Development of Kinetic Inductance Detectors in Grenoble

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Outline

1 – A ground-based KID instrument: NIKA2

2 – KID for higher frequencies (>300GHz)

3 – KID for lower frequencies (<100GHz)

4 – Getting ready for space...

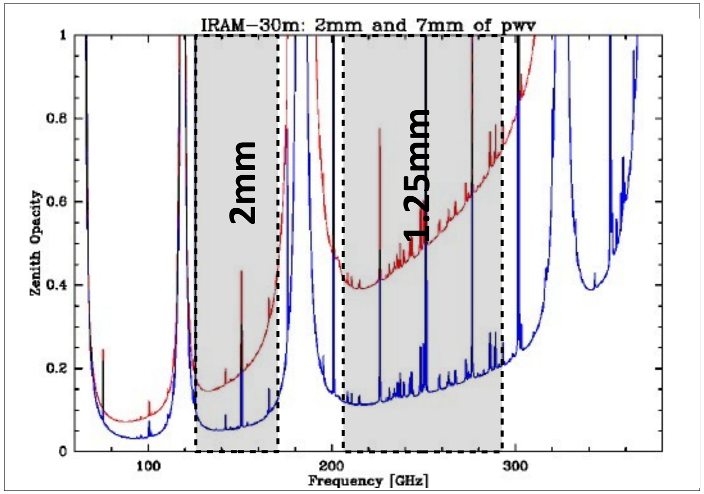
The IRAM 30m telescope

One of the largest single-dish antennas worldwide for the millimetric band

- 30 m aperture
  - 17 arcsec @ 2mm
  - 12 arcsec @ 1.25mm
- Correct Field Of View up to **6.5 arcmin**
- Multi-bands measurements

*Thousands of ultrasensitive detectors → **KID!***

Sierra Nevada (Spain) @2900m a.s.l.

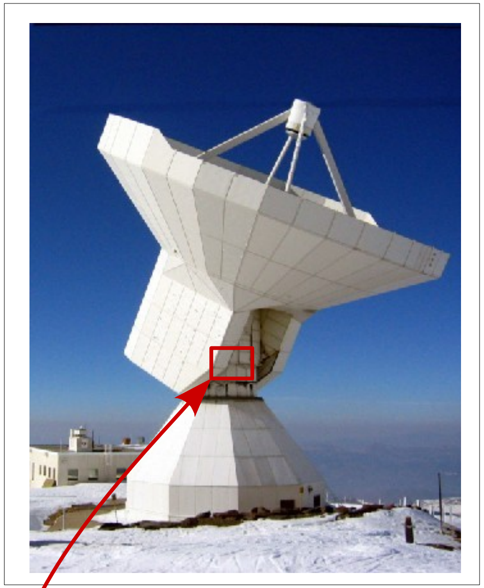


A unique tool for mm-wave astronomy!

The NIKA2 camera

NIKA: the first KID based camera open to external astronomers!

