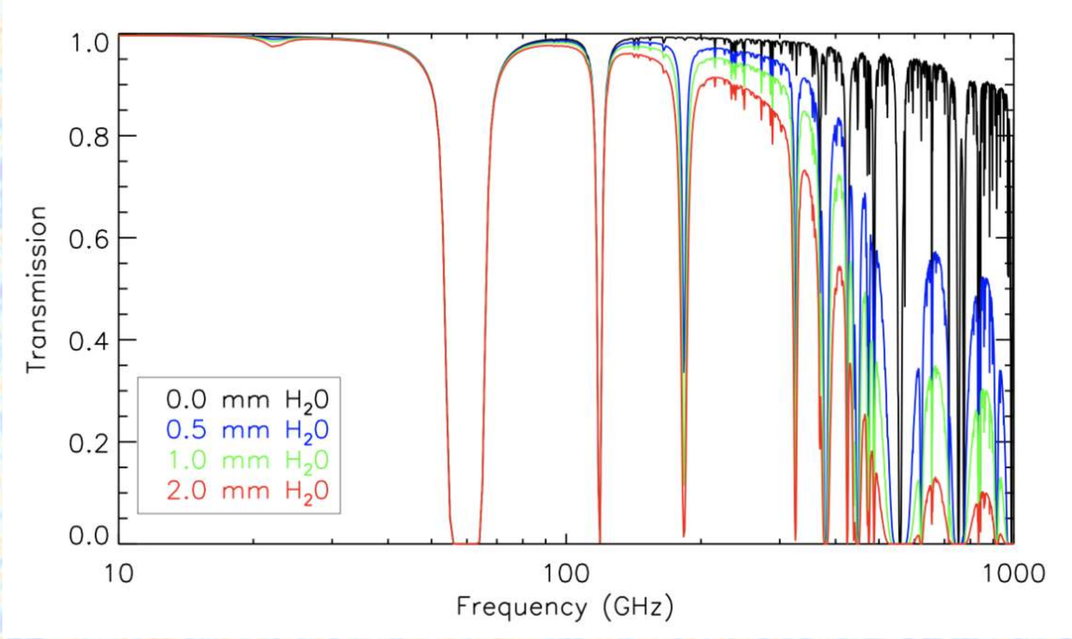
Observations of the early Universe at millimeter wavelengths: The Grenoble GIS Contribution

Millimetre Wavelength Science

Millimetre and Sub-Millimetre astronomy is a recent branch of astronomy.
It was only in the 70s that the receivers became sensitive enough to detect the millimeter waves originating from space. Since then, this observing technique has become a key tool of investigating the universe.

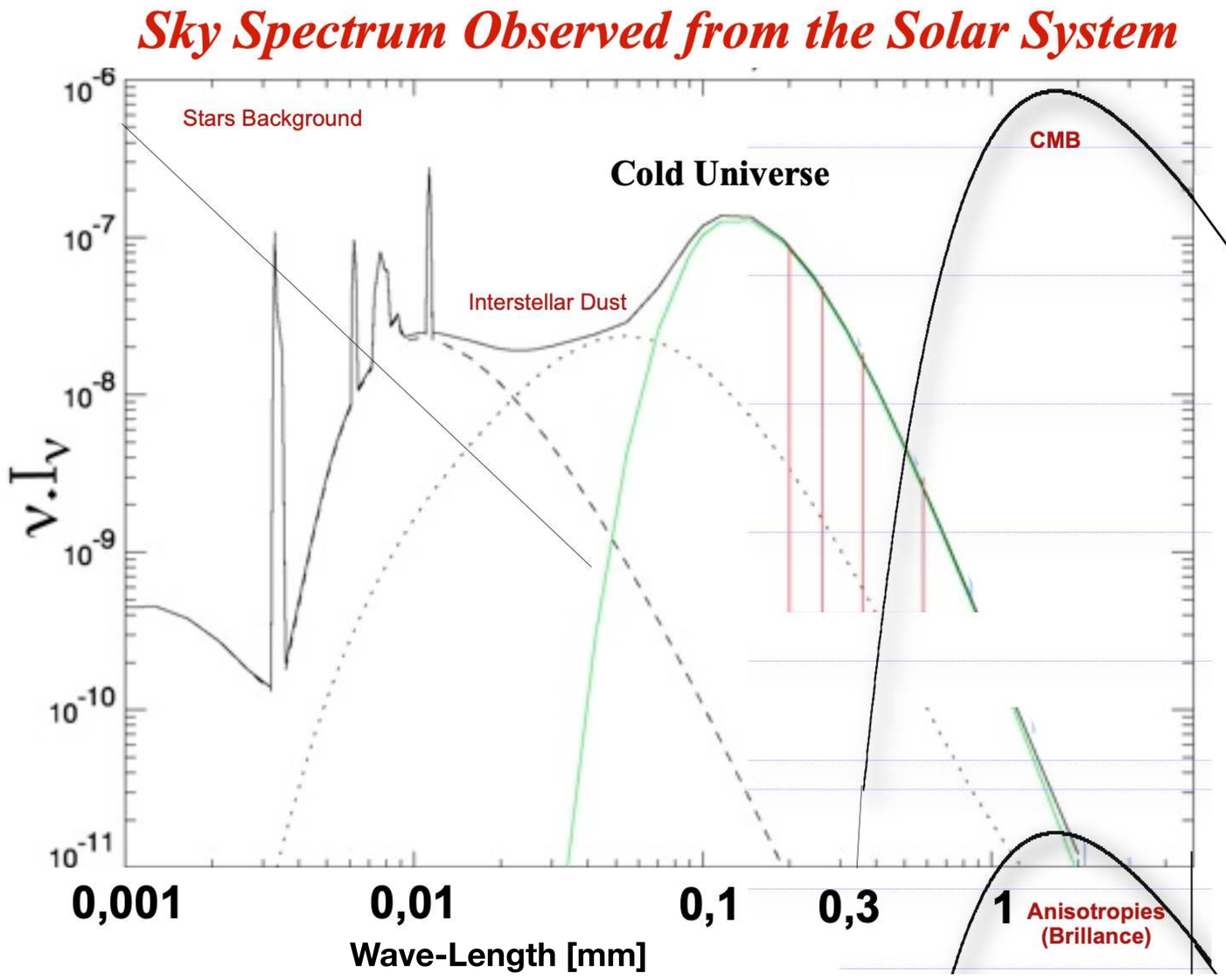
Atmosphere (for ground-based Obs.)



Peculiar Characteristics:

- **Cryogenics Detectors**
  (High impedance Bolometers, Superconductor Detectors)
- **High Altitude observations or Space.**

Why in the Millimetre Wavelength range?



