IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2015.
EUCAS 2015 invited presentation 3M-E-02.1. Not submitted to *IEEE Trans Appl. Supercond*.

(Planar) Superconducting resonators:

Kinetic Inductance Detectors (KID)

and other applications

Alessandro MONFARDINI – Institut Néel
CNRS – Grenoble – FRANCE
For a larger collaboration

EUCAS 2015

Presentation plan:

- Superconducting resonators
- Kinetic Inductance Detectors (KID)
- New IRAM KID Arrays and NIKA2
- Further applications

Superconducting Resonators

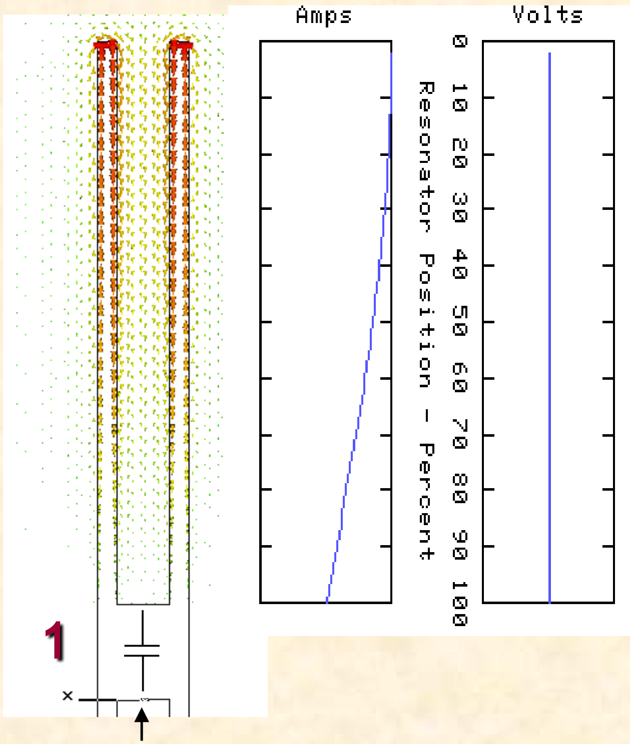
Distributed vs. Lumped Element

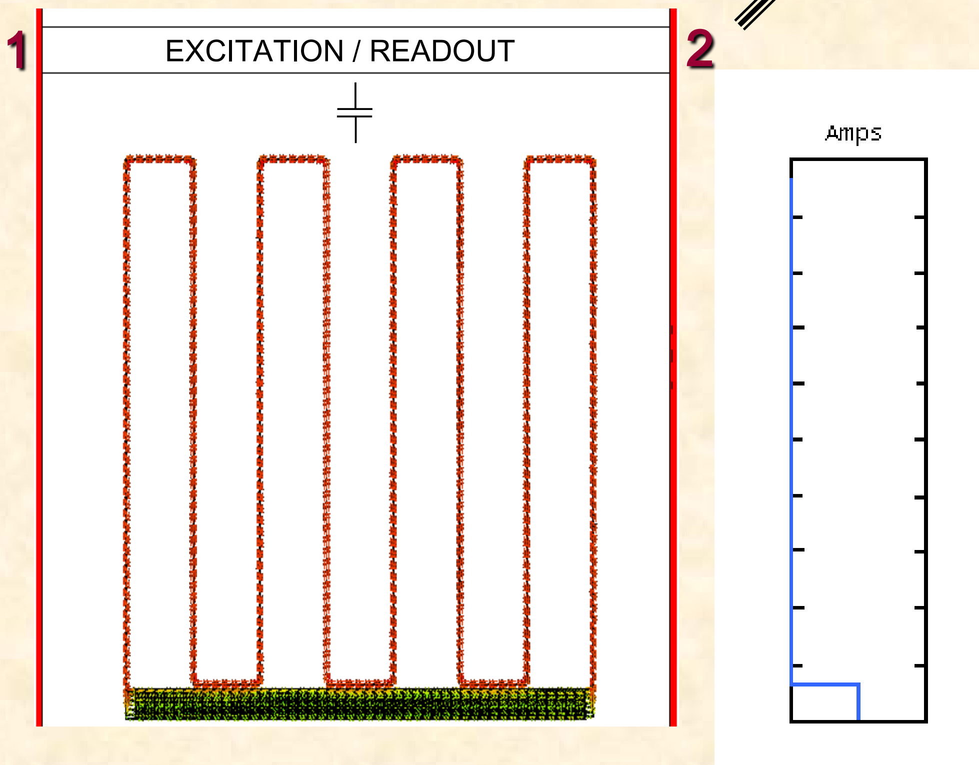
Distributed or Lumped for your application ?

L-C distributed (λ/4)

L-C Lumped

S21





EXCITATION / READOUT ⟹ S11

Sensitive devices

Quality factor: $Q \equiv \Delta f / f_0$ (typ. $10^3 - 10^7$) **superconductivity**

Q is a kind of « internal gain ». *Best Q is application-dependent.*

An LC(R) resonator is sensitive to L, C and (R) changes. **Obvious.**

Quarter Wave Electrical Measurable:

Transmission (complex) (S21) $\Rightarrow$ I,Q **(projections on complex plane)**

Physically interesting quantity:

Frequency shift $\Rightarrow \delta f \propto$ power (L.J. Swenson et al., APL 96, Issue 26, 263511 (2010))

EM environment (C): dielectrics + geometry

Quasi-particles density (L,R): KID

Kinetic Inductance Detectors (KID)

Proposed in early 2000s by JPL-Caltech (see J. Zmuidinas talk tomorrow morning !!)

Kinetic Inductance Detectors : how it works

WHY : MULTIPLEXING !!

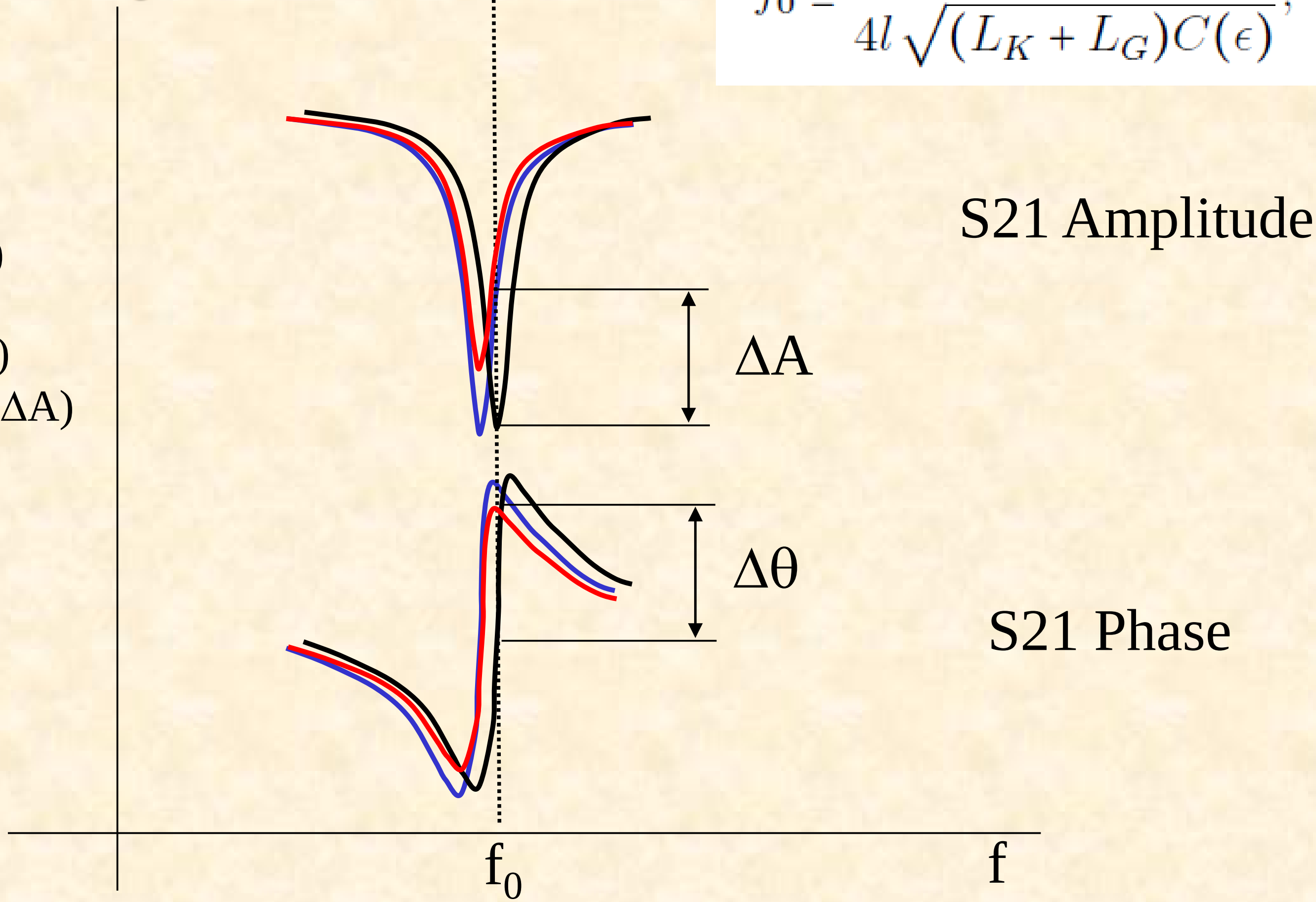
HOW : Superconducting RF Resonators

$$f_0 \cong \frac{1}{4l\sqrt{(L_K + L_G)C(\epsilon)}},$$

Dark, $T << T_c$

Photons: more L_k
Change in phase ($\Delta\theta$)

Photons: more qp (R)
Change in amplitude (ΔA)



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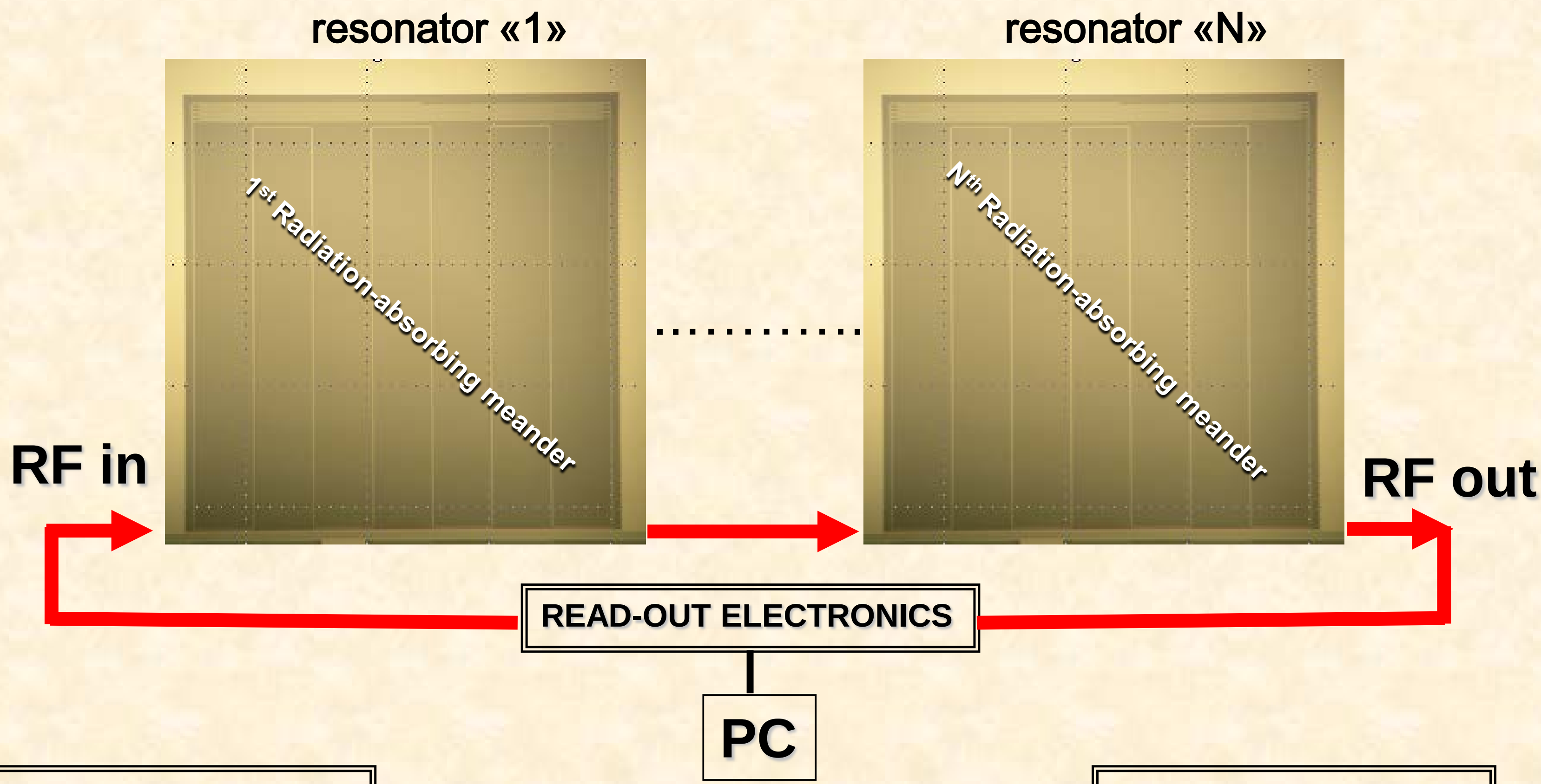
Kinetic Inductance Detectors MUX



