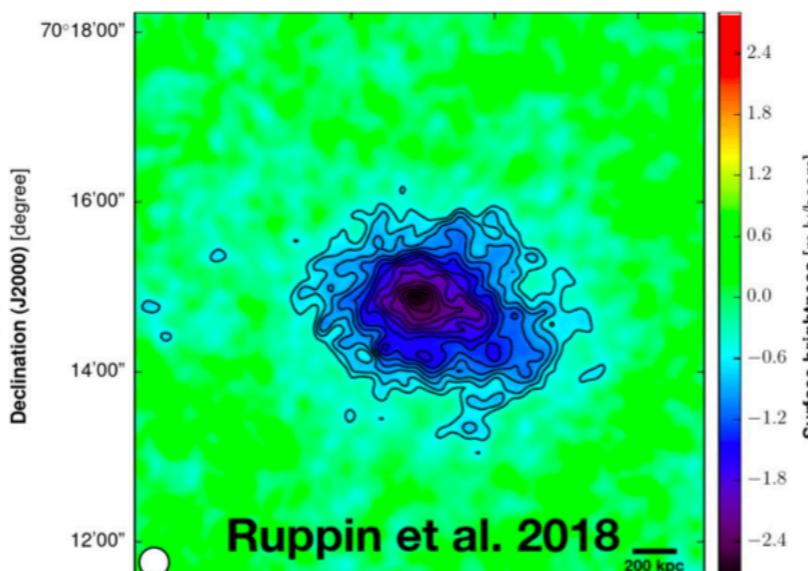
**NIKA2 is making science!**

**The instrument is installed at the 30 m IRAM since September 2015. On September 2017 ended officially the Commissioning Phase.**



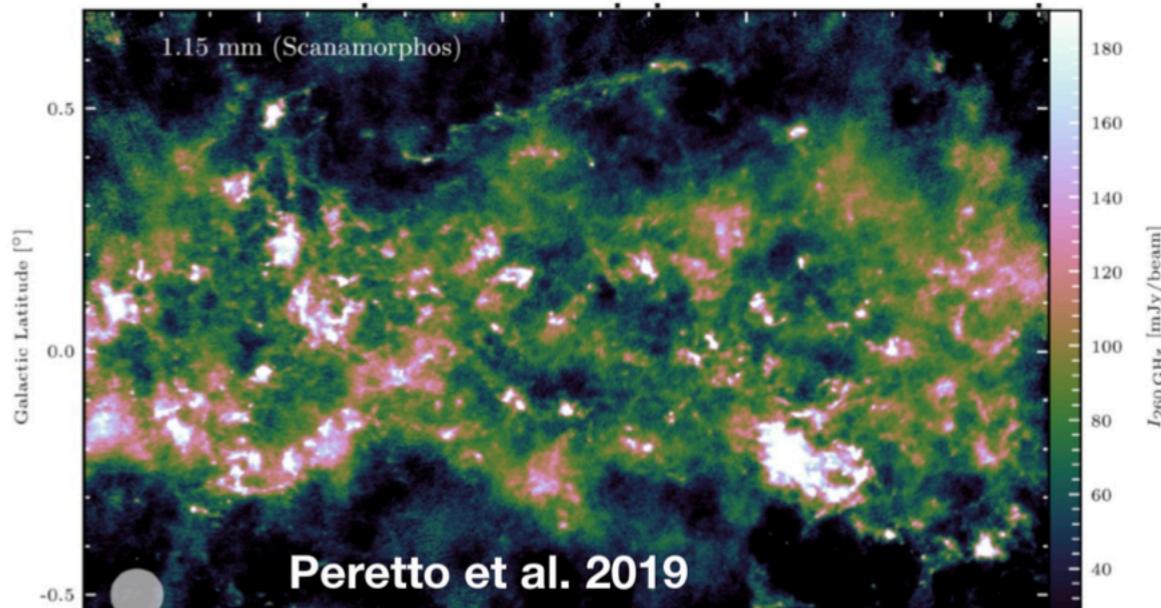
	Array 1&3	Array 2	Reference
Reference Wavelength [mm]	1.15	2.00	
Reference Frequency [GHz]	260	150	Sect. 8.1.1
Frequency [GHz]	254.7&257.4	150.9	Sect. 2.5
Bandwidth [GHz]	49.2&48.0	40.7	
Number of designed detectors	1140&1140	616	Sect. 2.3
Number of valid detectors <sup>a</sup>	952&961	553	Sect. 5.3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