Cold Matter Emission

- *Typical Energy involved in Molecular Transitions*
- *SED of Galaxies.*
- *Dust Emission.*
- ***Cosmic Microwave Background Emission***

The CMB experimental Context

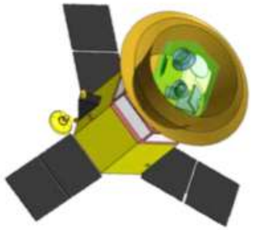
Space-borne Experiments

1st Generation (1989-1993) - COBE

2nd Generation (2001-2010) - WMAP

3rd Generation (2009-2014) - Planck

4th Generation (2030?) - LiteBIRD



Ballon Experiments

Boomerang (1999-2003)
2 Flights

MAXIMA (1998-1999)
2 Flights

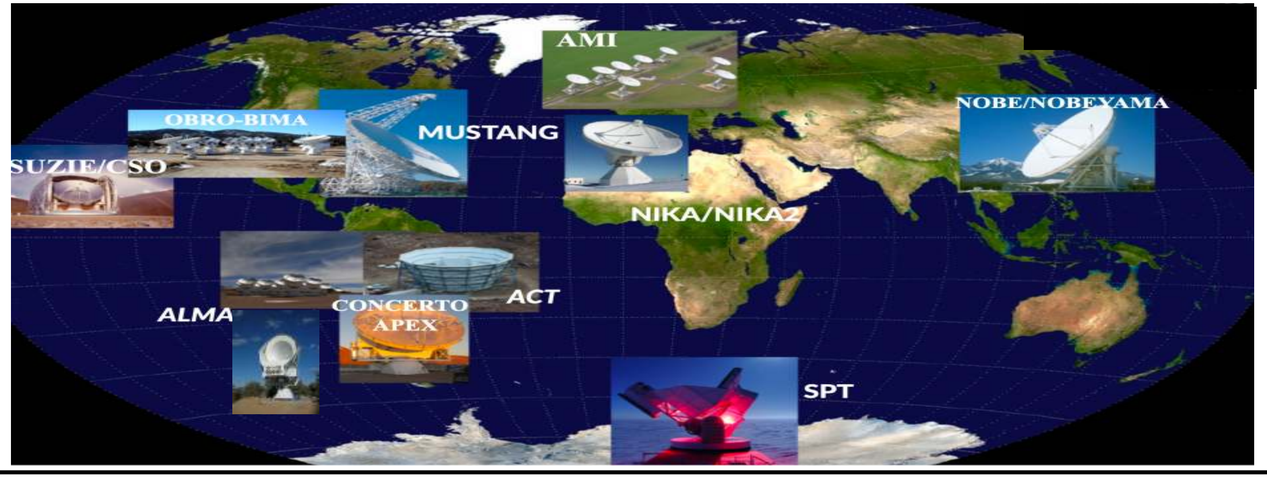
Archeops (2001-2002)
3 Flights

OLIMPO (2018)
1 Flight

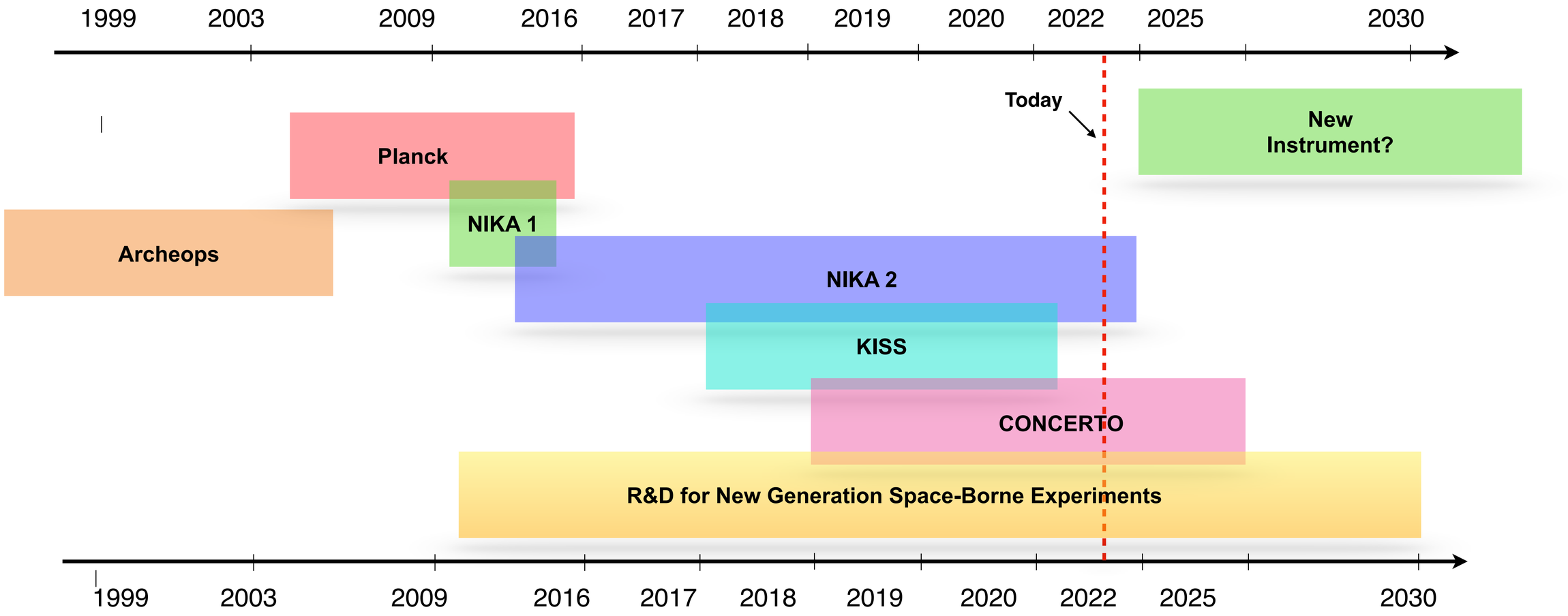
Perspectives

EBEX?
Bisous?
Others?

Ground-based Experiments



Our activities are always driven by real instruments…

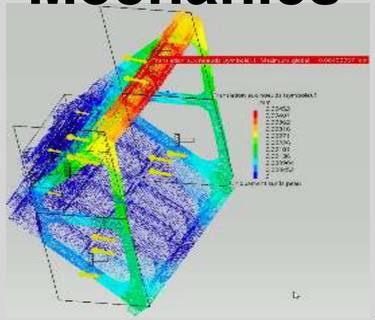


Most of this work has been developped in a strong collaboration between institut Néel (INP), LPSC (IN2P3) and IPAG (INSU). These three labs together with IRAM are consolidating through a GIS (*Groupement d'intérêt scientifique*).

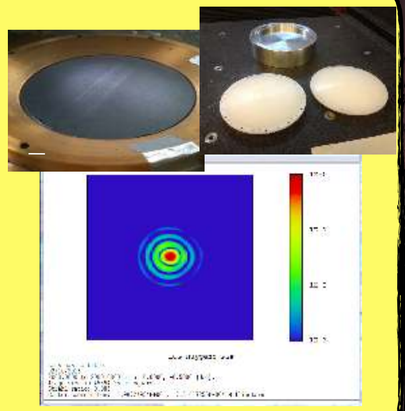
Core Technology: KID

Cryogenics

Mechanics

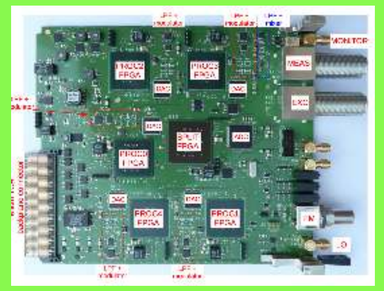


Optics

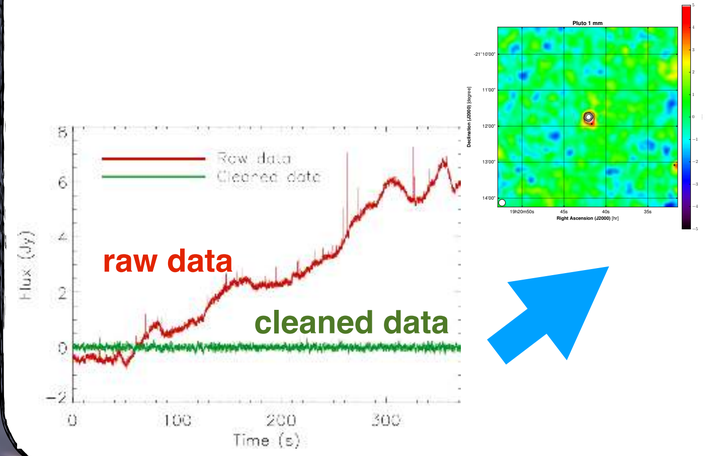


KID

Electronics

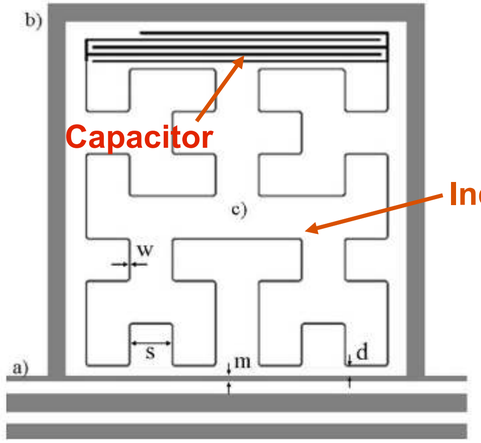


Data Acquisition-Pipeline



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

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



Capacitor

Inductance ($L_K + L_G$)