NIKA2: New IRAM KID Array 2

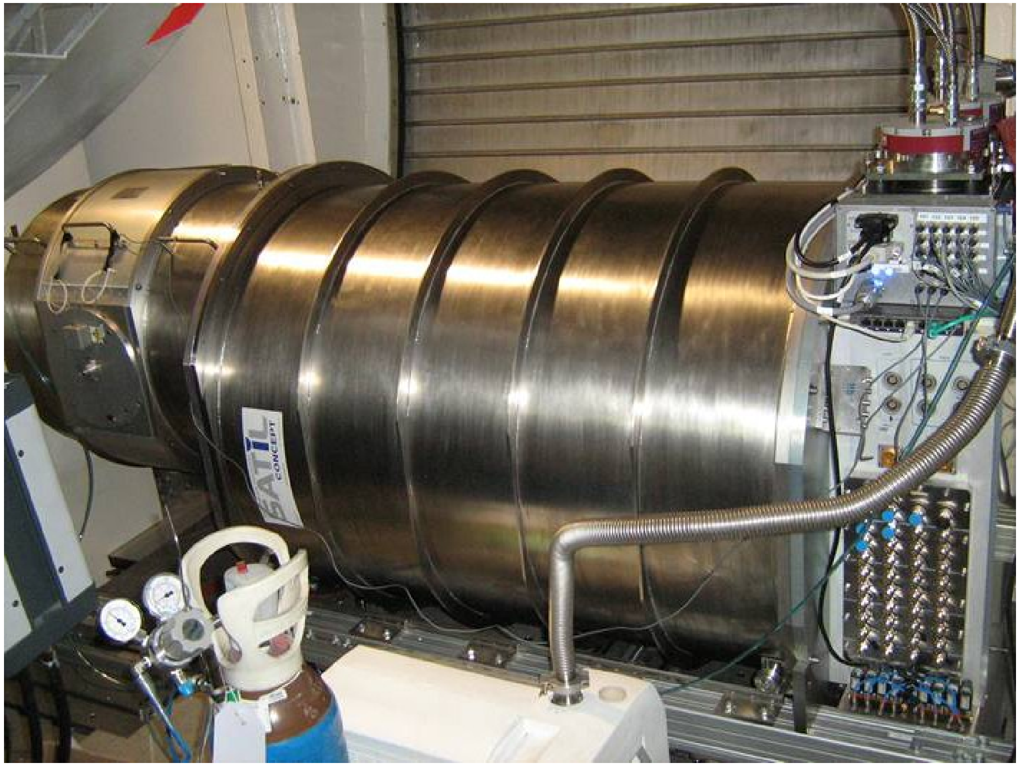


- Correct FOV: ***6.5 arcmin***
- Total pixel count: ***≈ 3000***
- Arrays count: ***3 (2mm + 2 x 1.25mm)***

The new generation photometric instrument for the 30m telescope

On site since last October! (…and for the coming 10 years…)

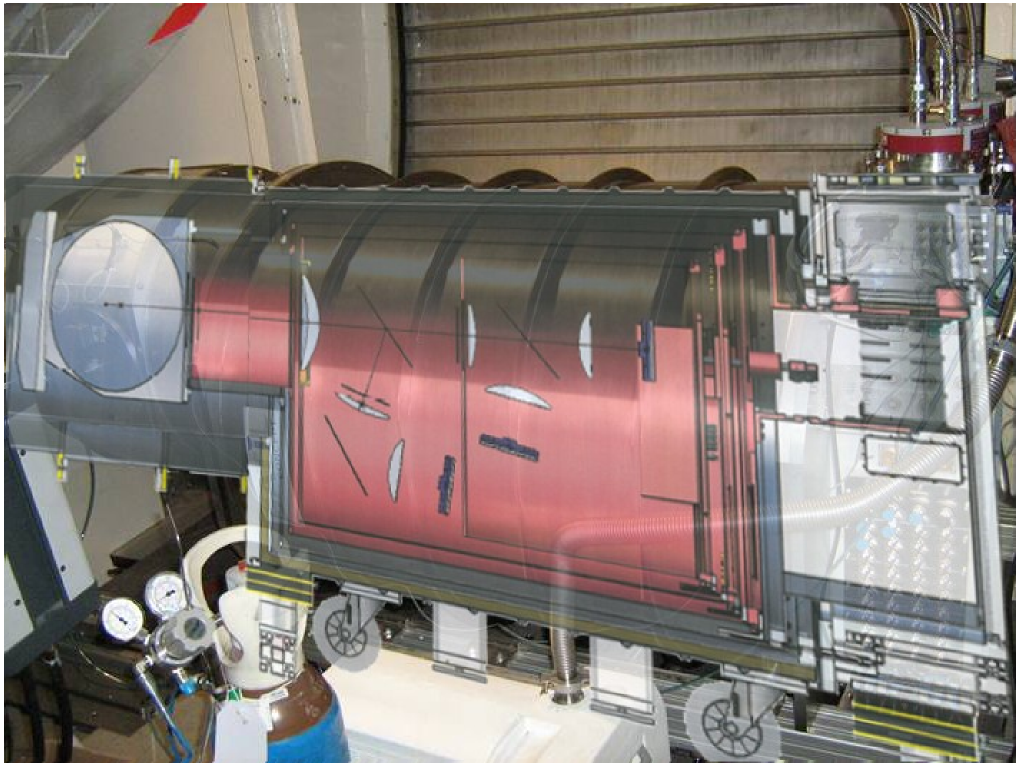
A NON-space-like cryostat!



The cryostat :

- **1.3 ton**
- 2.3m length
- Full remote operation
- Cryogen free
- Base T ≈ 150mK

A NON-space-like cryostat!