**PSZ2-G144.8 @ 2mm**



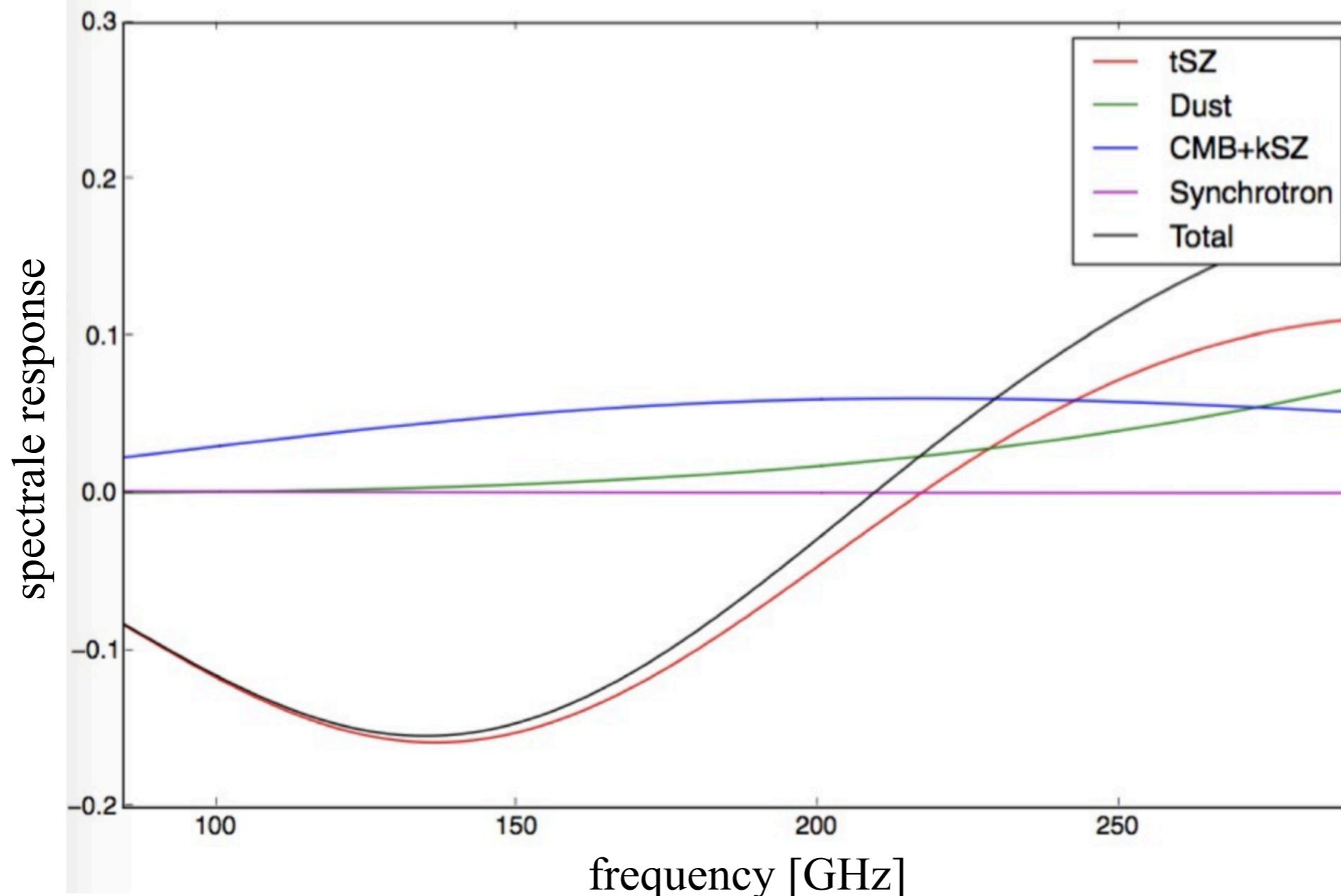
The NIKA consortium redeemed as guaranteed time observations (GTO) of 1300 h in 5 large programs.