Feedline 50Ω

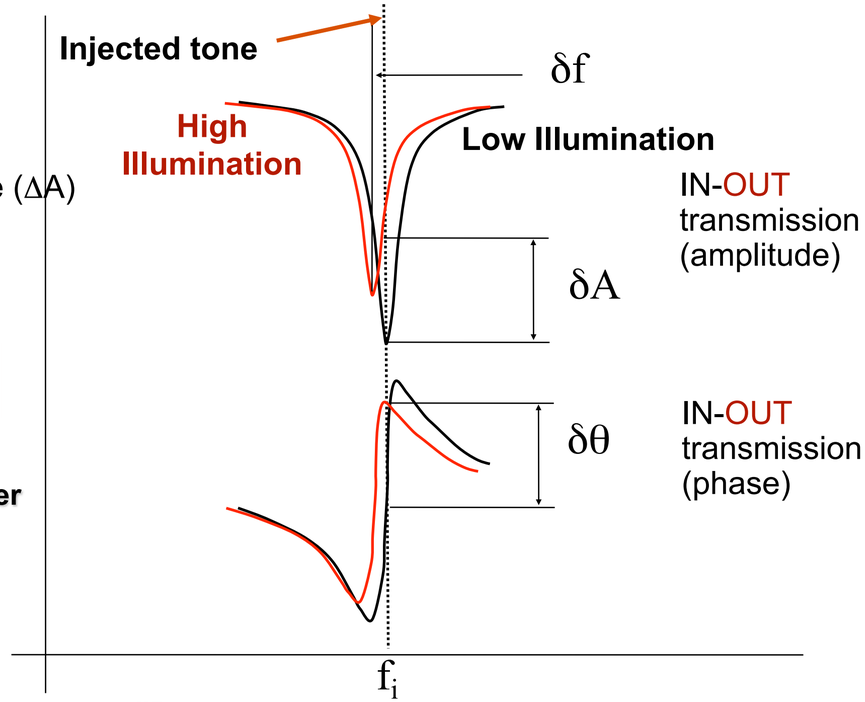
The incoming photons break Cooper pairs (supercurrent carriers) in a superconducting LC resonator → measurable signals

Dark, T << T_c

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

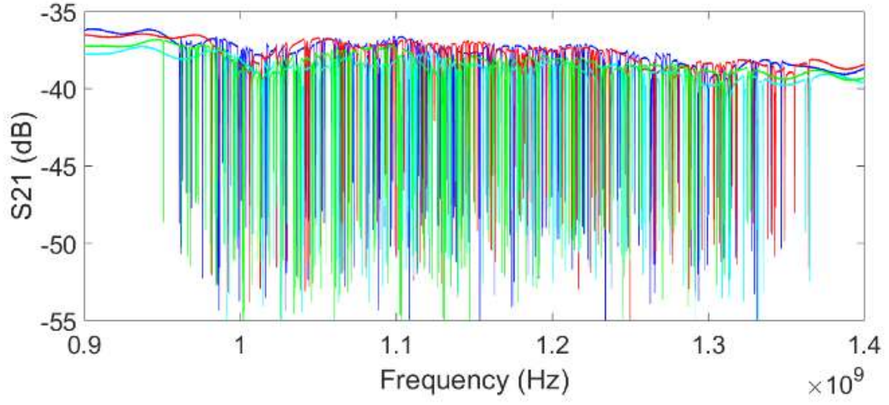
$\delta f \propto \delta L_K \propto \delta P$

δf = frequency shift
δP = incoming power



IN → f_o f_1 ..... f_{n-1} → OUT

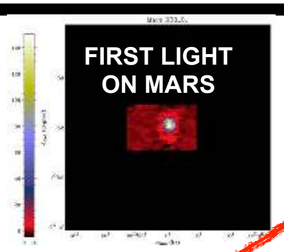
Each 400 pixels are connected to a single transmission line