N ≈ 100 ÷ 1000

RF ≈ 1-10GHz

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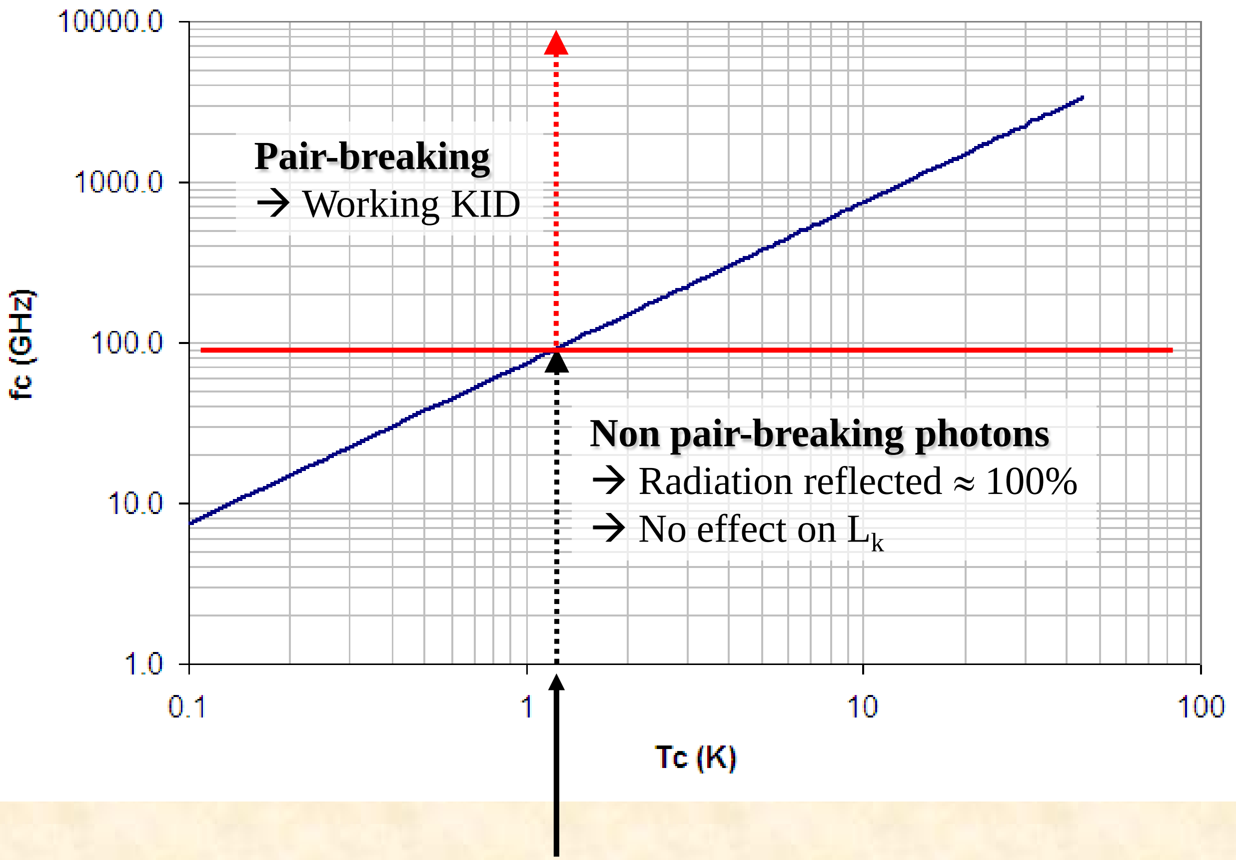
"Classical" films for planar resonators



Examples:

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

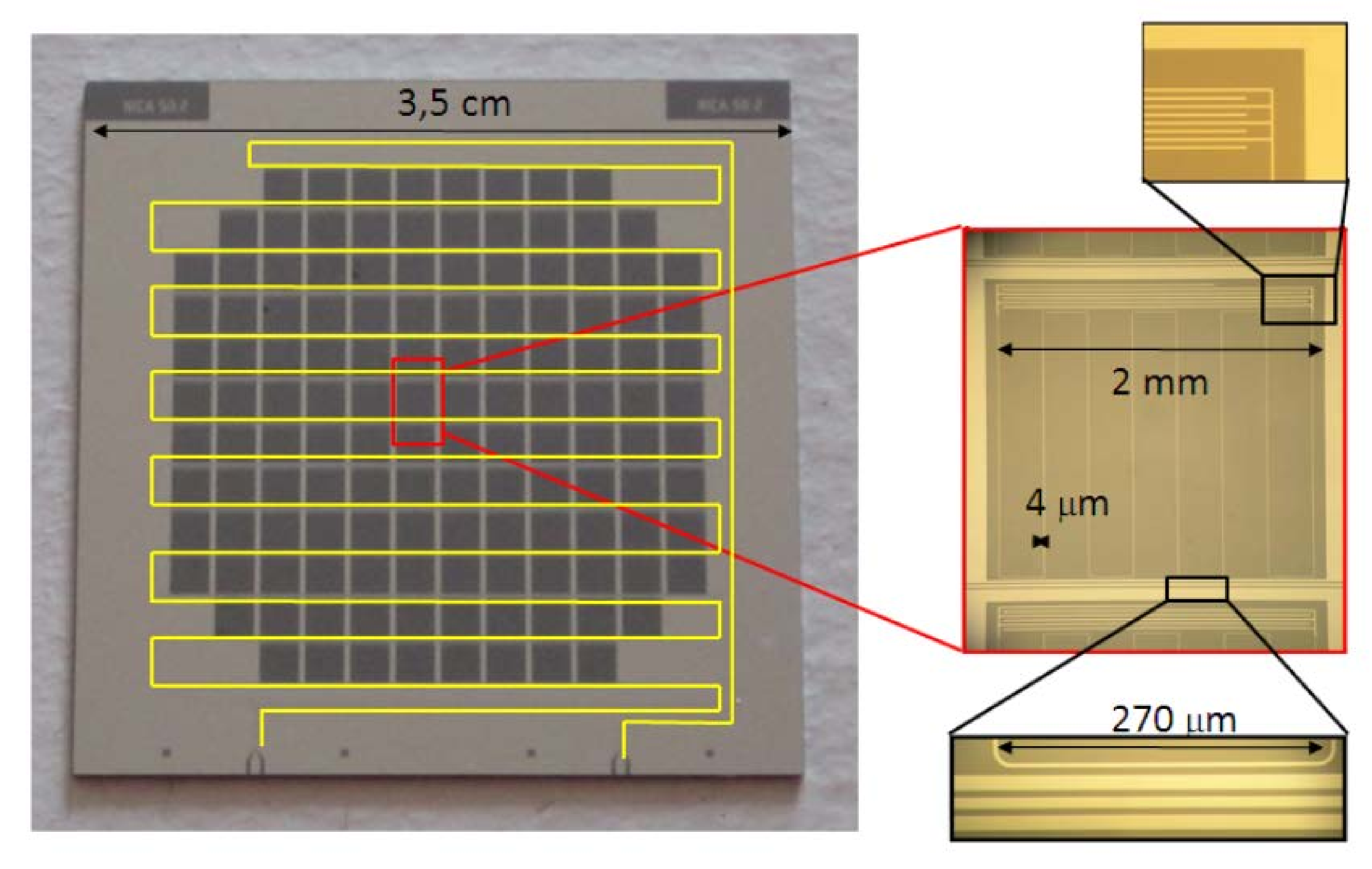
Nb_xSi → adjustable

TiV_x → adjustable

Multilayers → adjustable

e.g. Al, our best friend !!

A real array



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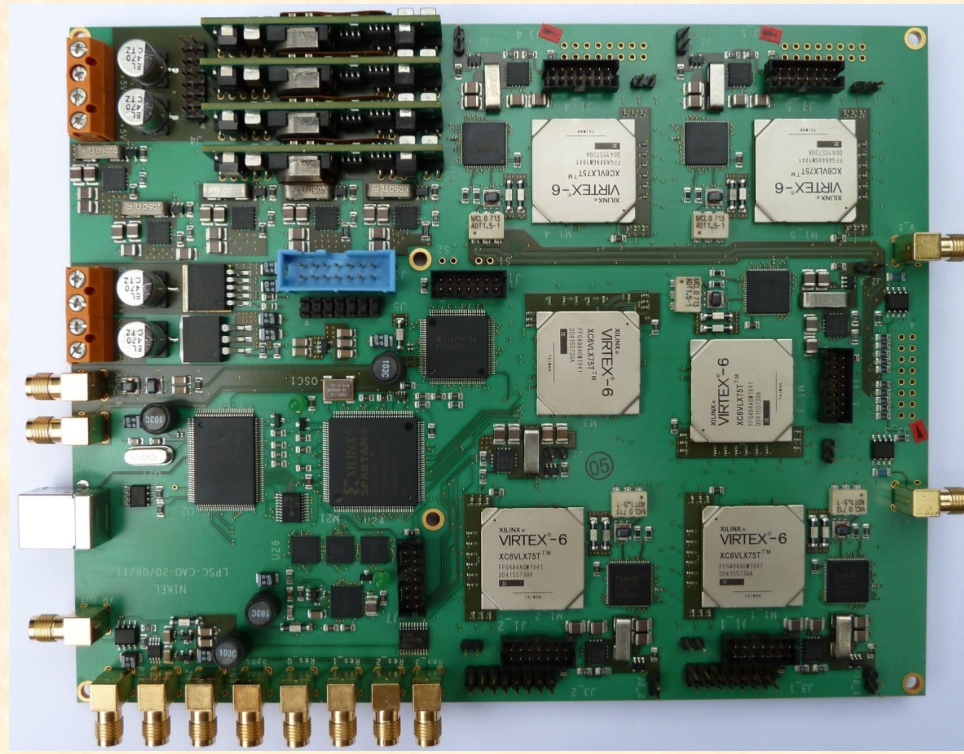
A real MUX electronics: NIKEL