**Galactic Plane (124 field) @ 1.2mm**



# After NIKA : Low Resolution Spectroscopy

Spectroscopy techniques can be used to separate different components and extract physical informations from spectral distortions: pressure, temperature, density, mass, LOS velocity.



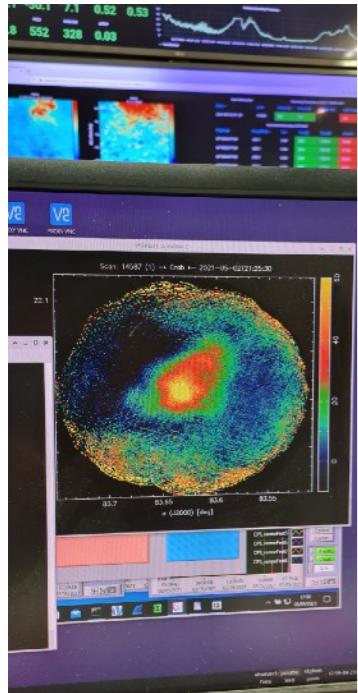
# KISS & CONCERTO

## Prototype - KISS

Quijote Telescope (2.2m) - Tenerife



Extended Source CRAB  
(2.5 minutes Integration)



APEX (12 m)

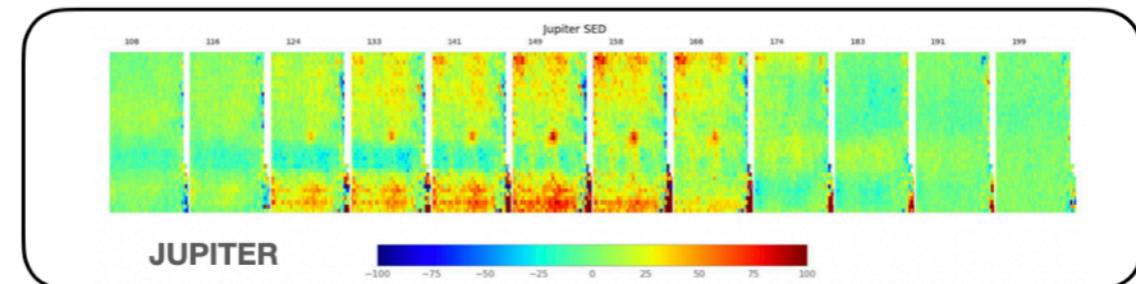


ATACAMA -Chile

Concerto has been installed at 12m  
APEX telescope in April 2021  
(and 3 weeks commission phase  
until now)