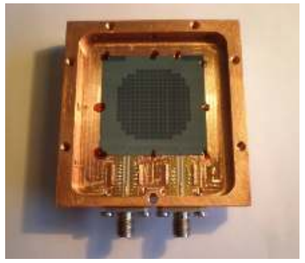


KIDs Development

2009

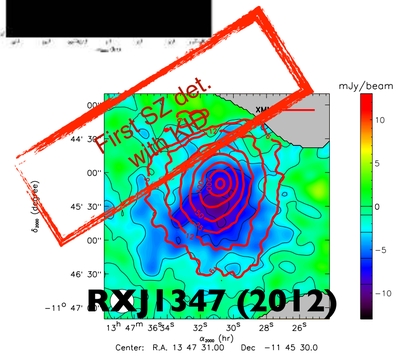
30 Pixels

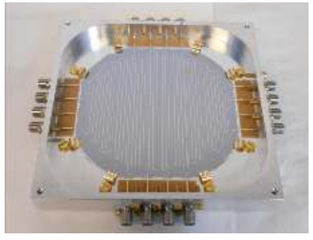




2010-2013

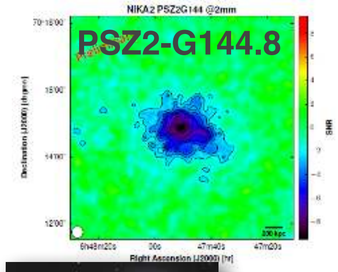
200 Pixels

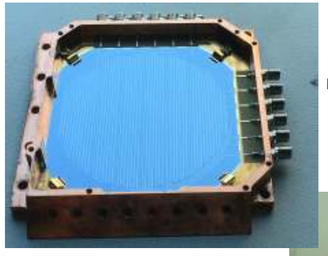




2014-2015

1000 Pixels





2015-Today

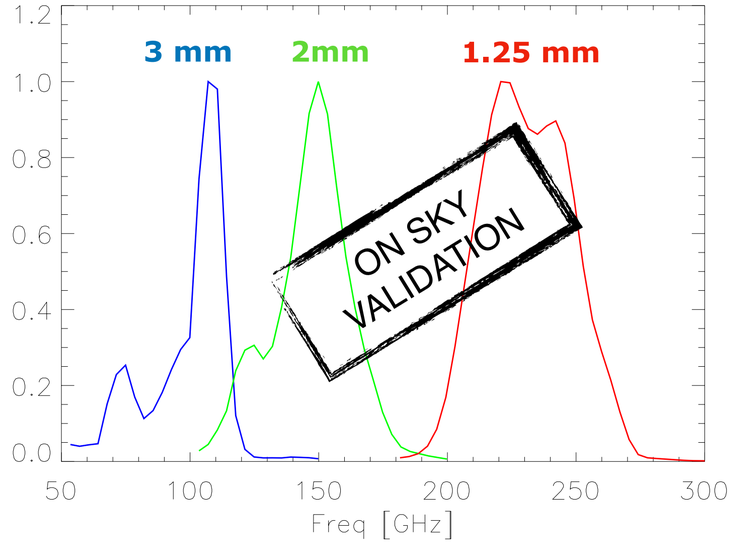
2000 Pixels

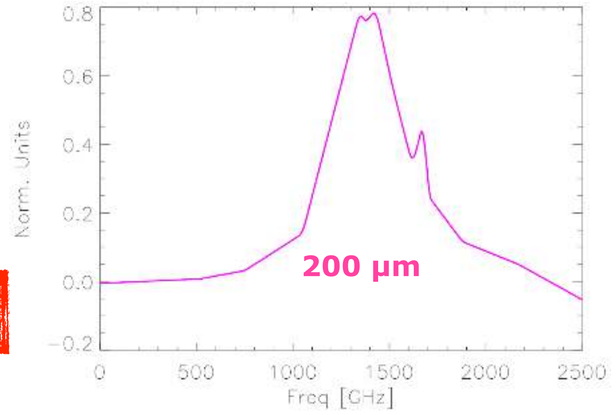
Today-2025

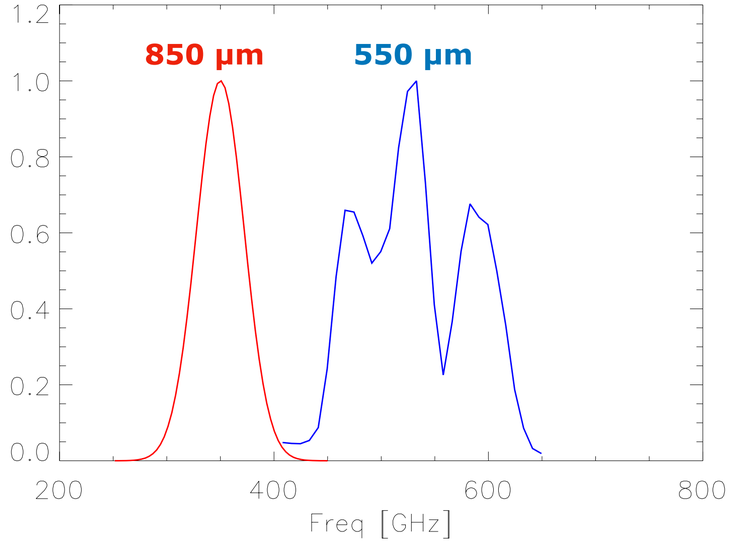
8000 Pixels

Prototype

KID has been validated in several bands

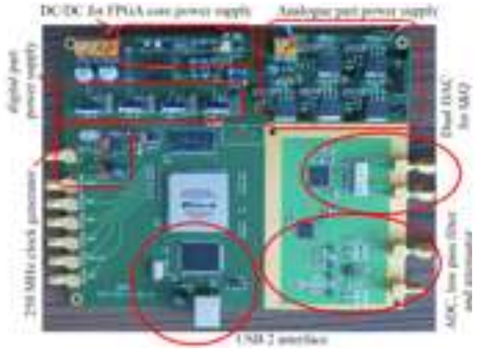






READOUT Development

2011: NIKEL proto

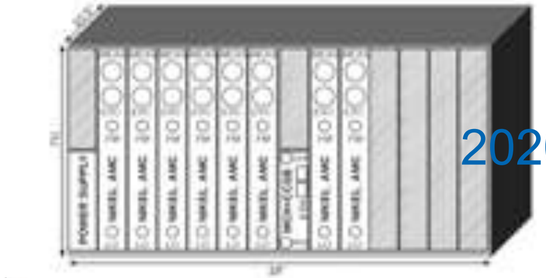


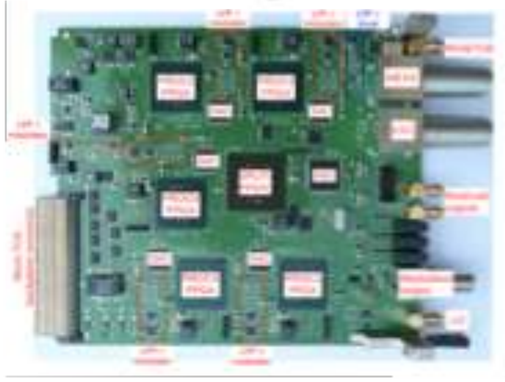
128 pixels
500 MHz bandwidth
external RF

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]

The New IRAM KID Arrays Project

Goal: install the most powerful ever continuum instrument at the 30 m telescope, with new features never available before (FOV, multi-band, polarisation)

Budget: the project is approved by IRAM and funded with 2.3 M€(30% IRAM, 70% external)

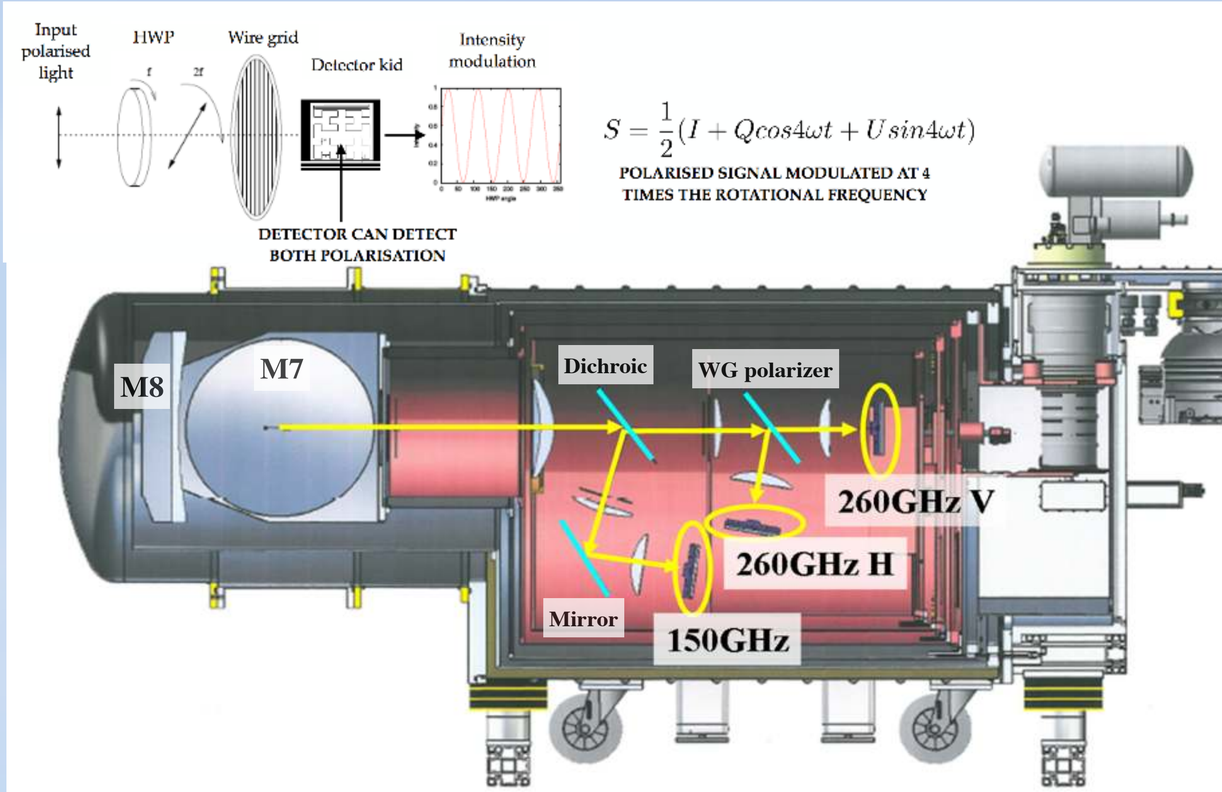
Schedule: Installed in 2017, operating until 2025

Science: the NIKA consortium redeemed as guaranteed time observations (GTO) of 1300 h in 5 large programs corresponding to our scientific interests.