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The optics :

- Splitting achieved using quasi-optical elements

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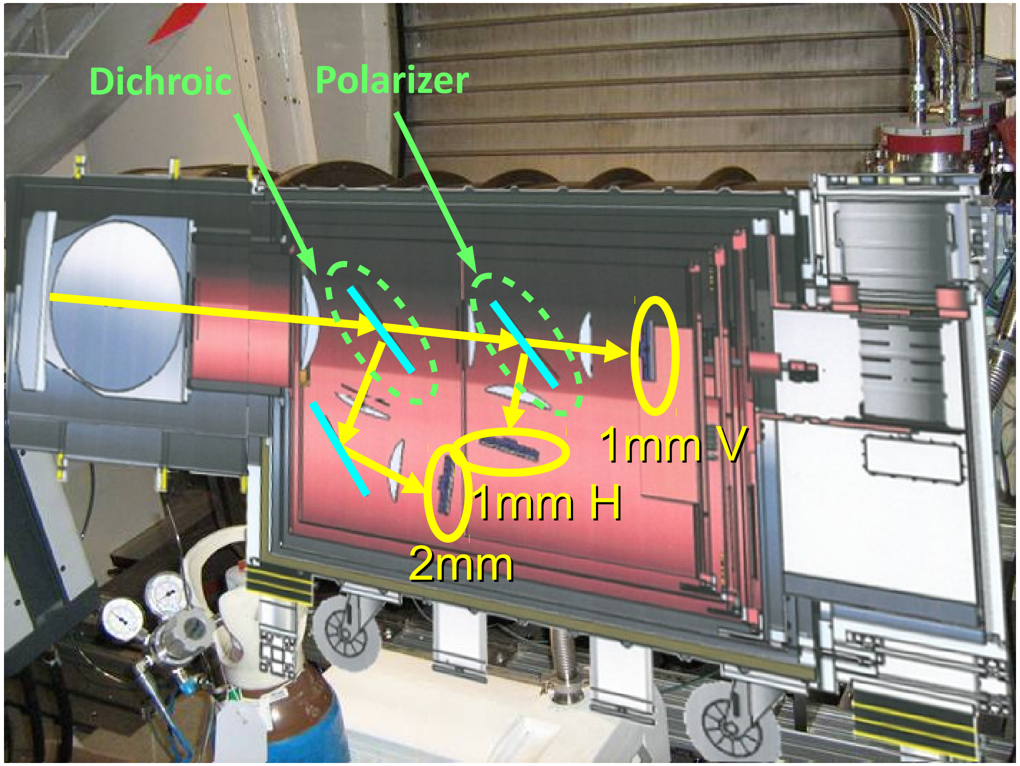