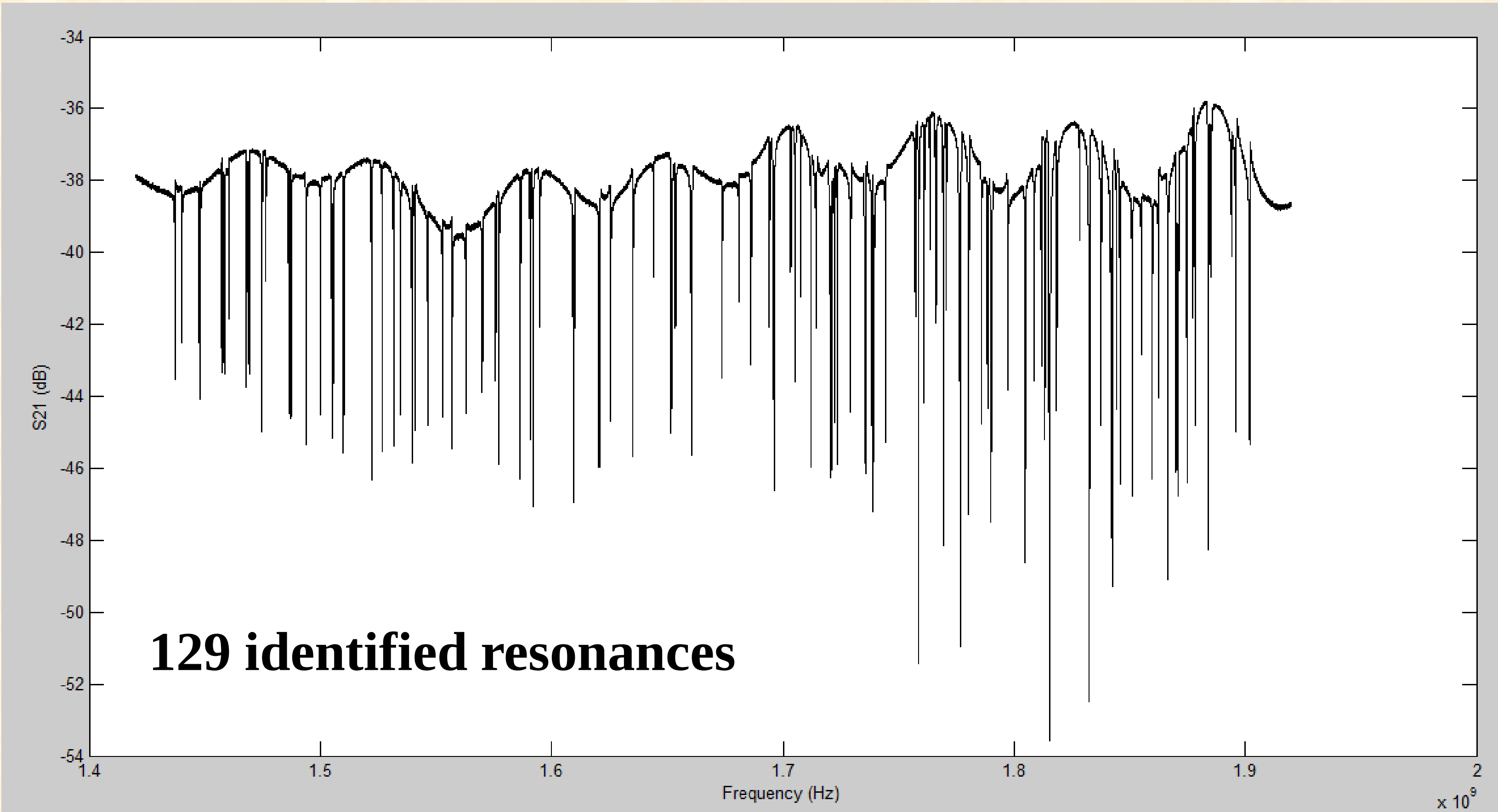
NIKEL specs:
500 MHz, 400 channels
- ADC 12 bits 1GSPS
- DAC 16 bits 1GSPS
- FPGA Xilinx Virtex-6



NIKEL functions:
- Excitation tones
- Up-and-down conversion
- Digital mixing
- mini-PC integrated, ethernet to DAQ

For full details: ***O. Bourrion et al., Journ. of Instrum. 7, P07014 (2012)*** arXiv:1204.1415

Transmission of a (good) 132 pixels array



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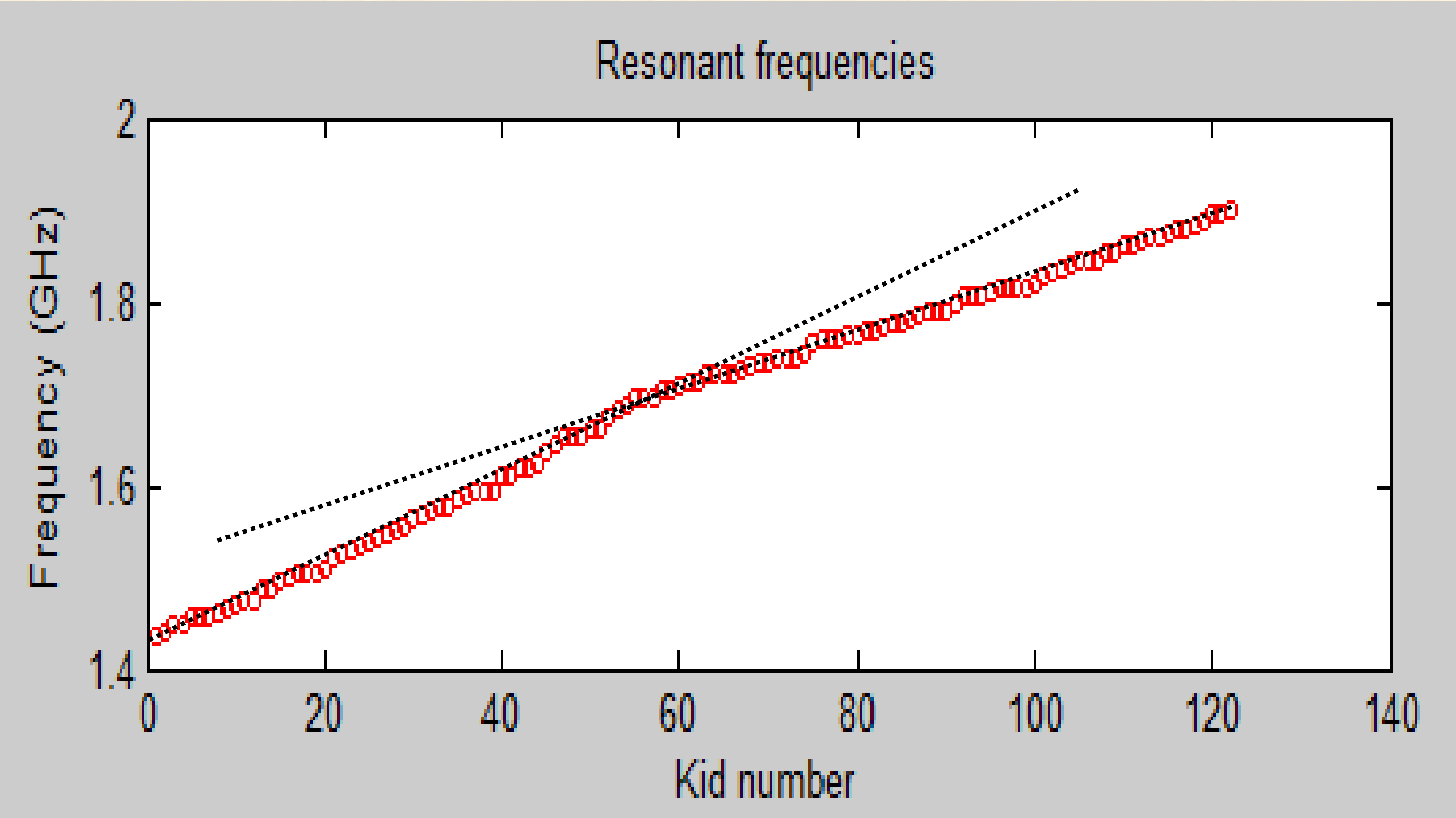
Frequency-space occupation



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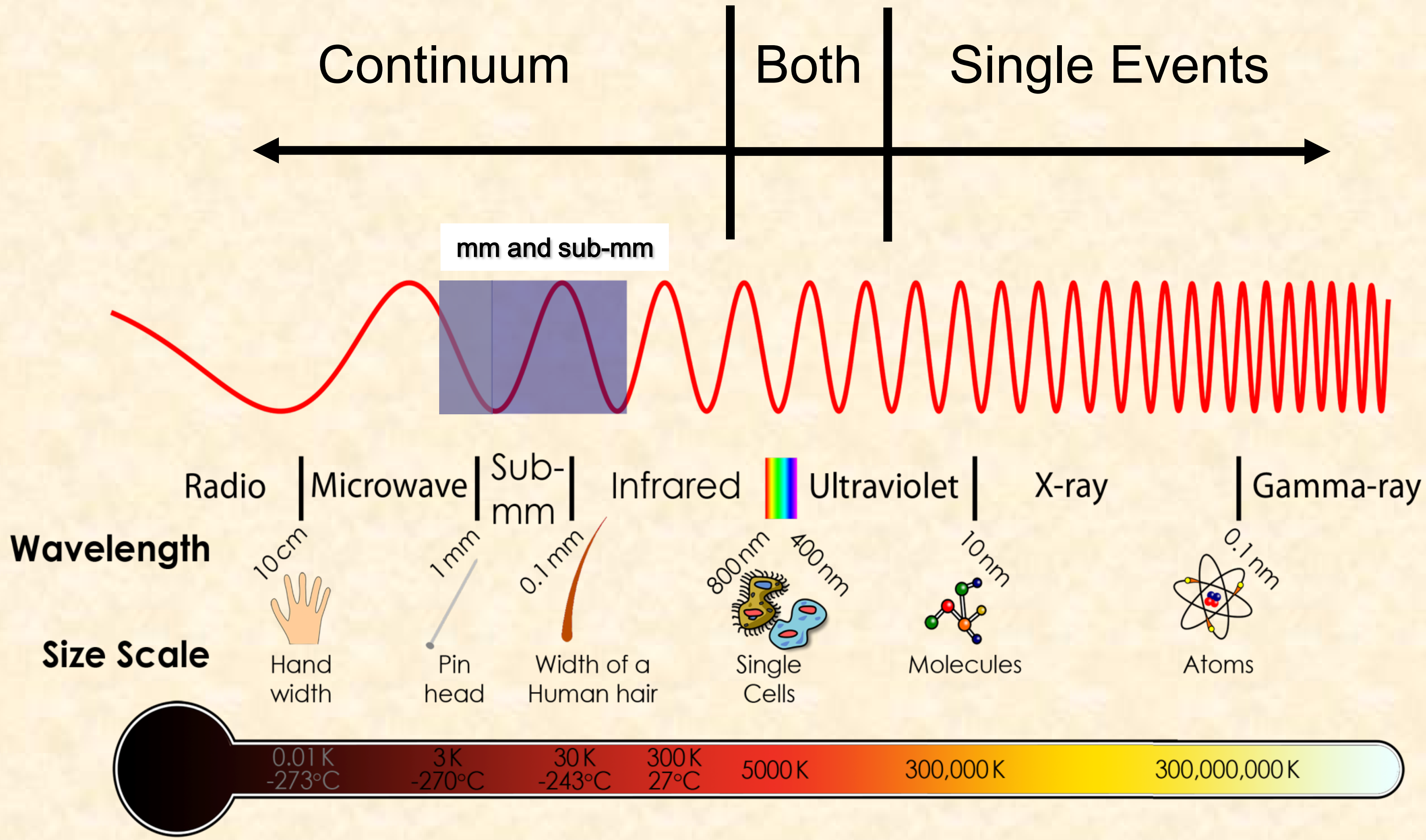
New IRAM KID Arrays (NIKA) and NIKA2

EM Spectrum - Counting vs. Recording



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mm and sub-mm Astronomy

Blackbody's Wien law → $\lambda_{max} \approx (5 / T)$ mm

→ «Cold» radiation (λ = 1mm ≡ 5K ; λ = 2mm ≡ 2.5K)

Astrophysics :

Galaxies, stars and planets are born from cold gas and powder.

→ Early formation stages of small-scale structures

Cosmology :

14 billions years ago, first H atoms formed from e^- and p^+ hot «soup».
A flash of UV light was emitted, at the same time, everywhere in the Universe.
Expansion → TODAY the Universe is cold (2.7K) and brightest in mm-wave.

→ Universe shape; large scale; primordial structures; inflation test

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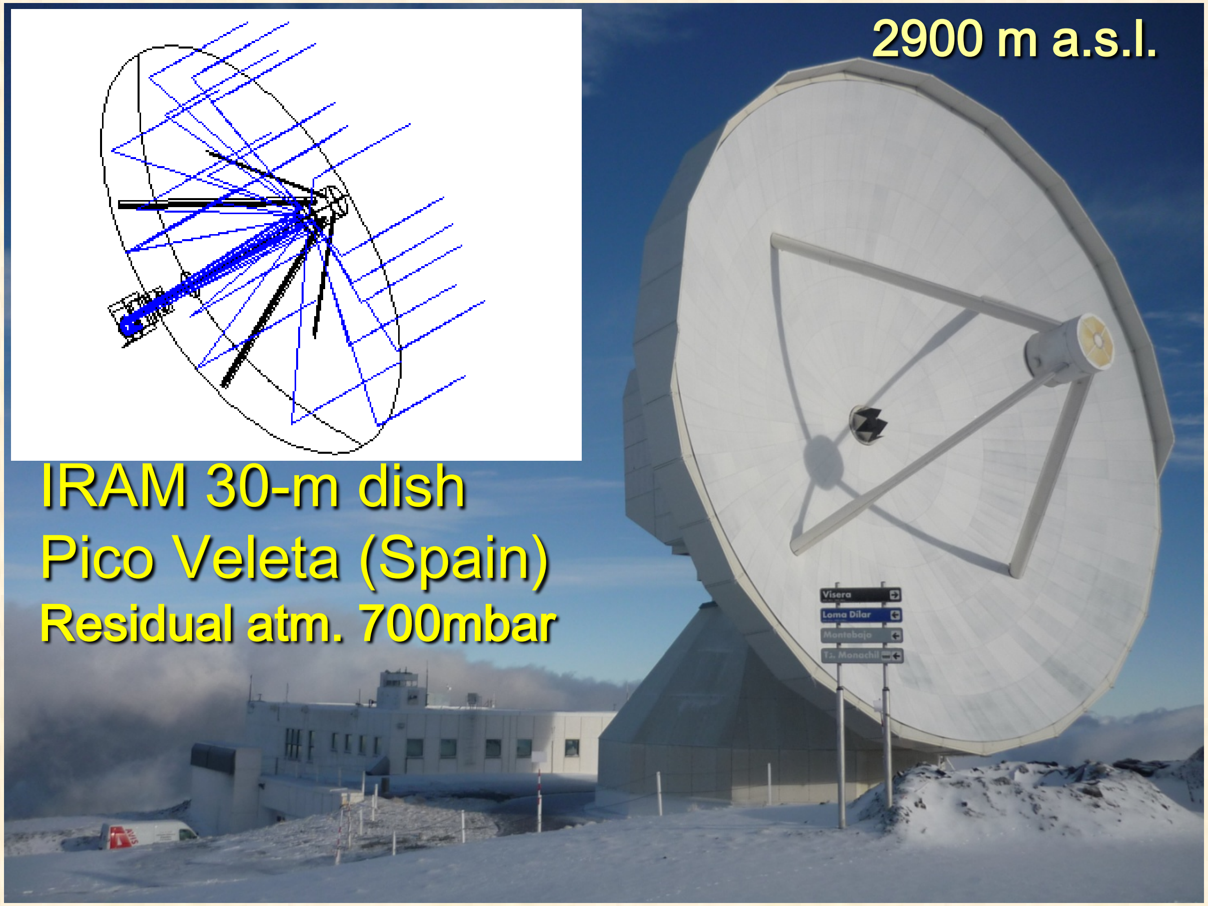
"Our" mm-wave telescope