Galactic : Study of star forming regions in the galaxy: filamentary structure and fragmentation, magnetic fields Resolved mm emission from nearby galaxies: dust emission, radio diagnostic of the SFR

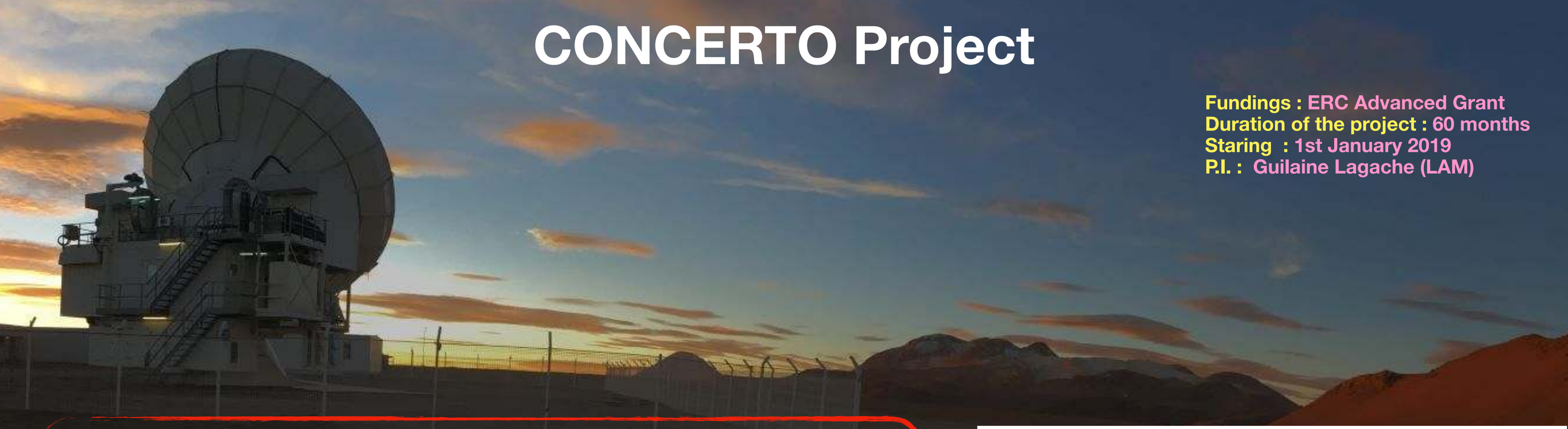
Extra-Galactic : Deep survey to map the dusty star formation at high redshift

Cosmology : Understand bias in galaxy cluster cosmology via the Sunyaev-Zeldovich effect



	260 GHz	160 GHz
beam (FWHM)	12" (10")	18" (16")
FOV (diameter)	6.5'	6.5'
# of detectors	2 x 1140	1020
Sensitivity	30 (15) mJy.s	20 (10) mJy.s
Polarisation	YES	NO

CONCERTO Project



Fundings : ERC Advanced Grant
Duration of the project : 60 months
Staring : 1st January 2019
P.I. : Guilaine Lagache (LAM)

- Spectro-Interferometer (spectral resolution R > 100)
- Observing between 120 GHz - 350 GHz from 12 m APEX Tel.
- Large Field of View (20 Arcmin)
- LEKID Technology
- Collaboration LAM - Inst. Néel - LPSC - IPAG

Telescope primary mirror diameter [m]	12
Field-of-view diameter [arcmin]	20
Absolute spectral resolution [GHz]	≥ 1
Relative spectral resolution R [#]	1–300
Frequency range HF | LF [GHz]	195–310 | 130–270
Pixels on Sky HF | LF [#]	2,152 | 2,152
Instrument geometrical throughput [sr m^2]	2.5×10^{-3}
Single Pixel geometrical throughput [sr m^2]	1.16×10^{-6}
Data rate [MBytes/sec]	128

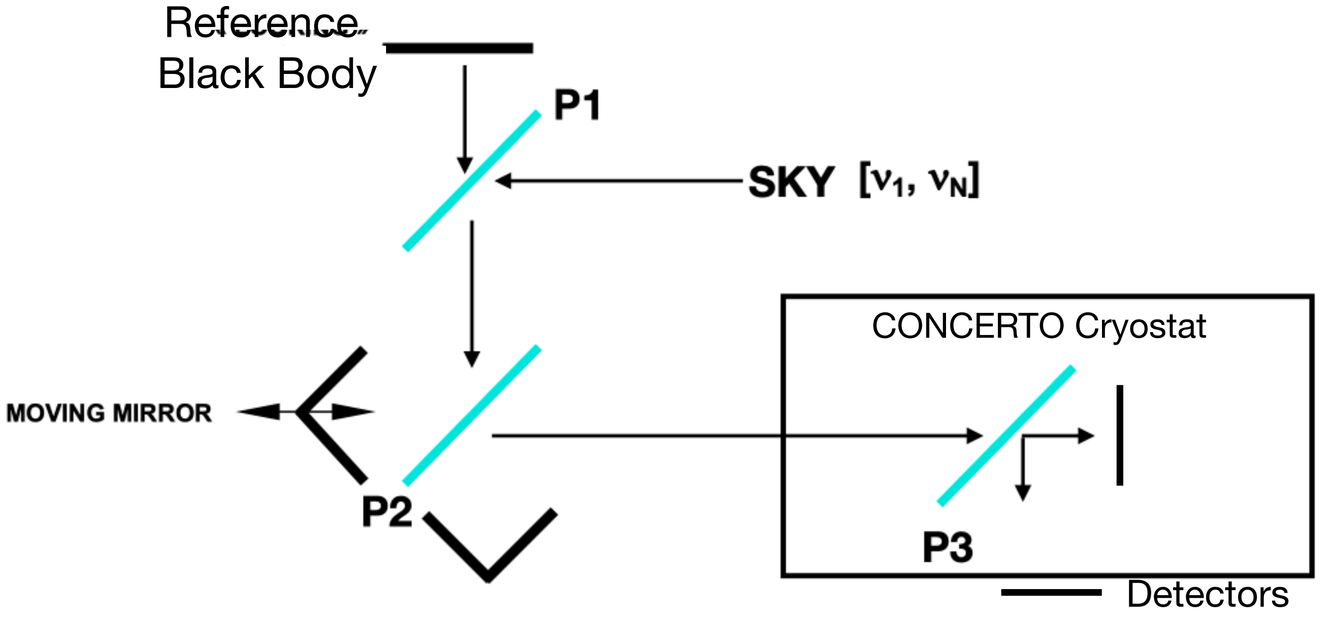
Main Goals: 1200 hours Observations of the [CII]-emission line at high redshift
20 hours SZ signal from galaxy cluster RXJ1347–1145 (z = 0.45)

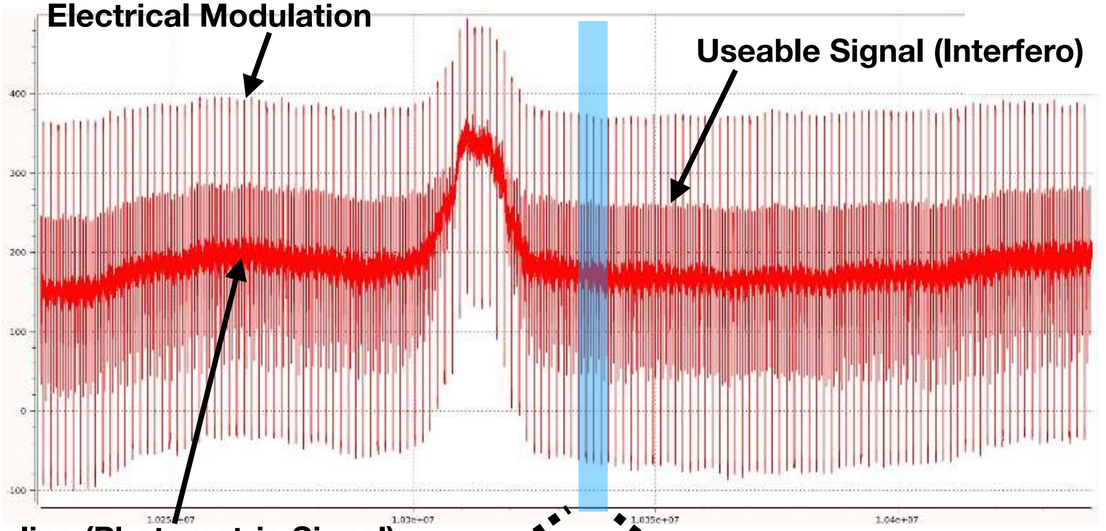
Pathfinder: KISS installed at Qujiote (Tenerife) since end of 2018. Still observing