Installed since end of 2018  
Dismiss in September 2021

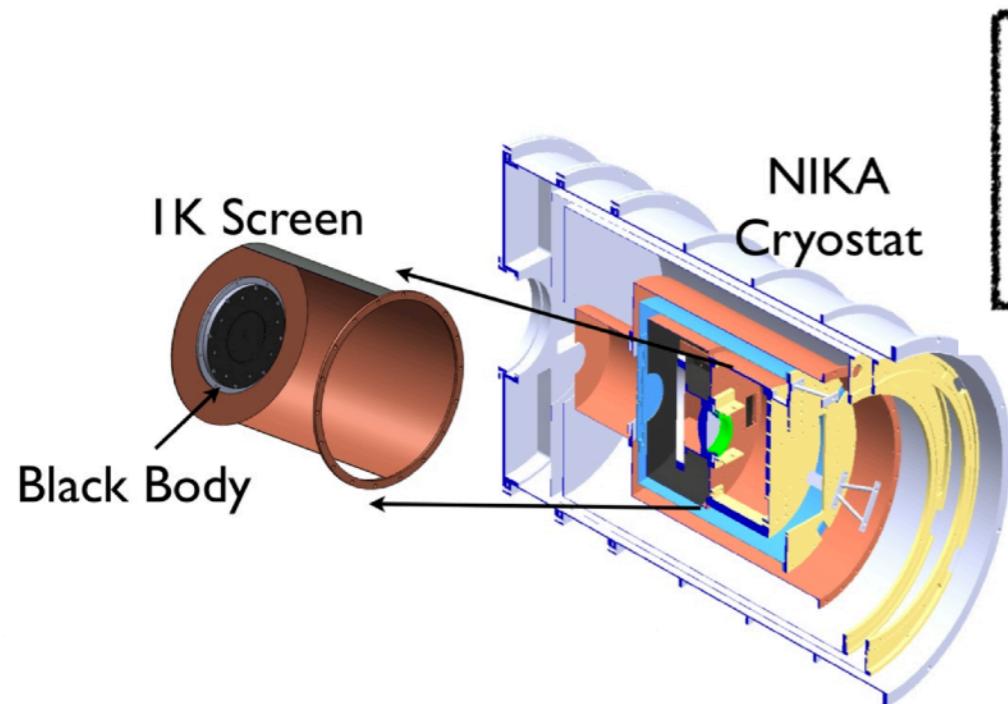