Working Bands:

3mm (100GHz)
2.05mm (146 GHz)
1.25mm (240 GHz)
0.87mm (345 GHz)

IRAM, based in Grenoble, was founded in 1979 by the French **CNRS**, the German **MPG** (Max-Planck-Gesellschaft) and the Spanish **IGN** (Instituto Geográfico Nacional).

IRAM = Institute for Millimetric RadioAstronomy

NIKA and NIKA2

New IRAM KID Arrays (NIKA)

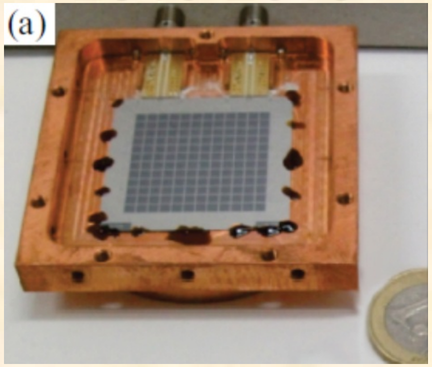
NIKA (until 2015)

- **Dualband (1.25mm and 2mm)**
- LEKID Arrays Detectors:
  - **132 pixels @ 2mm (150 GHz)**
  - **224 pixels @ 1.25mm (240 GHz)**
- NIKEL Read-Out Electronics
- State-of-the-art sensitivity (even compared to TES)
- PIs: A. Benoit & A. Monfardini
- Ten successful observing runs at the telescope (2009-15) … celebrated our 100th day on top of the Sierra Nevada
- **Fully justifying NIKA2 !!**

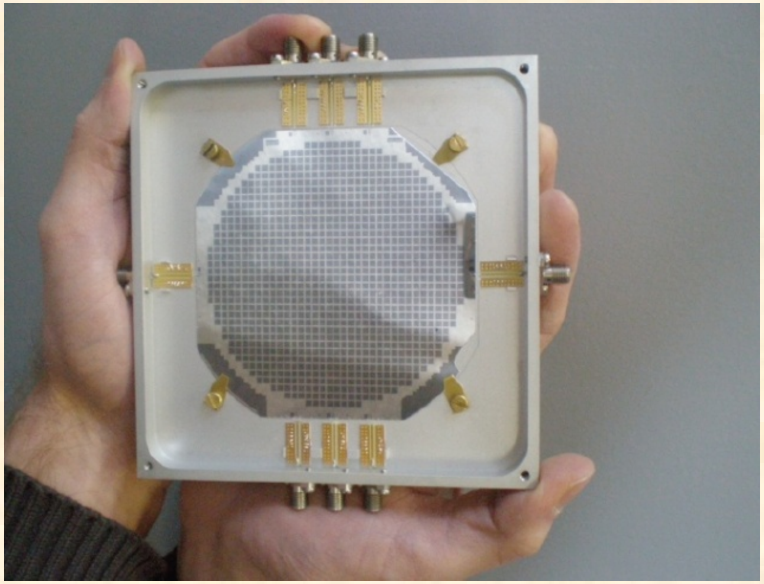
From NIKA0 to NIKA2 arrays evolution

2009

2010-2013



2014



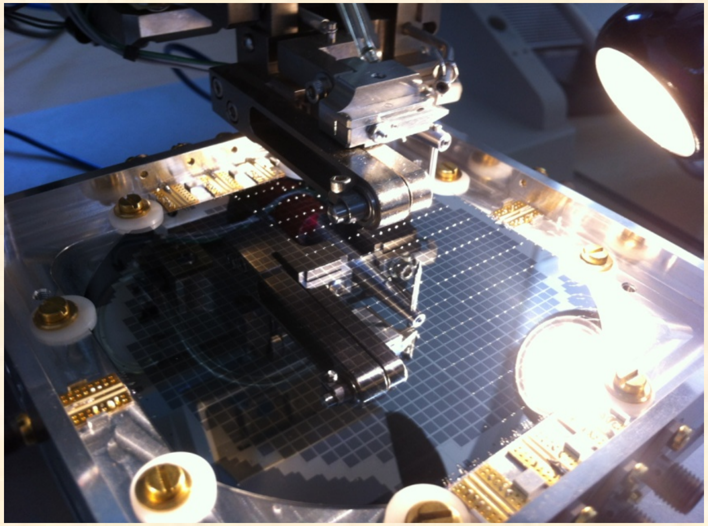
2009:

- 30 pixels, detectors noise limited

2014:

- kpixels, photon-noise limited
- large area (full 4 inches)
- Readout line 2.5 m long !!

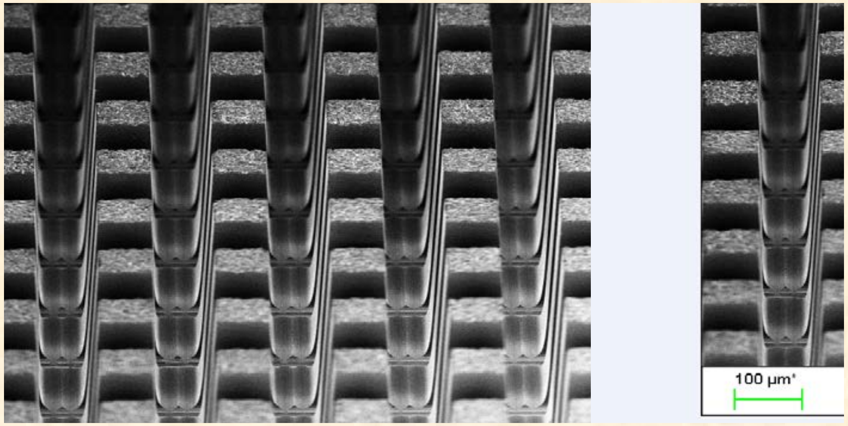
The NIKA2 arrays technology

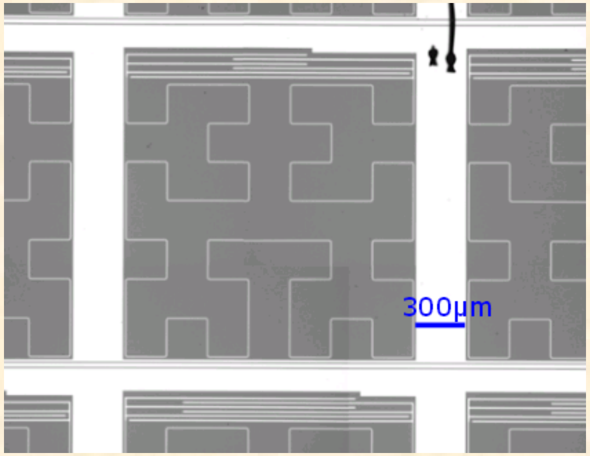


- Pixels are fractal Hilbert-shaped LEKID
- Films: thin Al (18 – 25 nm)
- Different arrays designed/fab/tested:

No AR layer ⟷ AR layer (dicing, etching)