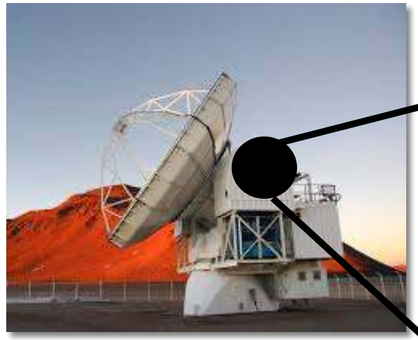
Status: Concerto is installed at 12 m APEX telescope since April 2021

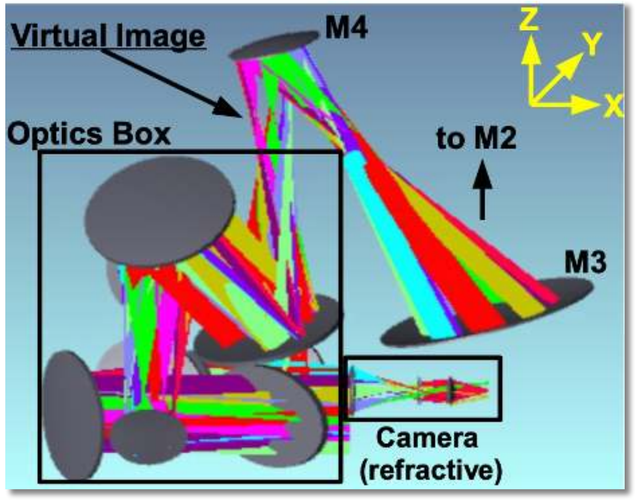
Schedule: Science Verification in June (2 weeks), Regular observations started in August 2021 until June 2023.

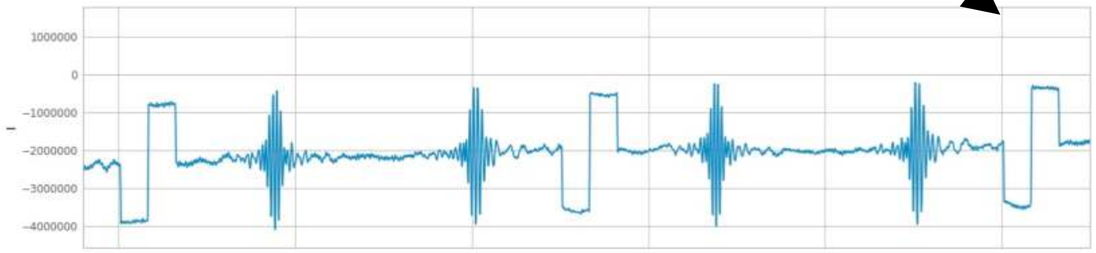
CONCERTO Design & Signal Processing







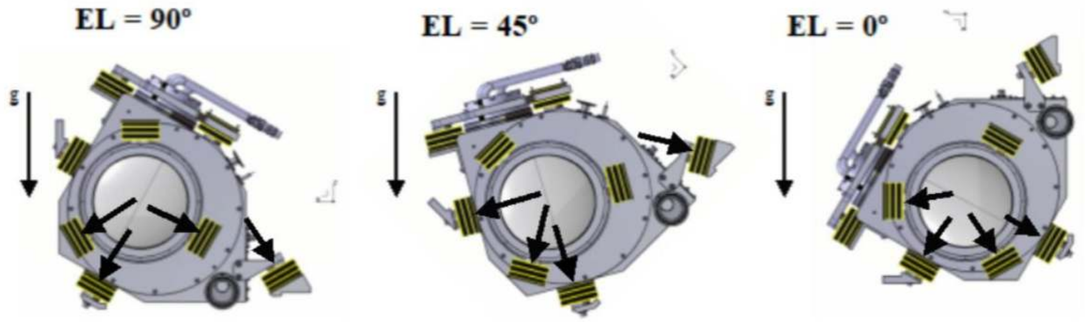


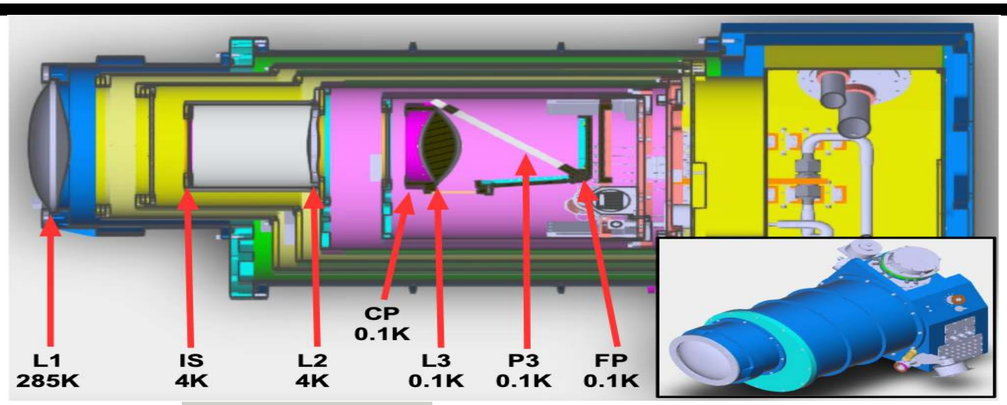


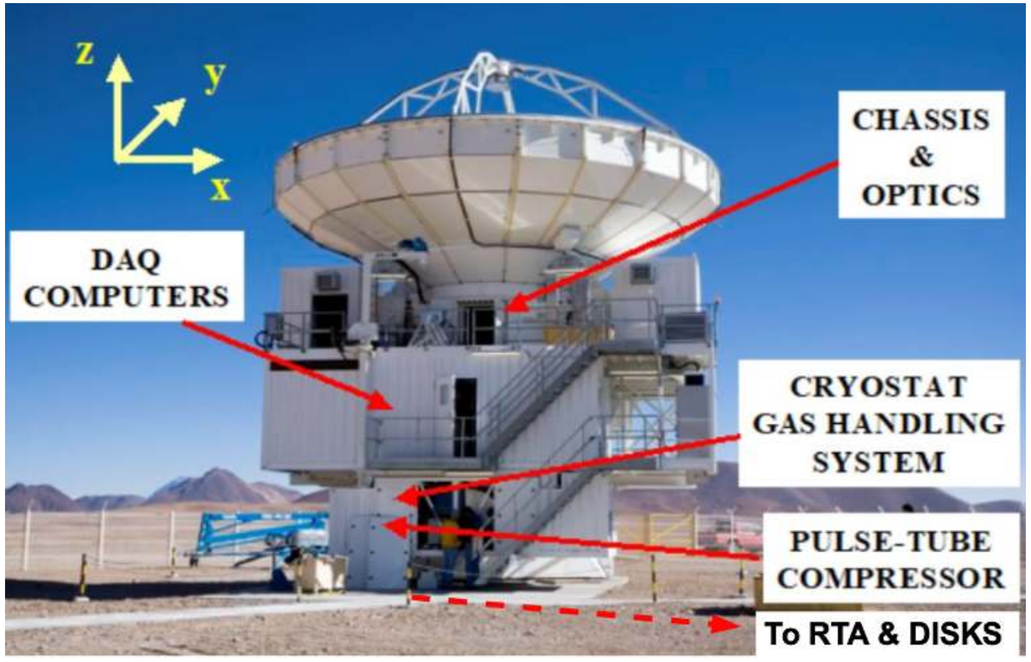
We modulate the frequency on the local oscillator before each interferogram producing some dead time at each block of data.