Spectroscopy



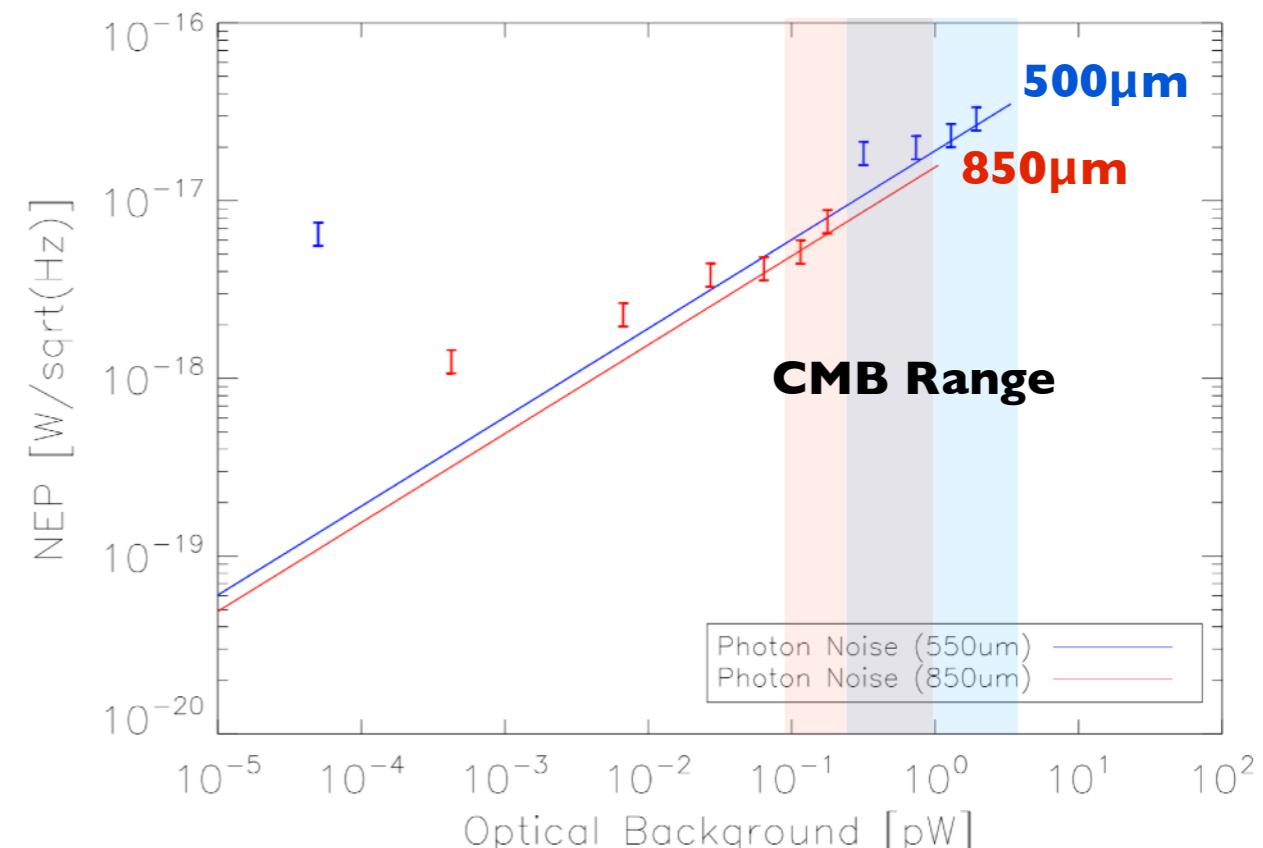
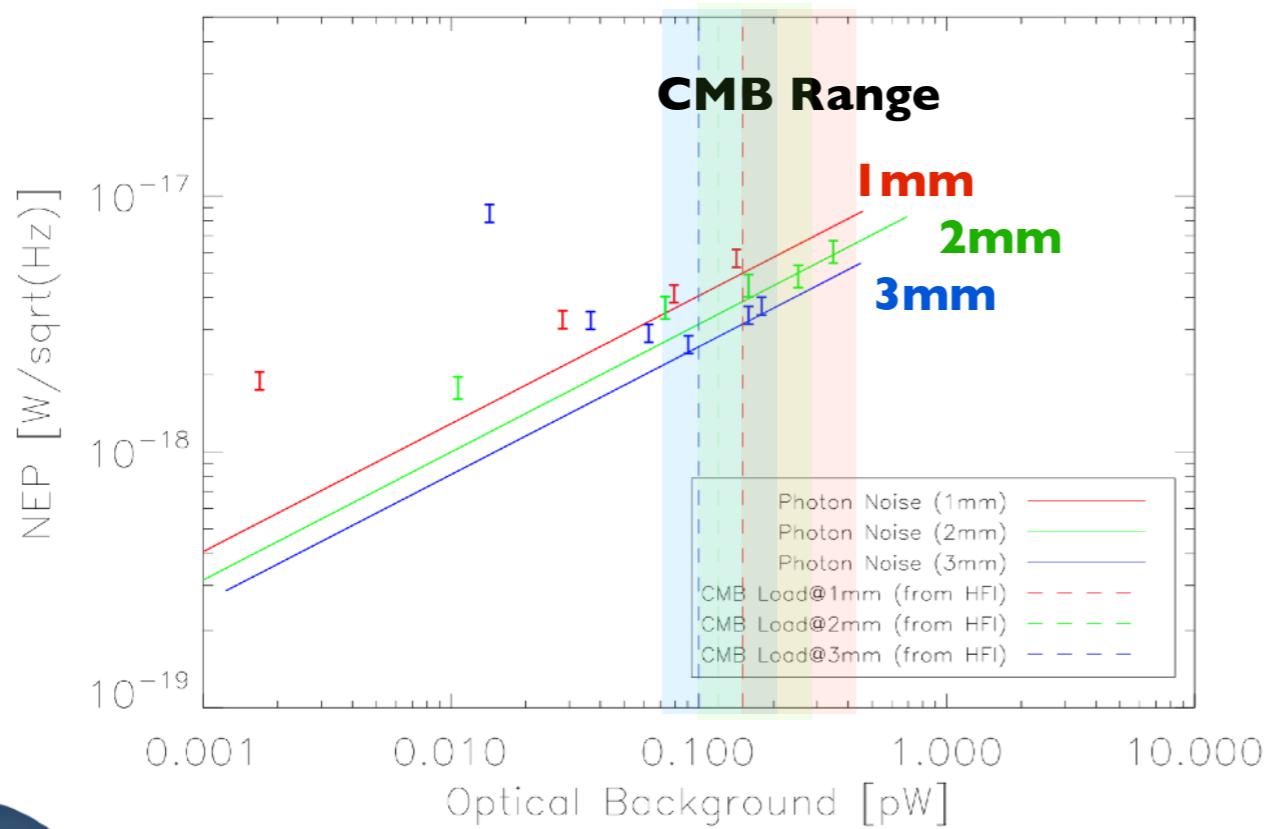