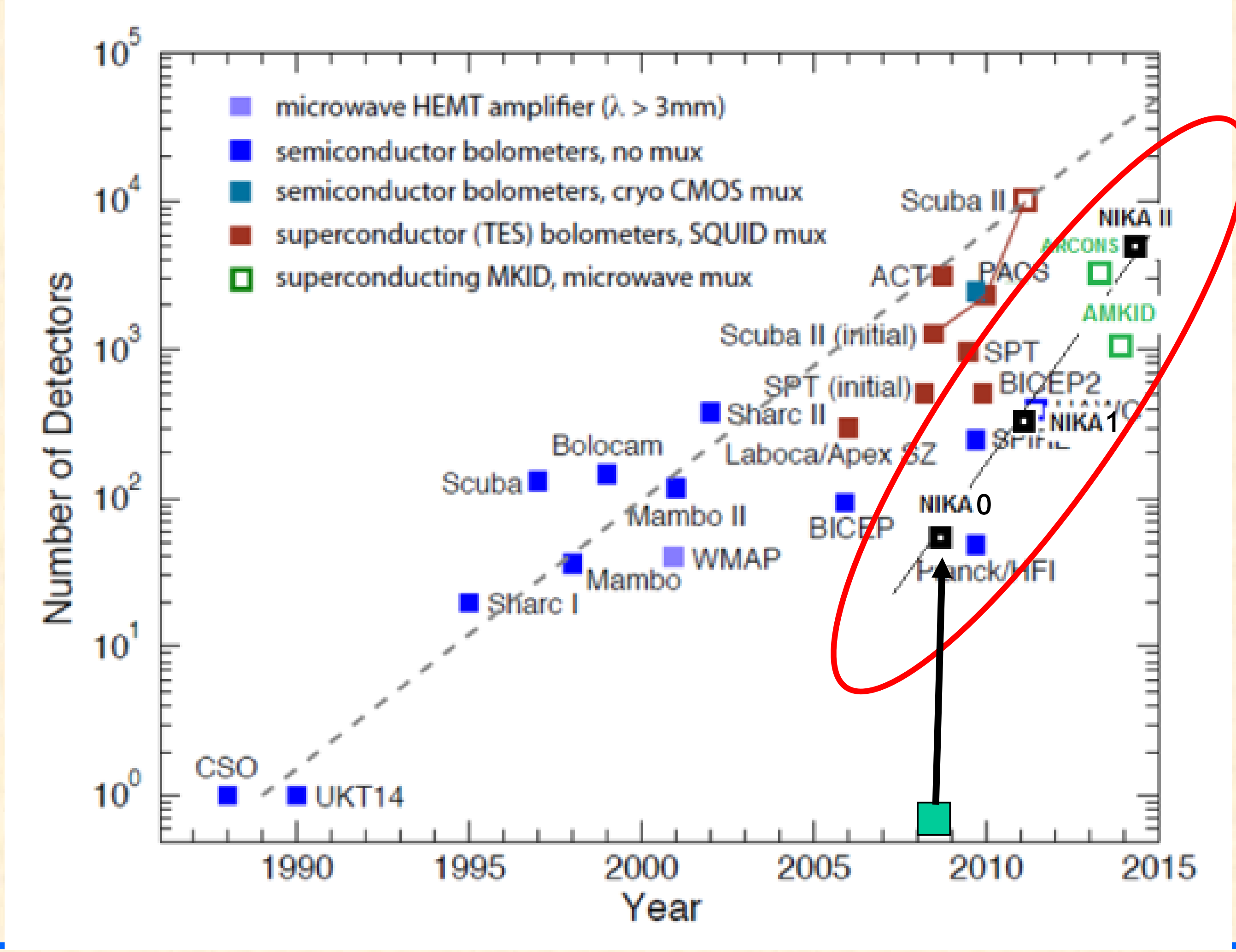
CPW feedline ⟷ **MS feedline**



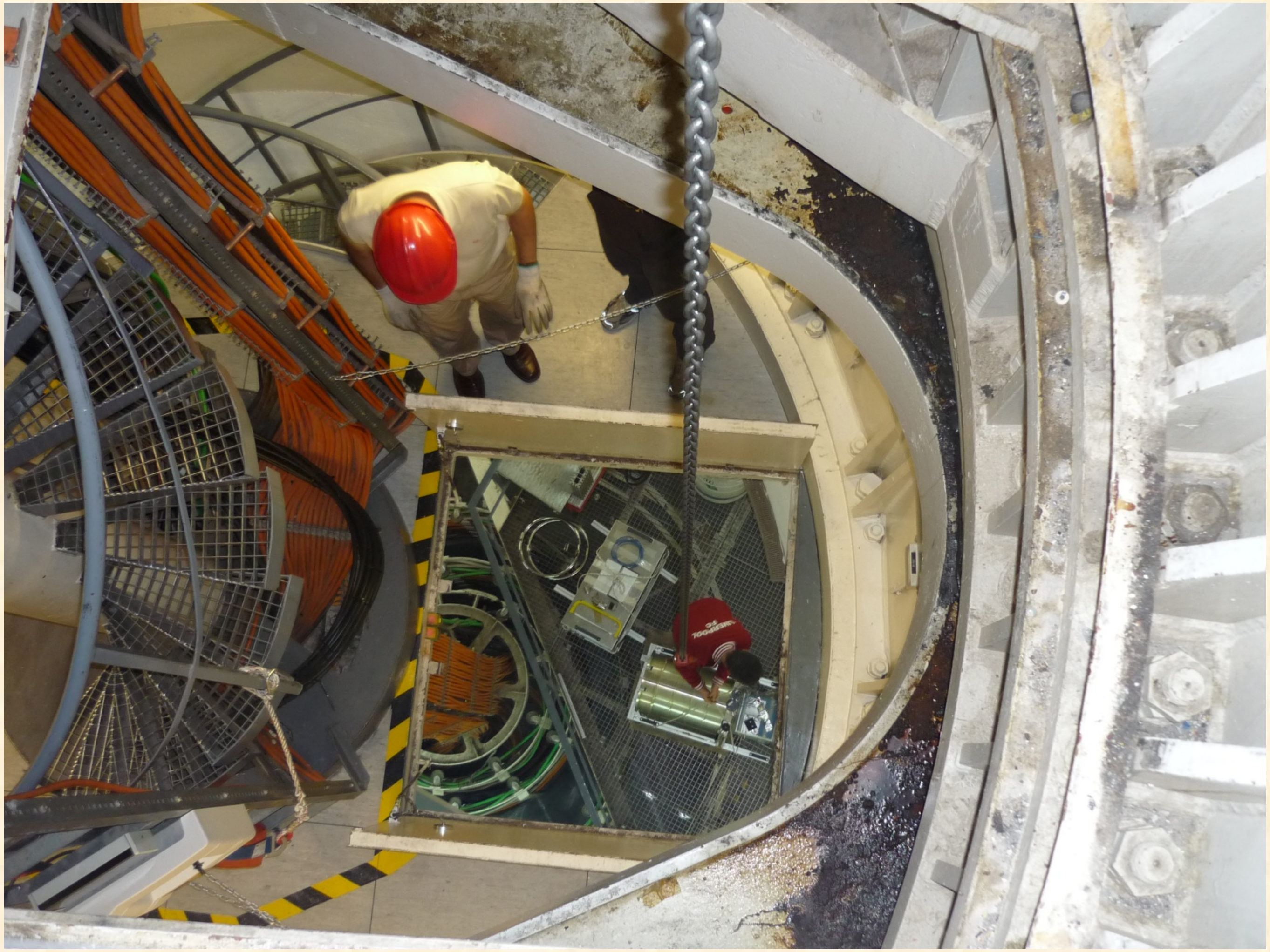


http://ltd16.grenoble.cnrs.fr/IMG/UserFiles/Images/06_GOUPY-LTD16.pdf

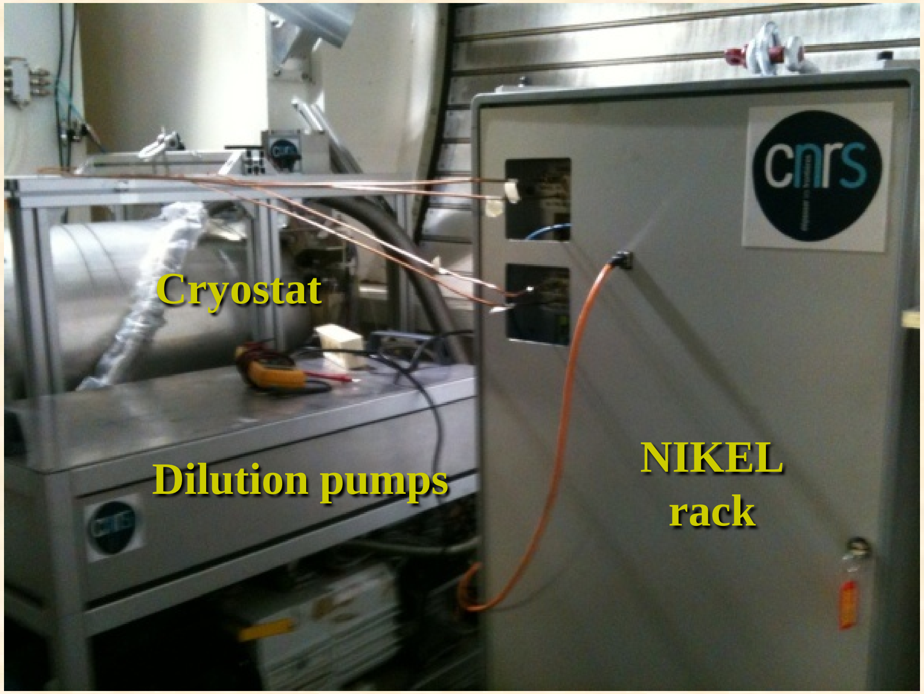
NIKA on the Moore plot !!

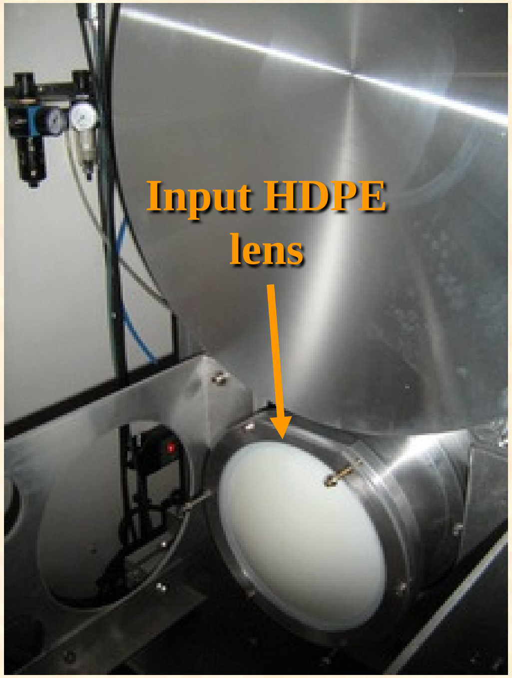


... not in clean-room today ?



NIKA at the 30m





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NIKA at the 30m

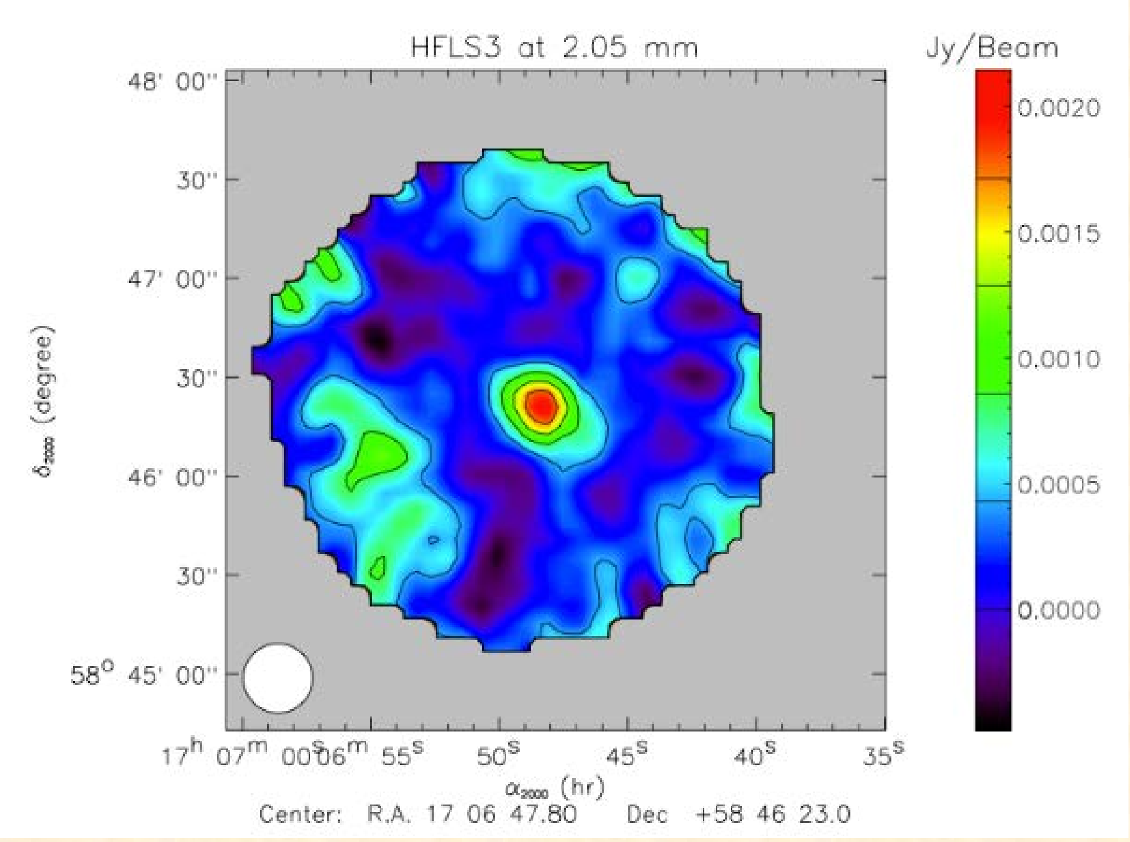
NIKA seeing glows in the Dark Age

$z \approx 6.34$

Intense starbust galaxy

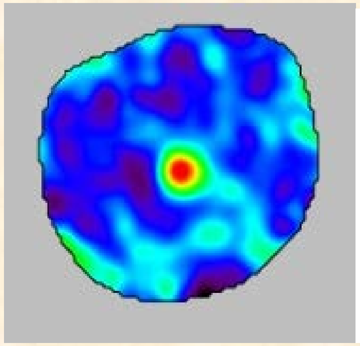
Producing 3000 $M_\odot$ per year

Milky Way ≈ 1 Sun per year

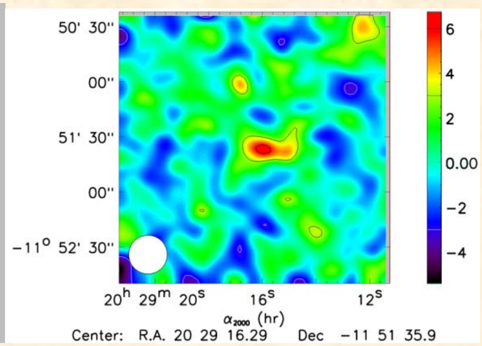


Looking 13 billions years in the past !! Universe only 0.88 Gyr old.