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- **1.3 ton**
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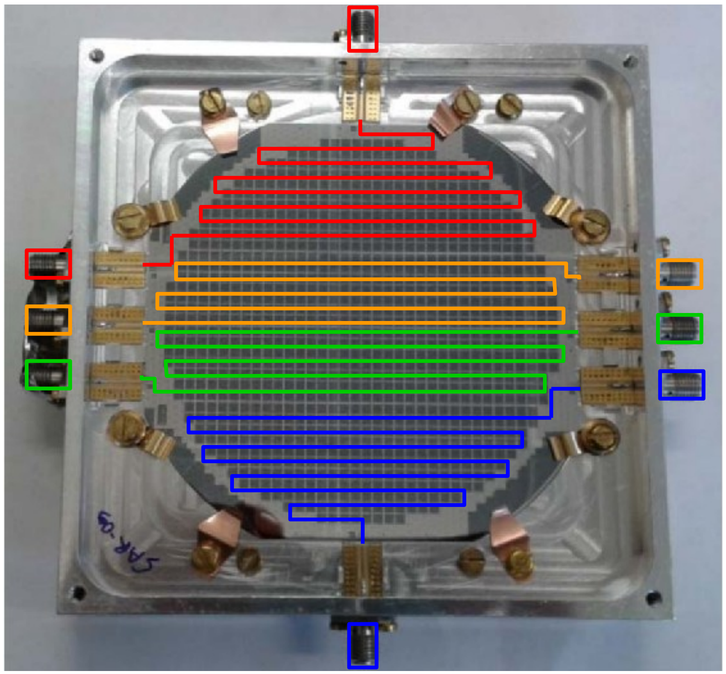
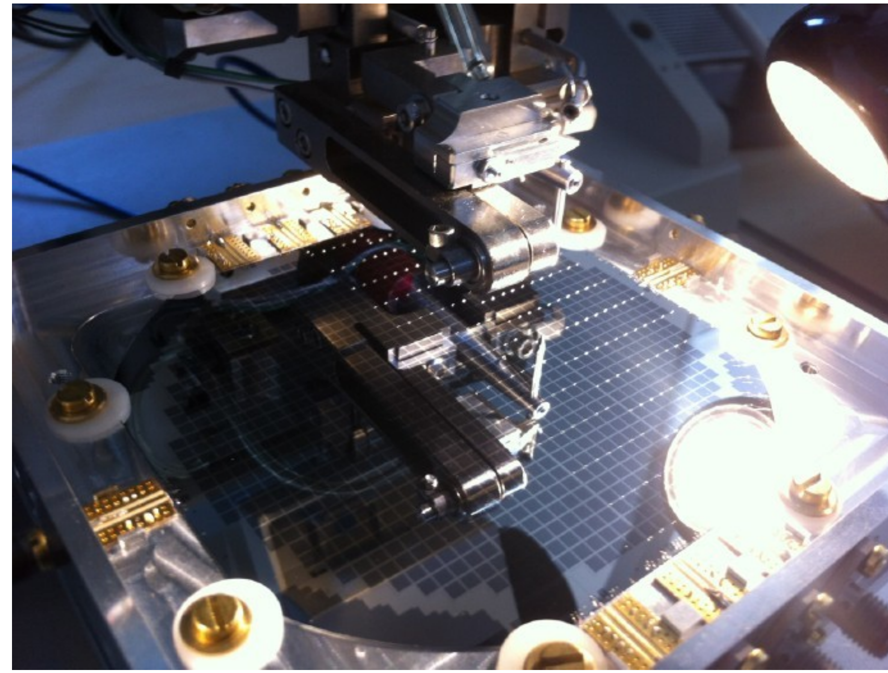
The optics :

- Splitting achieved using quasi-optical elements
- 2 colours, + 2 polarizations at 1mm

NIKA2 KID arrays



1000 pixels 2mm array



O. Bourrion et al., 2012 JINST 7 P07014

- 2mm: 600÷1000 pixels → 4 feedlines
- 1.25mm: 1200÷2000 pixels → 8 feedlines

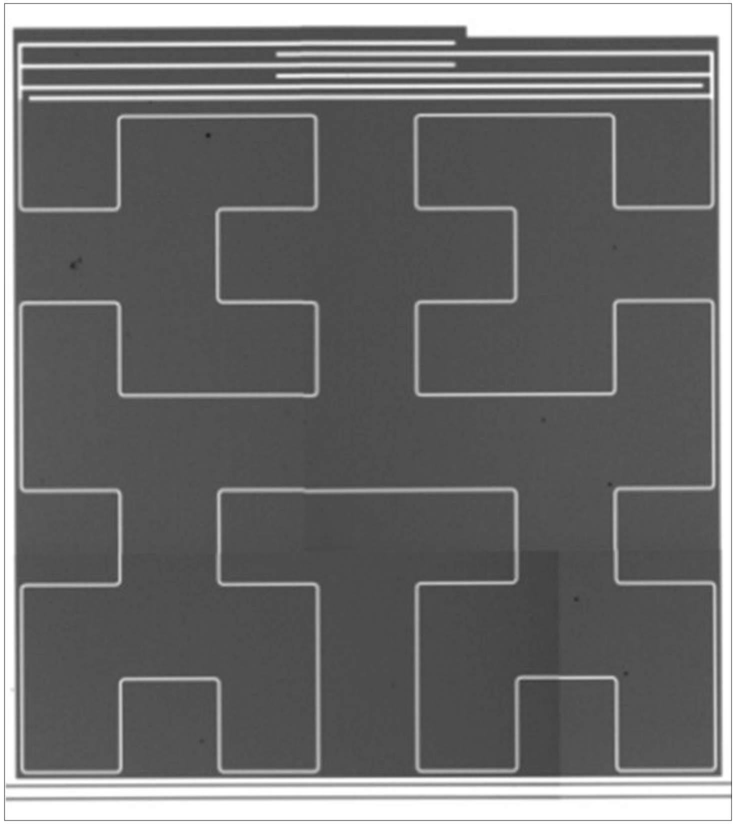
Single 4'' wafer fabrication

NIKELv1 boards: MUX factor 400 over 500MHz band

Current MUX factor: ***250*** (for safety + Q_i on ground!)