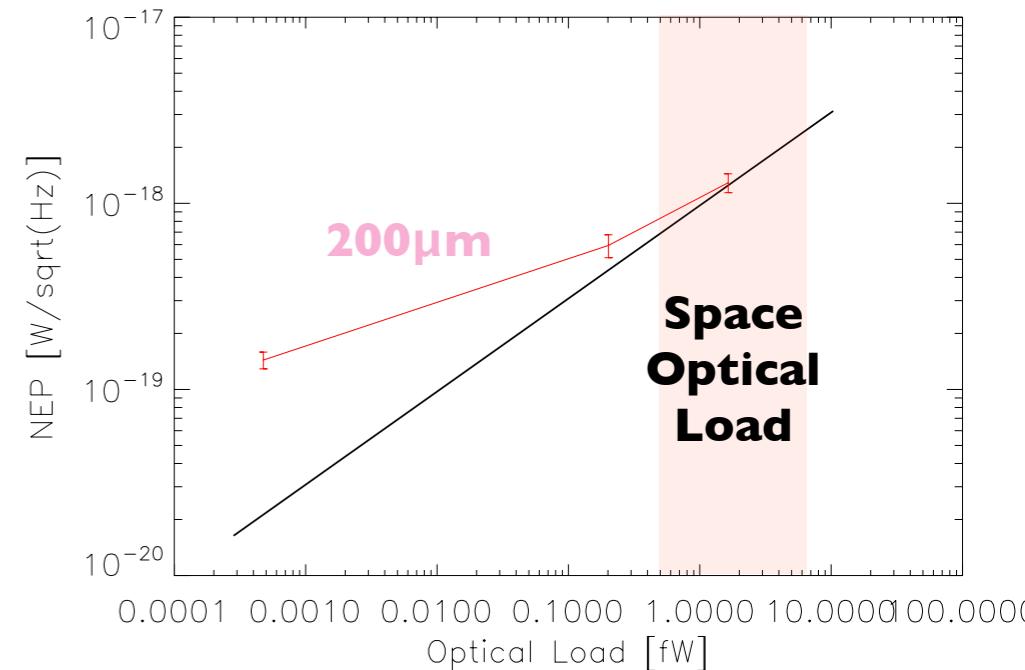
CONCERTO Installed! (April 2021)