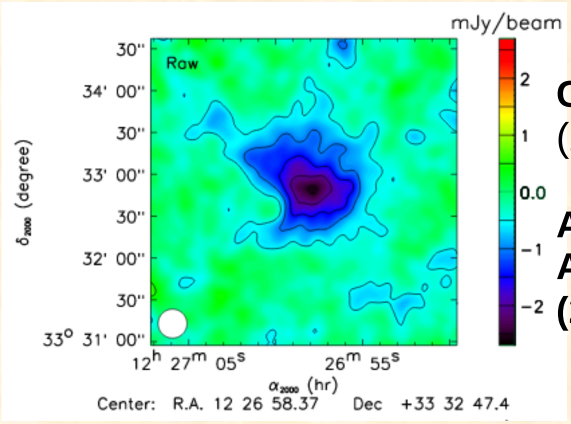
Selected NIKA images



Pluto at 150GHz

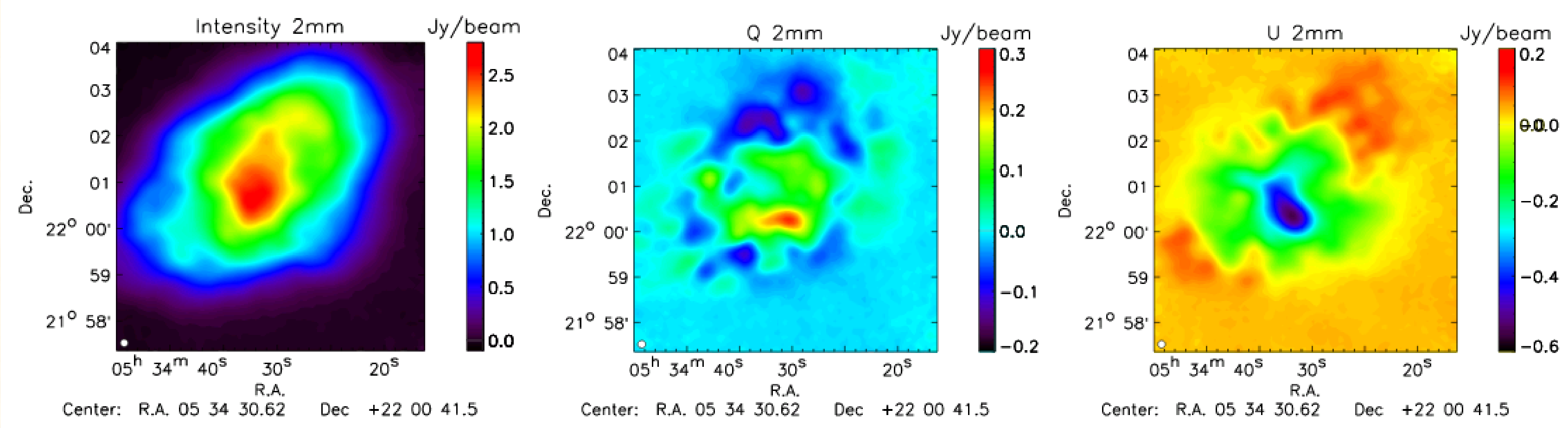


GRB121123A



CL J1226.9+3332
(z = 0.89)

Adam et al., A&A 576, A12 (2015)

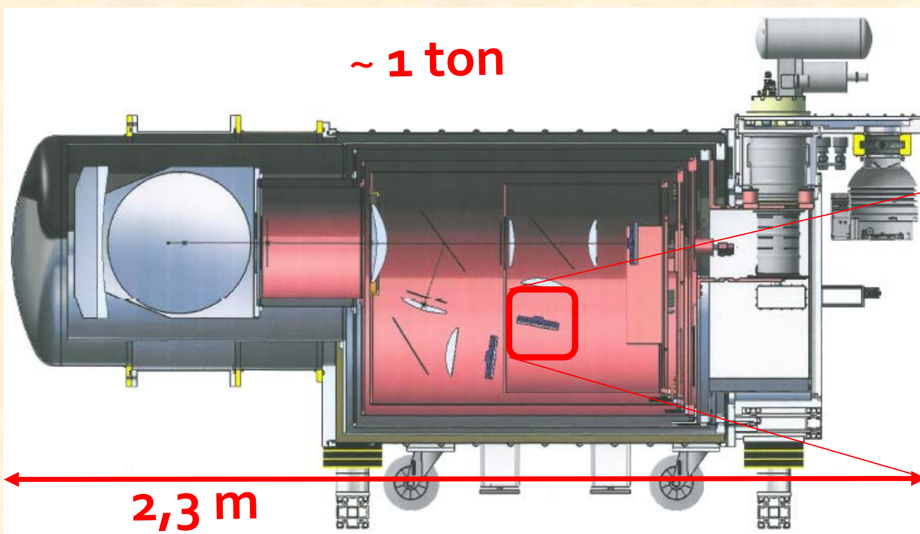


The Crab nebula – Intensity and polarisation (A. Ritacco et al., arXiv:1508.00747)

NIKA2 fabrication in Grenoble (2013-15)

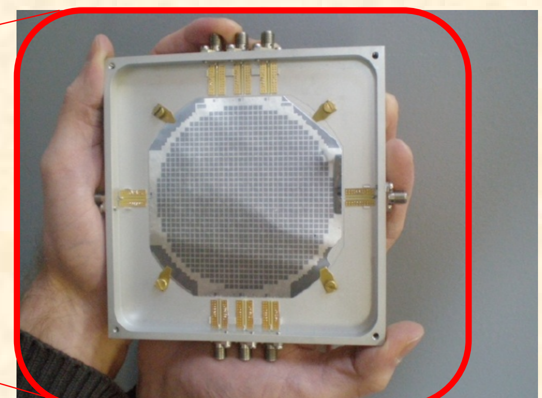
Goals et Varia

- 6.5 arc-min FoV (≡ IRAM 30m)
- Close to background-limited
- Dual-band imaging + polarization
- Derived from NIKA R&D



Characteristics

- **Dual-band (1.25mm and 2mm)**
- **Polarization @ 1.25mm**
- KID Arrays Detectors:
  - **1000 pixels @ 2mm**
  - **2 × 2000 pixels @ 1.25mm**
- NIKEL Read-Out Electronics



A. Monfardini et al., arXiv:1310.1230

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NIKA2 is real !

It's *massive* :

- 1.1 ton
- 2.3m length
- 2 Pulse Tubes
- ≈ 3000 pieces
- ≈ user friendly!

Fully operational, fully equipped (optics, detectors)

- > 20 cooldowns
- Base T ≈ 100mK
- Full remote operation + cryogen free
- **Going to the telescope in 2 weeks**

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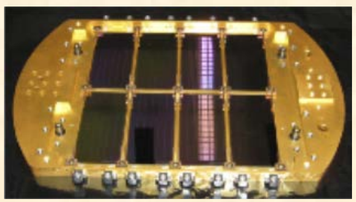
More instruments using KID

MUSIC and MAKO (US)

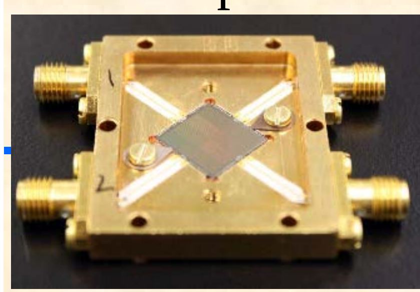
- 10.4 m CSO telescope (Hawaii)
- Mm and sub-mm (MAKO) bands
- Antenna-coupled (MUSIC) and LEKID (MAKO):



  - 2,304 pixels (MUSIC)
  - 100s pixels (MAKO)

ARCONS (US)

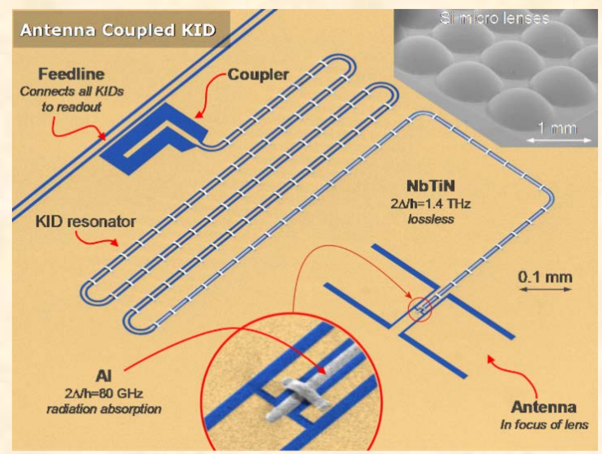
- 5 m Palomar telescope (visible)
- Counting/measuring visible photons
- Lumped Element KID:



  2,024 pixels

A-MKID (EU)

- 12 m APEX telescope (Chili)
- Two sub-mm bands (350 and 850 GHz)
- Antenna-coupled KID:
  - 3,500 pixels @ 0.85mm
  - 20,000 pixels @ 0.35mm (PLANNED)
  - Bonn FFTS read-out



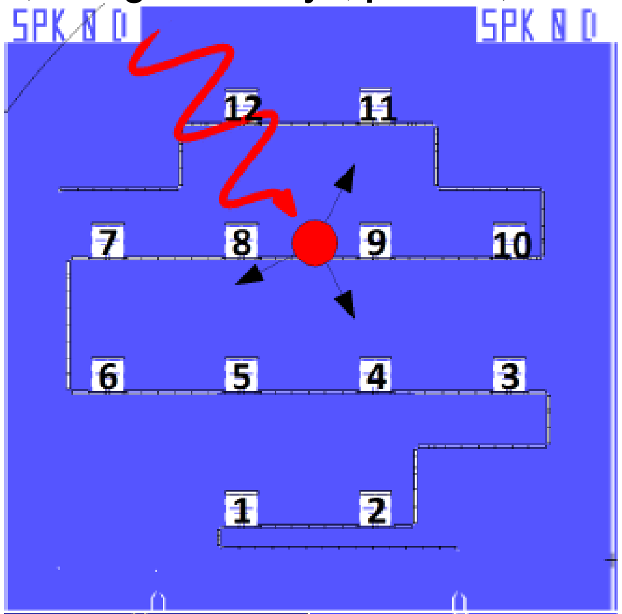
More applications:

- High energy impacts imaging/spectra
- Fundamental Hydrodynamics studies
- London Depth sensors
- Fundamental superconductivity studies

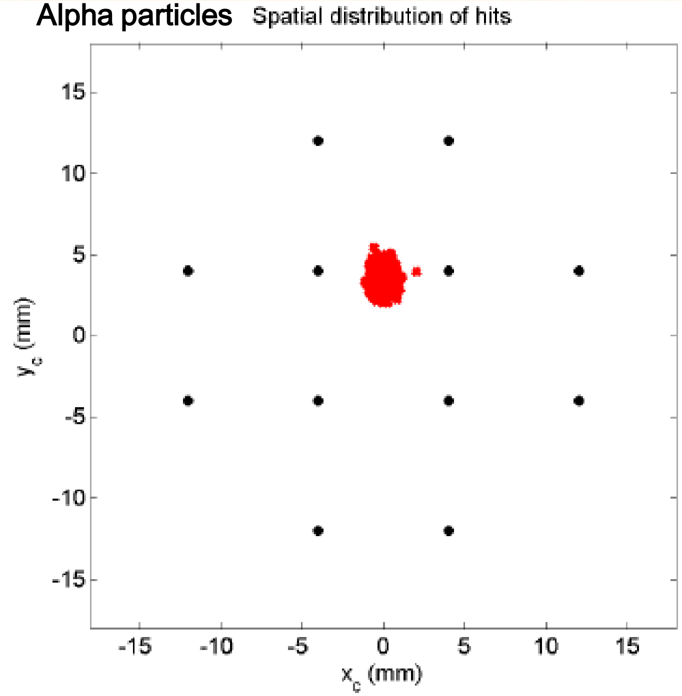
…… a lot more would be possible

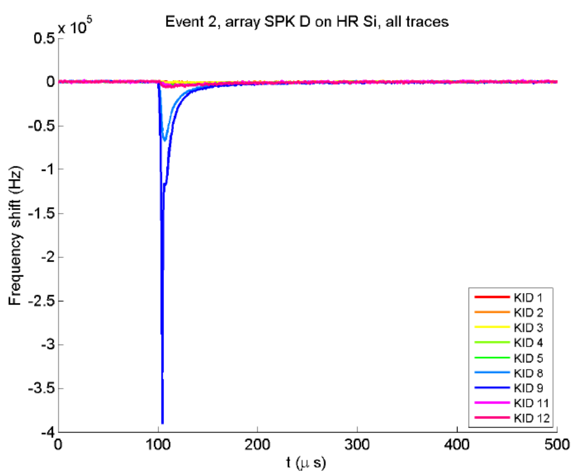
A-thermal phonons-mediated imaging

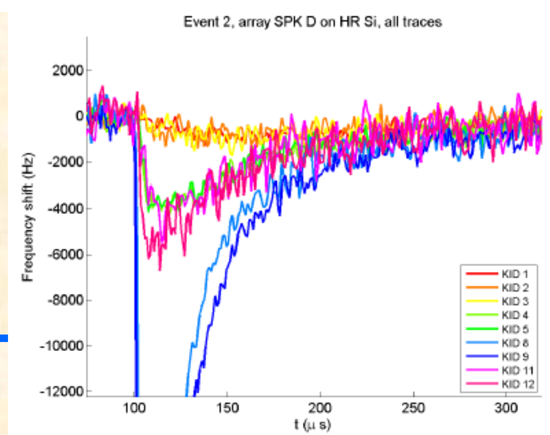
Alphas, x or gamma rays, protons, muons etc.