The 'house specialty': Hilbert LEKID

- Hilbert LEKID: a modified version of the standard LEKID design



Hilbert LEKID design, *2-pol*

M. Roesch et al., Proc ISSTT 2011

- Inductive line based on Hilbert fractal pattern
- Inductor = radiation absorber!

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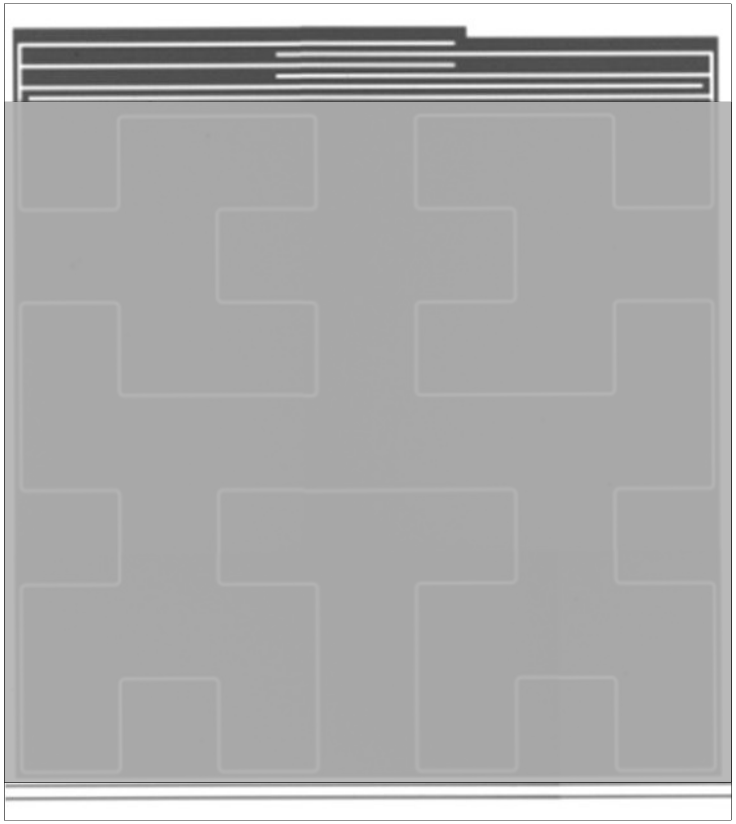

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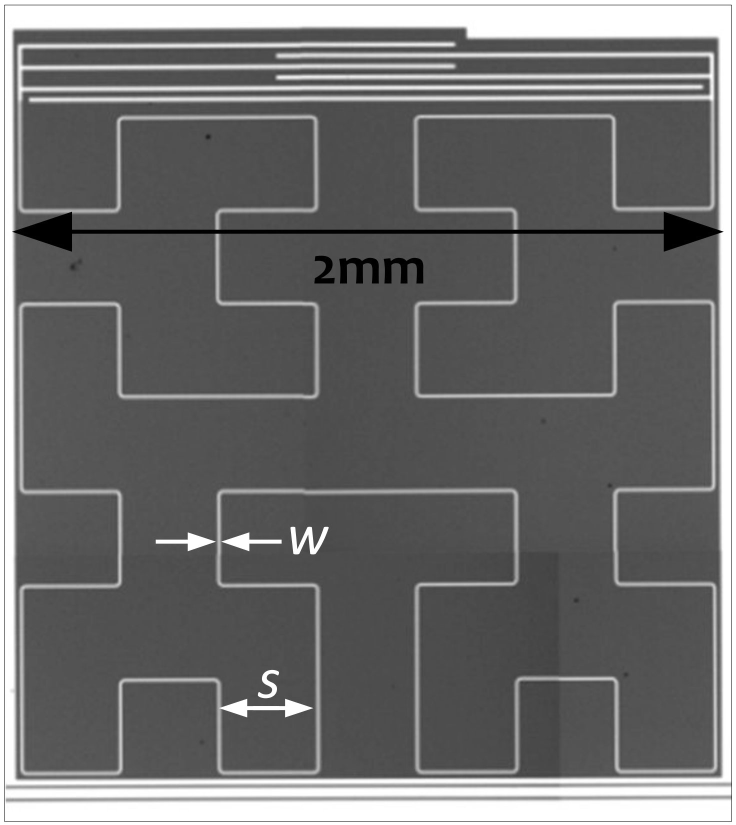