# Maturity in terms of Sensitivity : Space



Under space typical background conditions KID show NEPs in line with CMB photon noise.

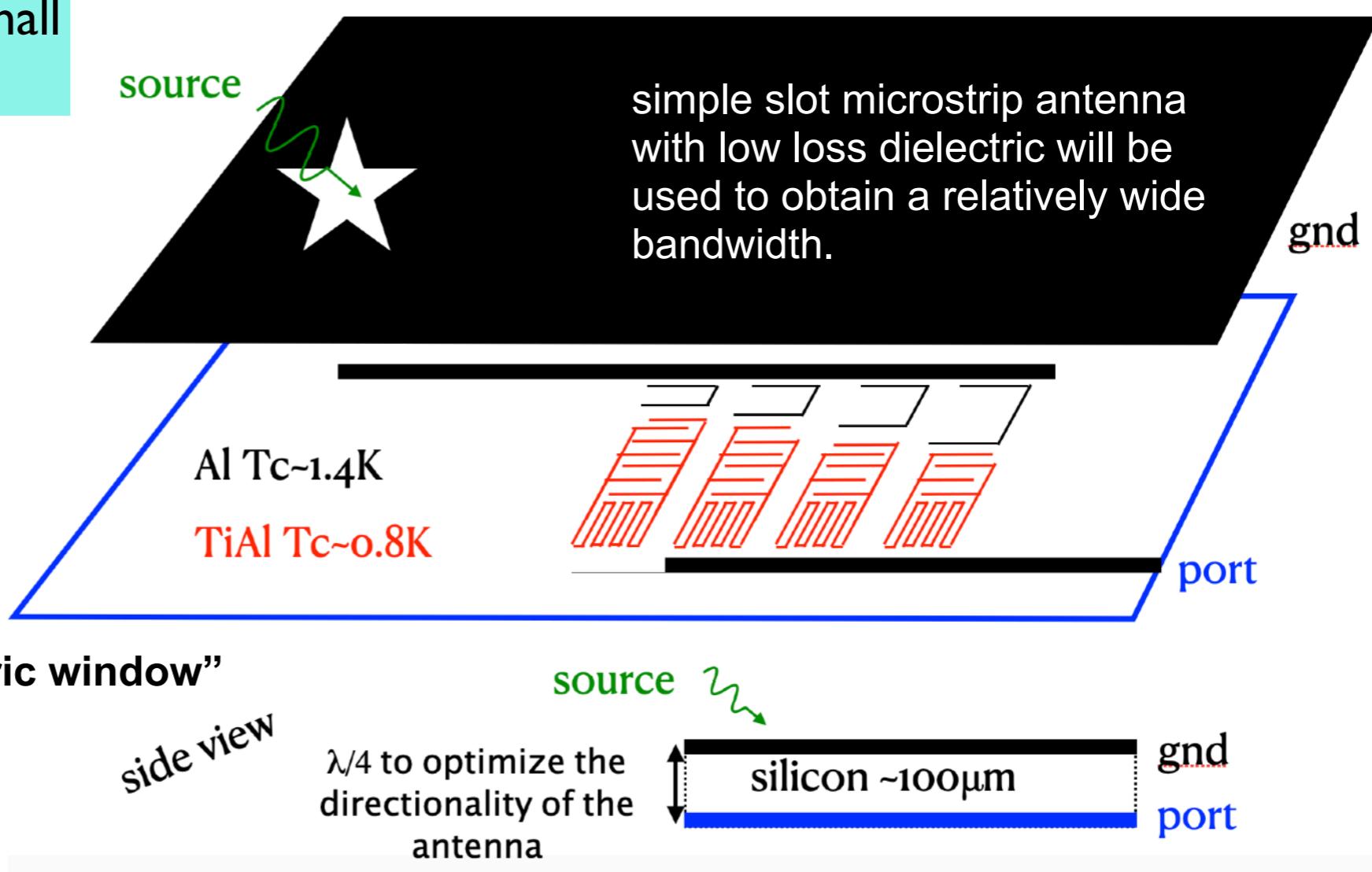


# On Chip KID Spectrometer R&D

**Mid-Term/Long-Term Timescale:** we develop in parallel on chip spectrometer using KIDs .  
PhD Thesis dedicated (Usasi CHOWDHURY)

**Goal:** improve the sensitivity and spectral resolution for future instruments at least for small patches of the field-of-view

The first design, in the range 80 GHz to 110 GHz, i.e. the so-called “3-mm atmospheric window” is already in development.



# Plan and Perspectives

The goals of our development is directly related to the preparation of the next generation instrument dedicated to sky observations in the (sub)millimeter domain.

- **Short-term goal (2021-2023) :**

- Maintaining activity with existing instruments NIKA2 and CONCERTO. Ensuring upgrades to increase the performance.
- Design, simulation and first prototype fabrication of on-chip spectrometers.

- **Mid-term goal (2023-2025) :**

- Begin studying the design for a S4-like instrument.
- Development of first large arrays of on-chip spectrometers.

- **Long-term goal (2025-2030) :**

- Be ready to deploy S4-like experiments.
- Be a valid candidate for covering the focal plane of the next generation space mission.