Alpha particles

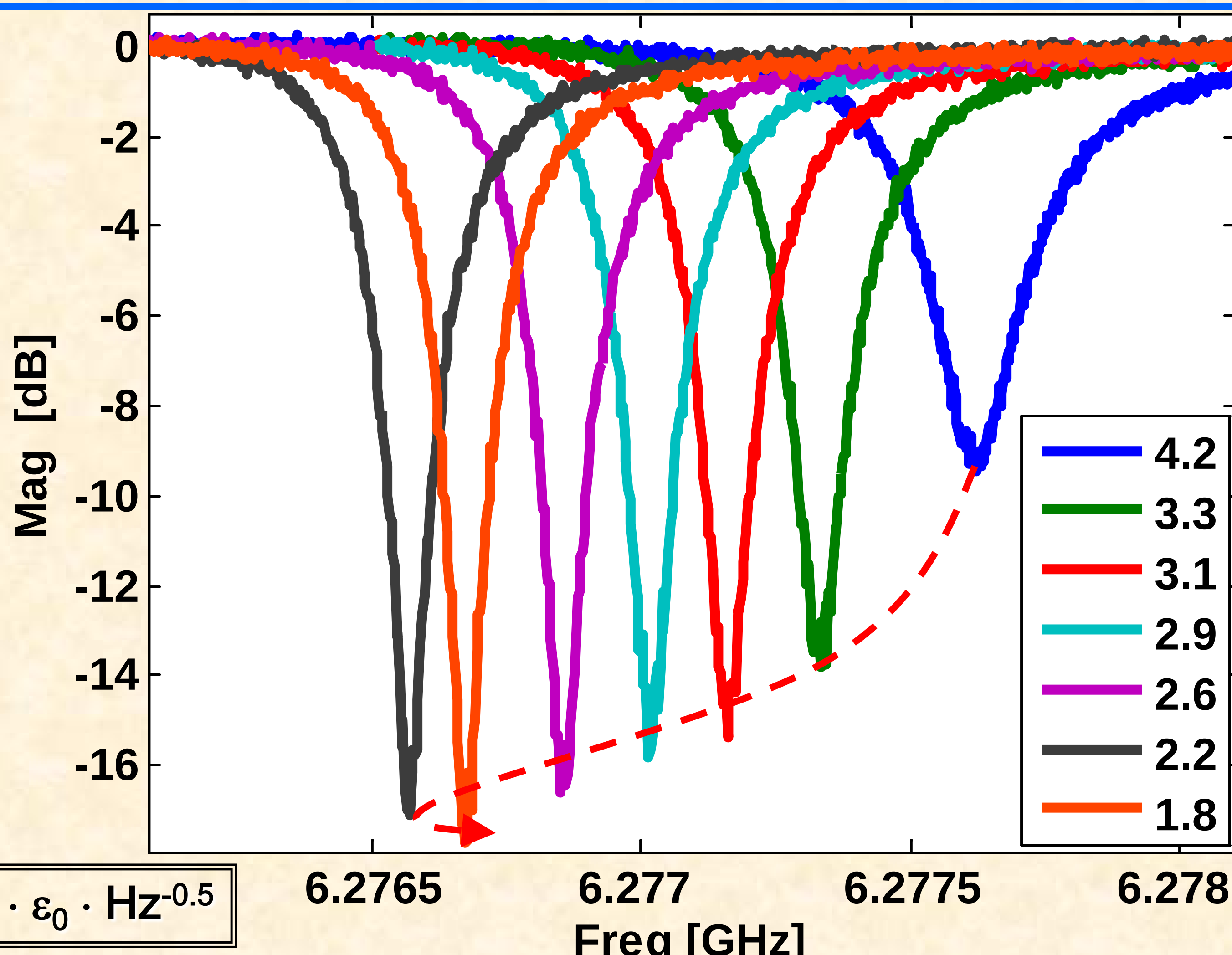






2015

EM sensitivity: NbN resonators in LHe



G. Grabovski et al., APL (2008)

$\varepsilon_r \approx 10^{-11} \cdot \varepsilon_0 \cdot \mathrm{Hz}^{-0.5}$

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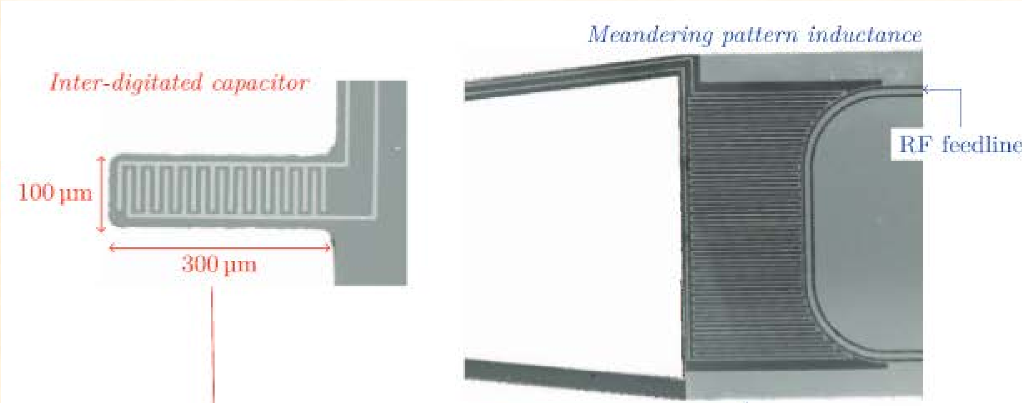
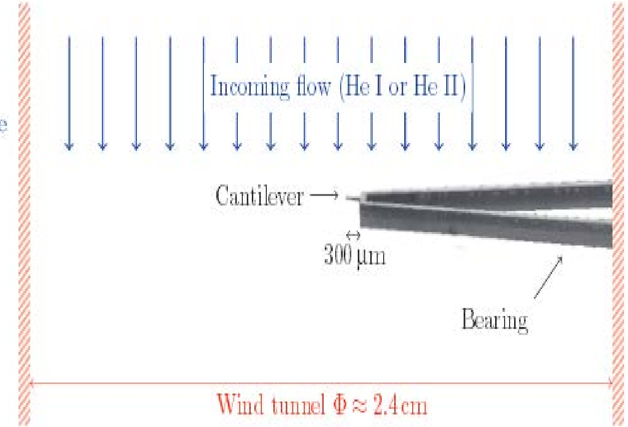
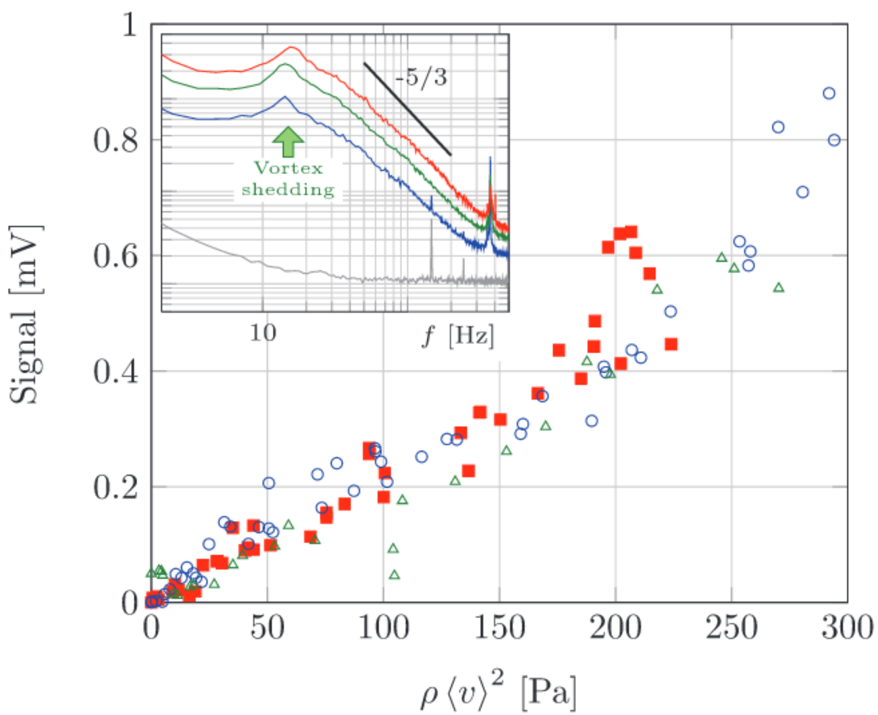
Superfluid LHe turbulence

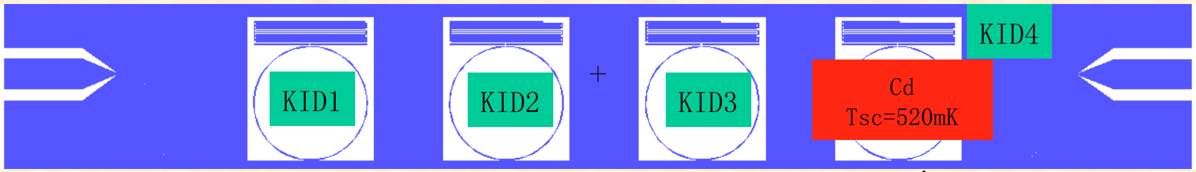




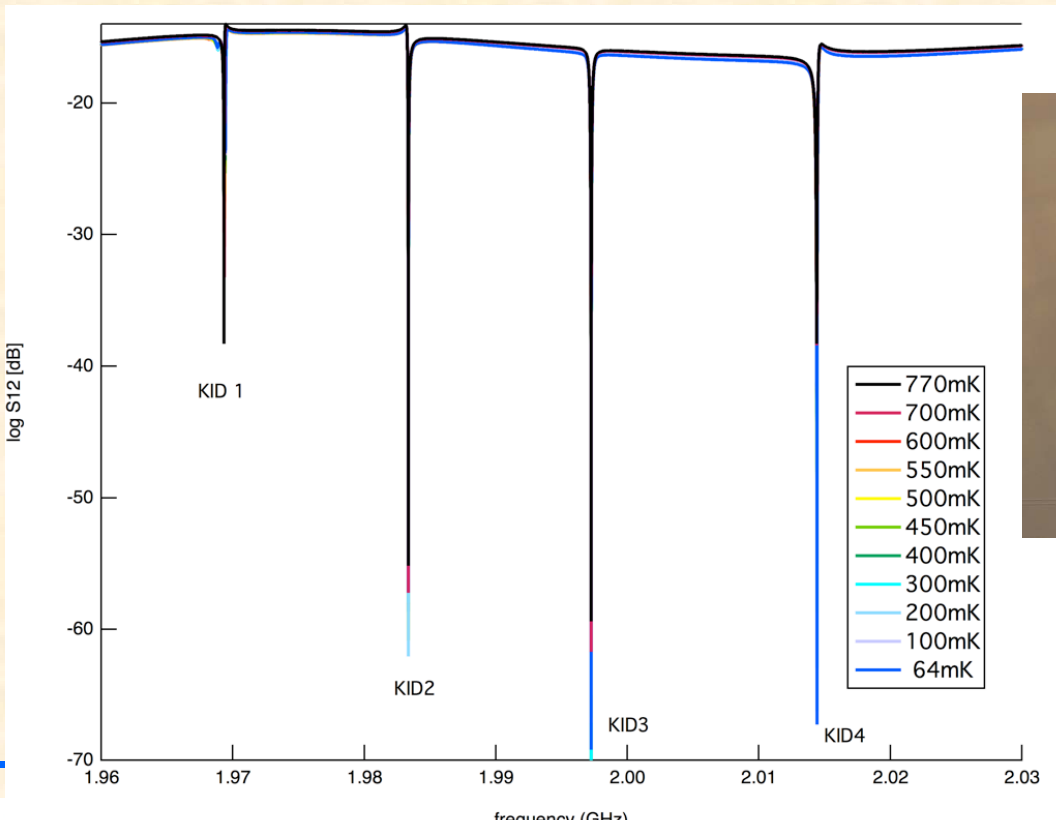


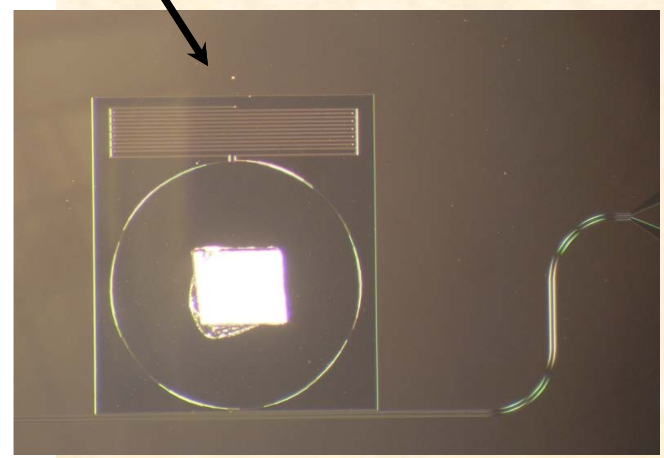
J. Salort, A. Monfardini and P.-E. Roche, Rev. Sci. Instrum. 83, 125002 (2012)