CONCERTO Enslavements

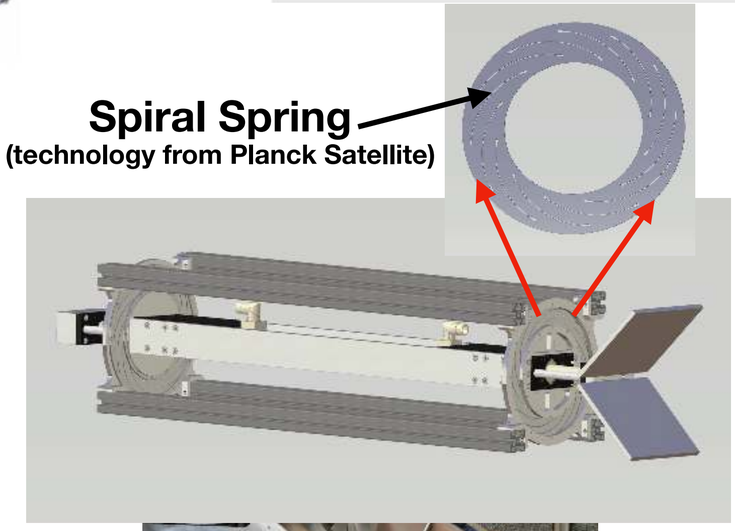
Rotation of the cryostat (and optics) following the telescope elevation







Spiral Spring
(technology from Planck Satellite)

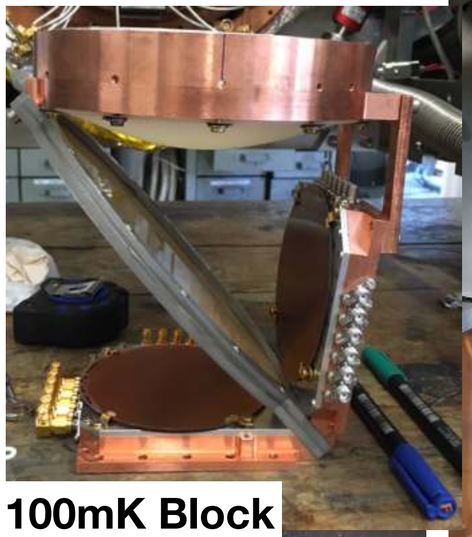


- 100mK Dilution Cryostat fully remote controlled
- MPI moveable roof mirrors with very low vibration level
- Large Size Polarizers
- Polypropylene Lenses with Geometrical AR.
- 10 Al Mirrors

CONCERTO Step by Step: from the lab…

07/2018 - 06/2020:

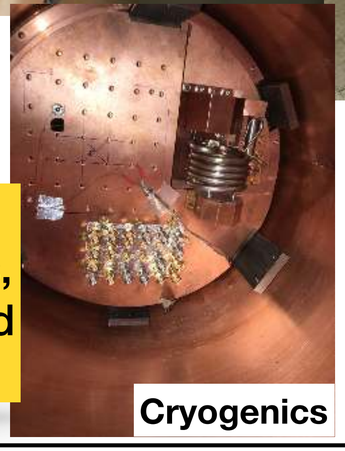
Design, Fabrication, Sub-systems Qualification



100mK Block

Polarisers

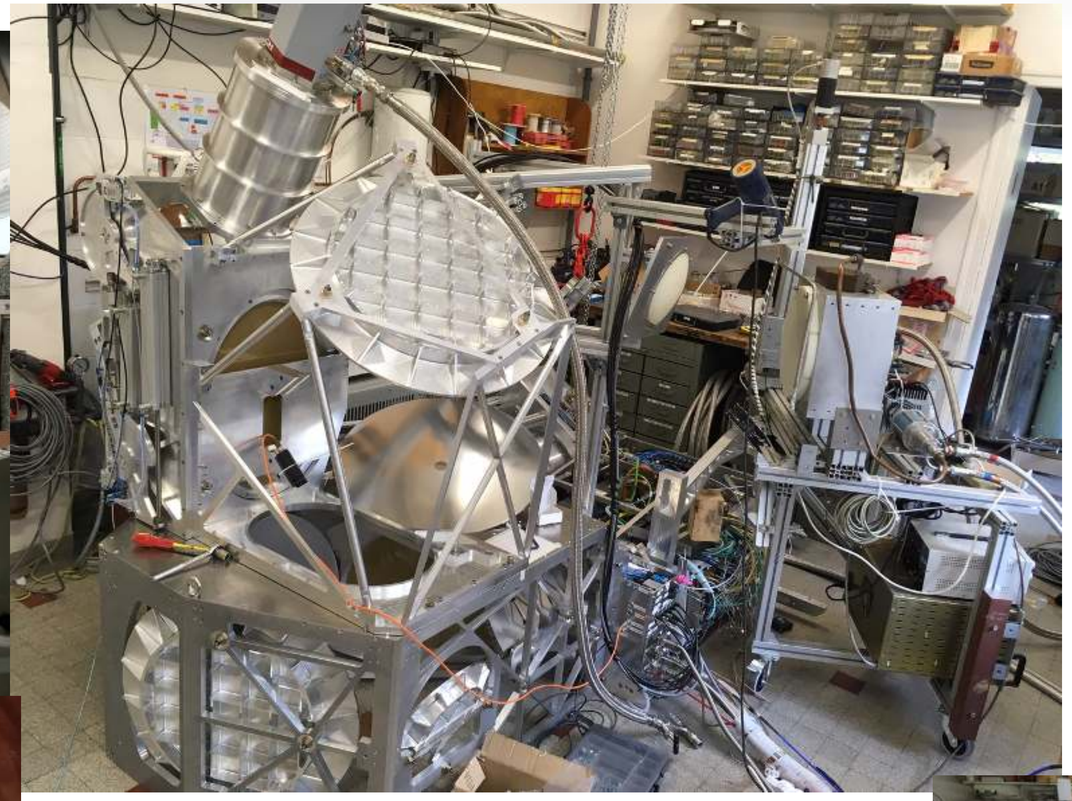
Mirrors



Cryogenics

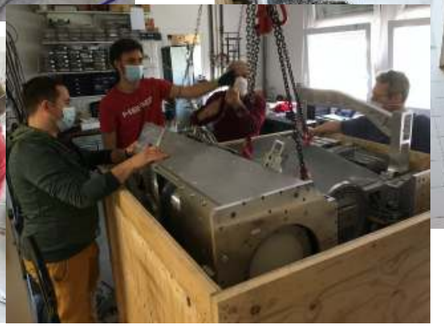
Detectors, REU, Lenses, Mirrors, Polarisers, Cryogenics, Mechanics have been designed and fabricated in our labs.

06/2020 - 02/2021: Assembly + Lab Tests



01/03/2021 :

Shipping to Chile



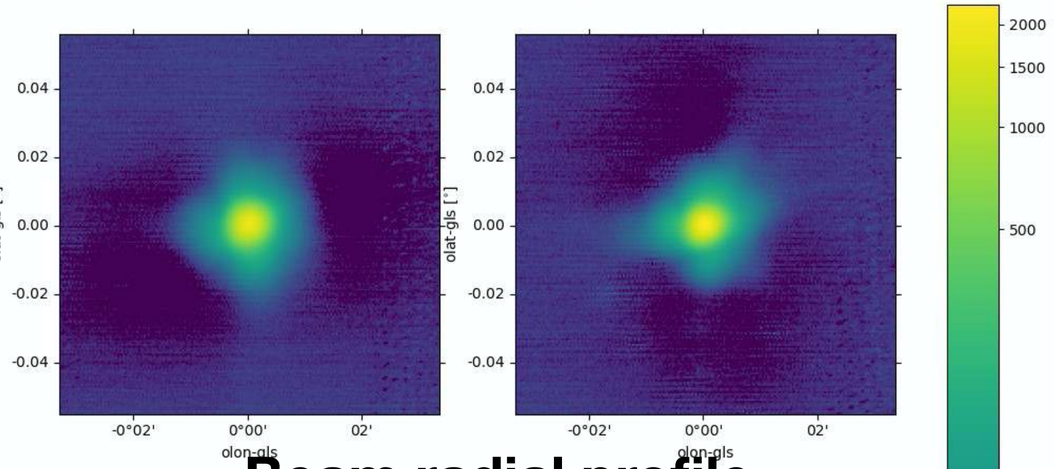
…to APEX

CONCERTO Boxes
at the APEX Telescope

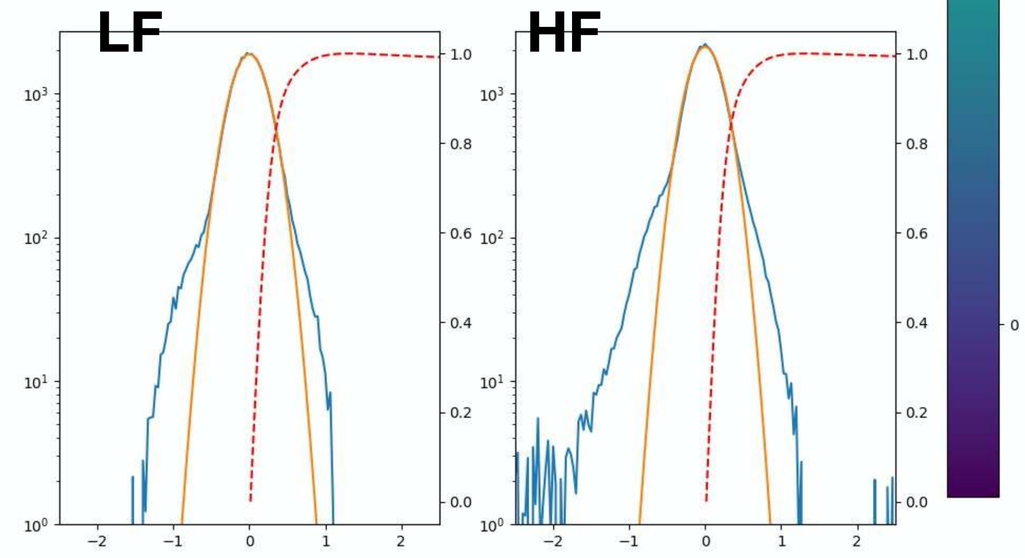
with a huge back up
and support of people
remained in France

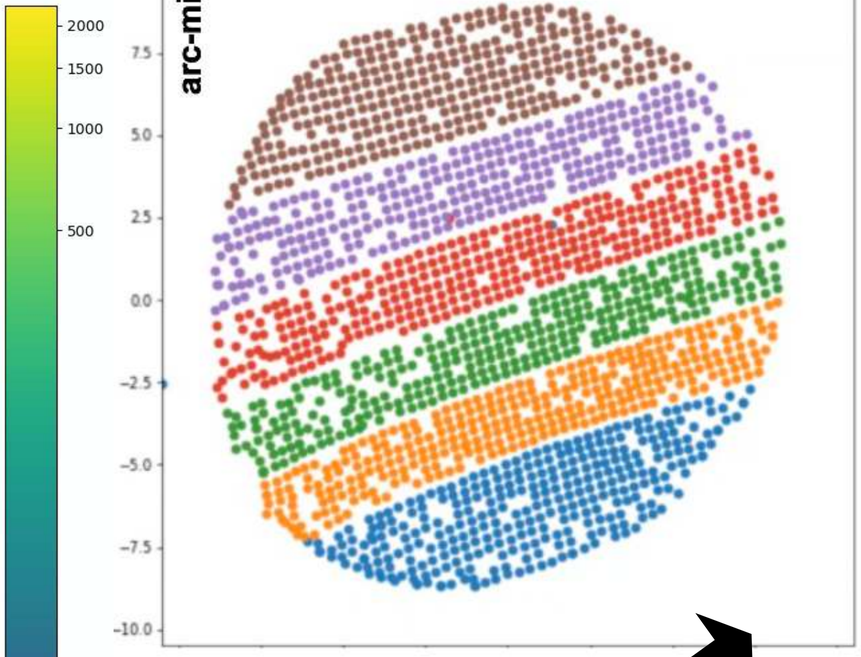
CONCERTO Commissioning

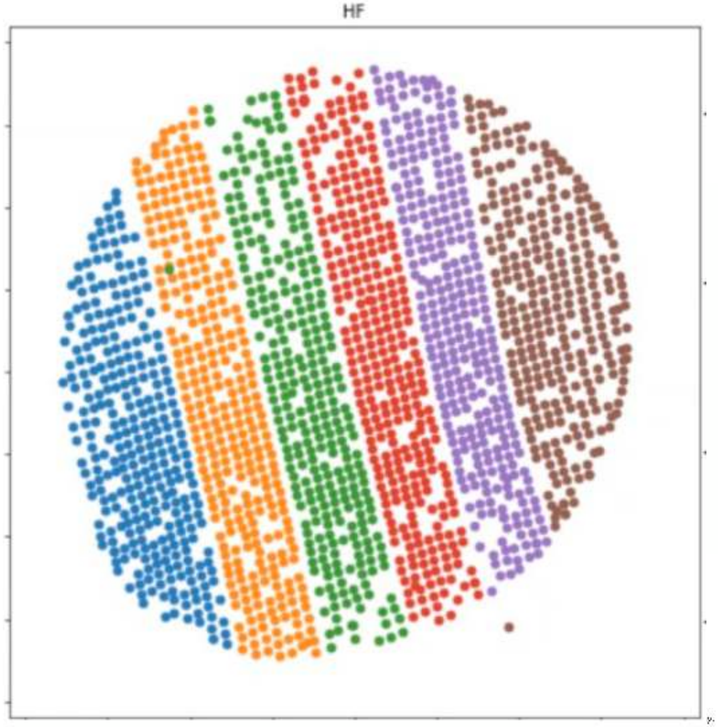
Mars Beam Map (02/05/2021)



Beam radial profile.

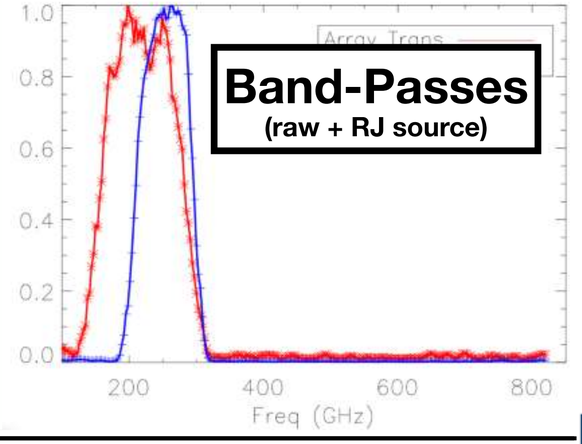






Focal Plane Geometry

> 90 % Functional pixels



CONCERTO First Photometric Observations

Cats Paws (NGC6334)

- 16 minutes integration
- LF Array (Blue)
- HF Array (Red)

CONCERTO First Photometric Observations

Crab Nebula (Tau A)

- 2.5 minutes integration
- LF Array (Blue)
- HF Array (Red)