Resonators as London depth sensors



$V_s(\omega)$





Collaboration with
P. Rodiere, F. Levy-Bertrand
Institut Néel

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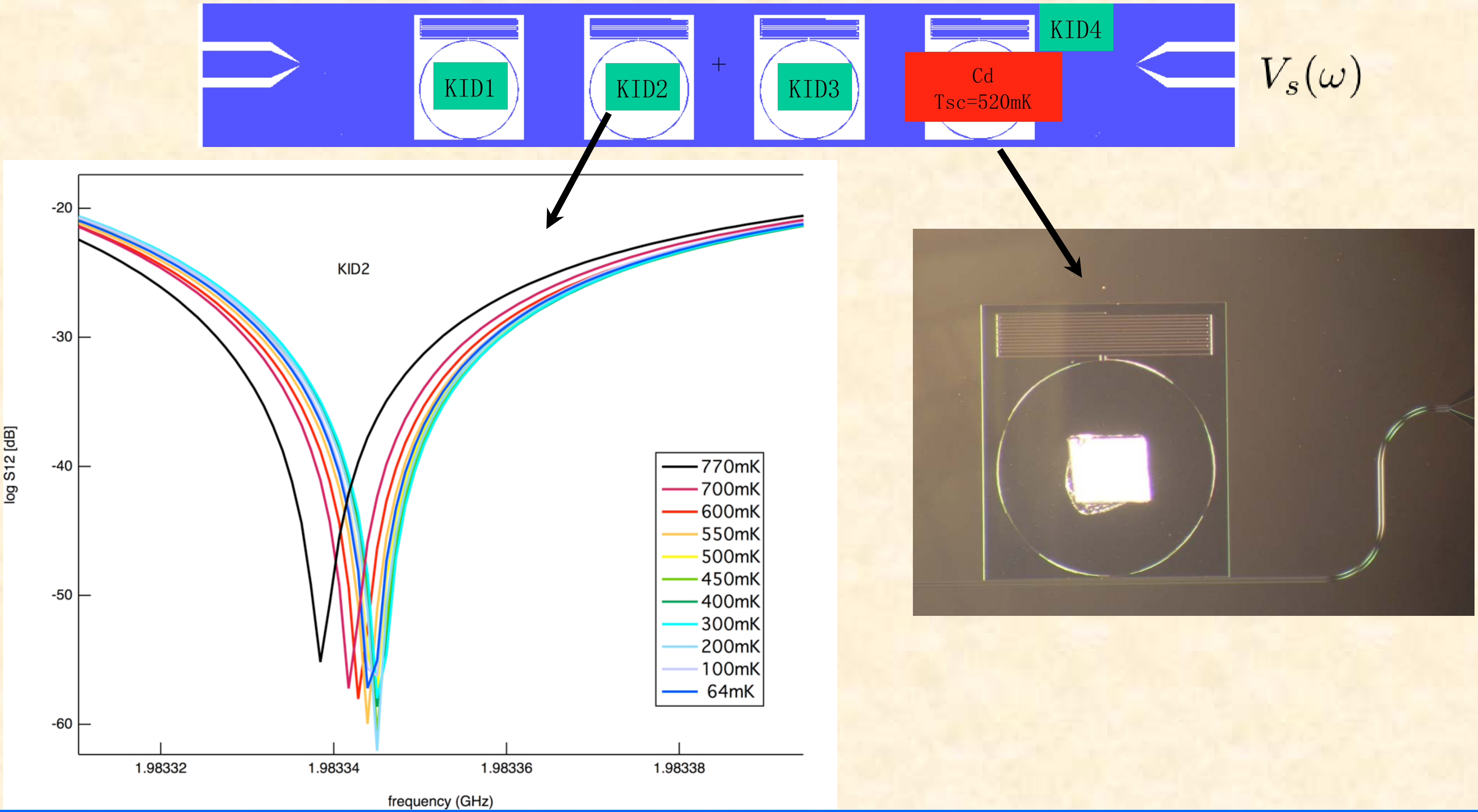
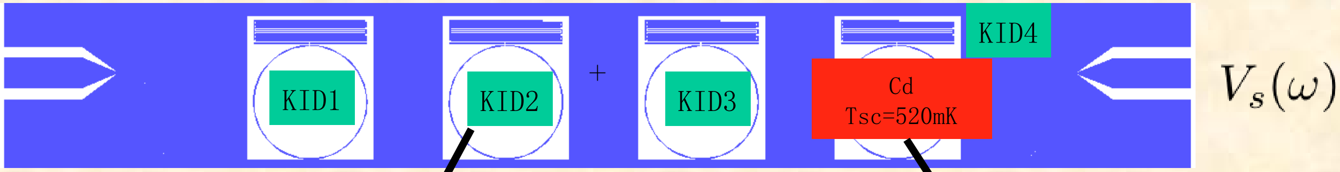
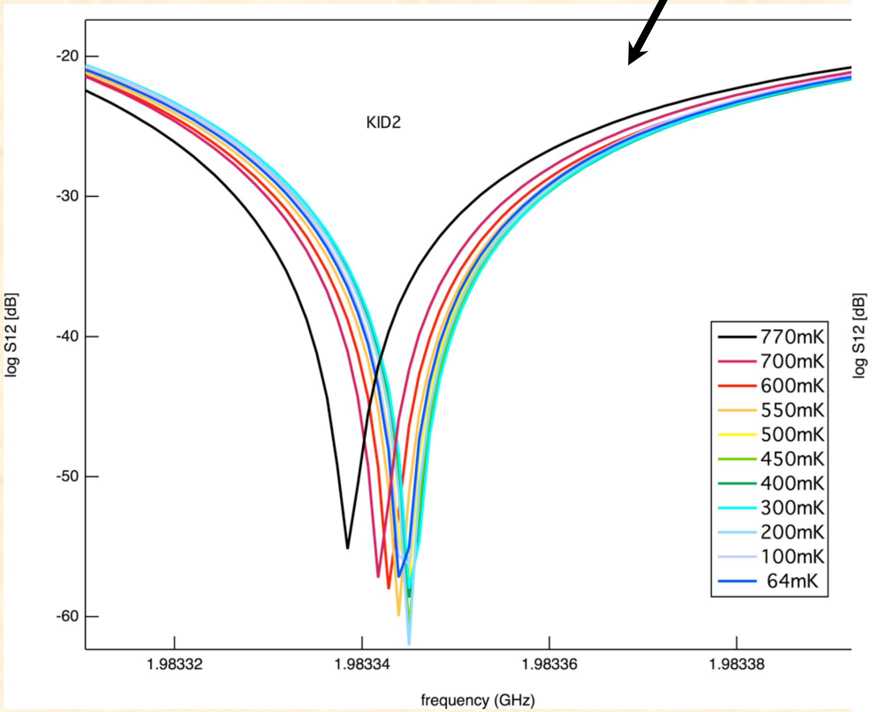
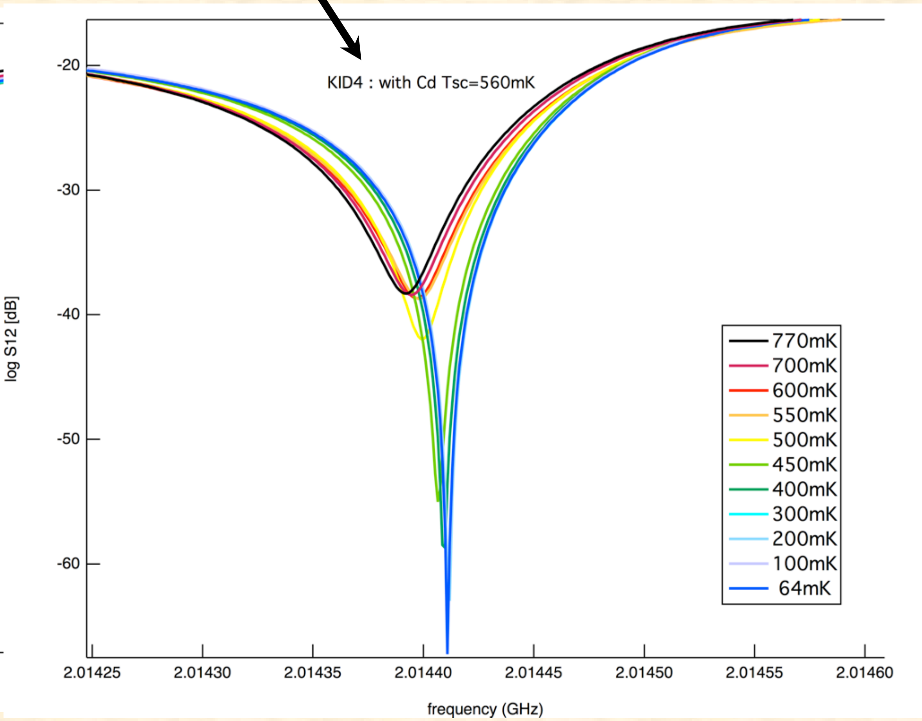
Resonators as London depth sensors



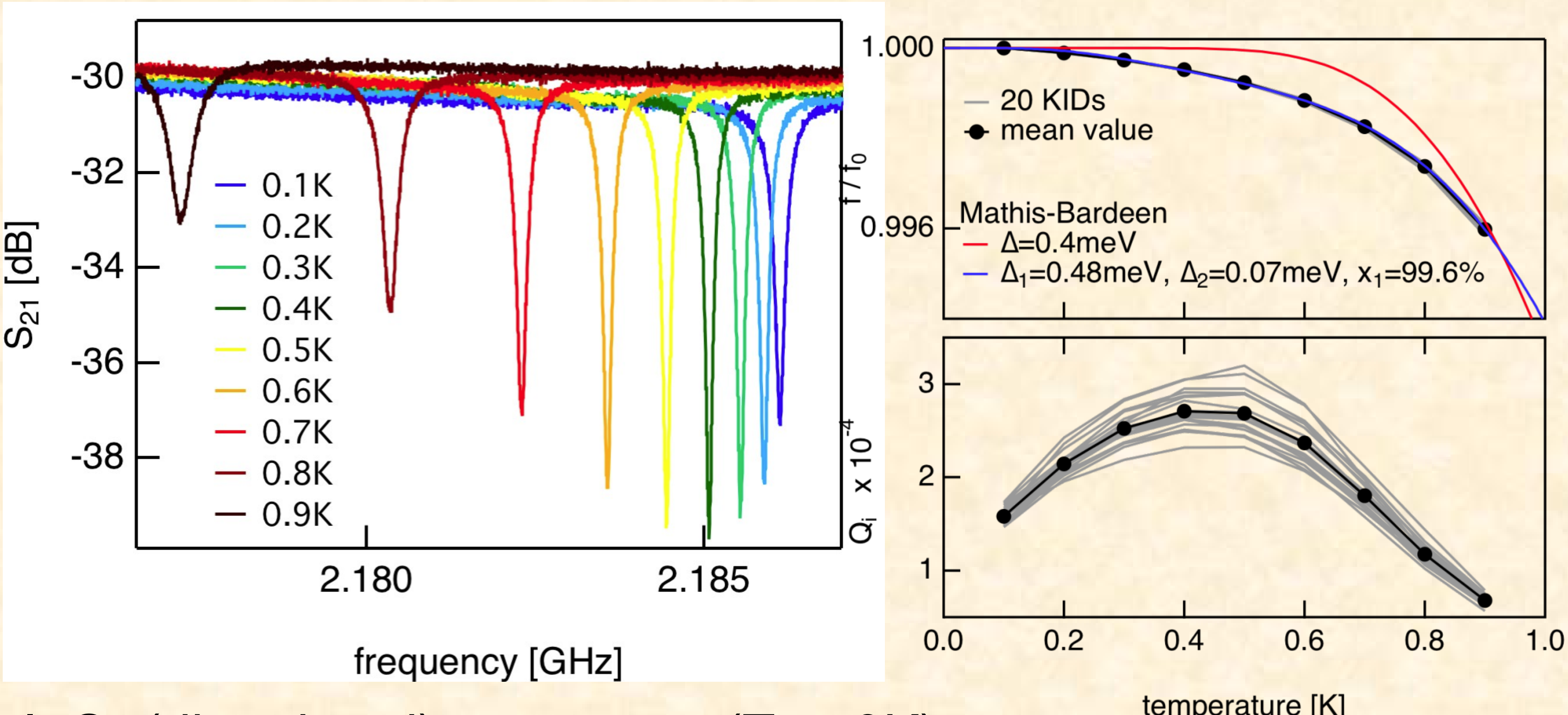
Resonators as London depth sensors







Superconductor films fundamental studies



InO_x (disordered) resonators ($T_c \approx$ 3K)

Study of fundamental superconducting thin films properties (collaboration with B. Sacepe, F. Levy-Bertrand – Institut Néel)

Thank you for your attention !!