Hilbert LEKID design, 2-pol

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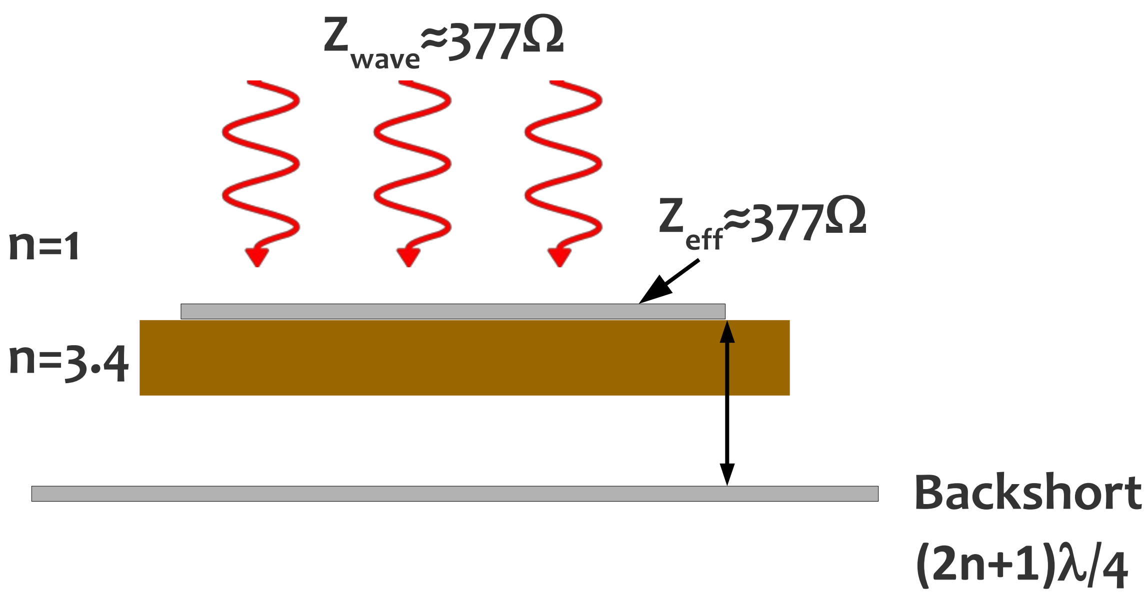
- Need to match Z_{eff} of meander to Z_{wave}

$$Z_{eff} = R_{\square} \cdot (s+w)/w$$

- High absorption efficiency over large band
- NIKA2 pixels based on thin film Al (*<20nm*)
- Feedline: CPW or MS

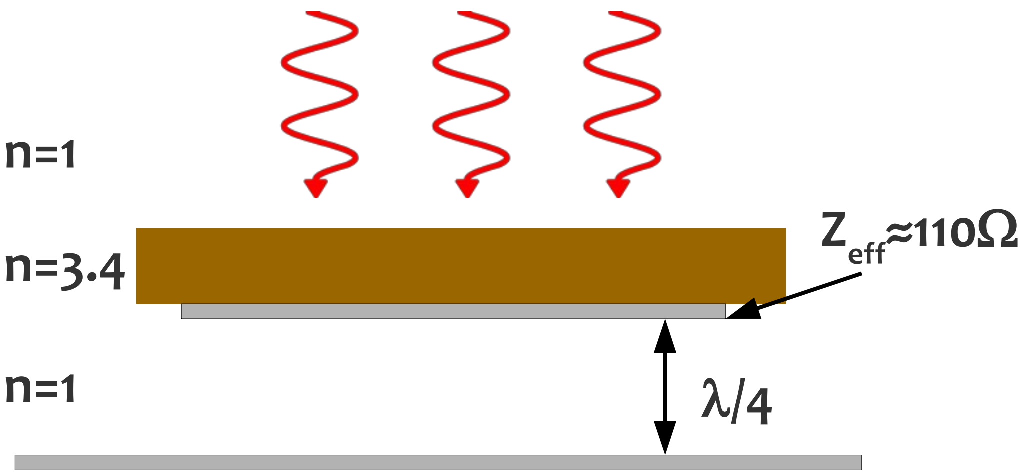
LEKID coupling to radiation

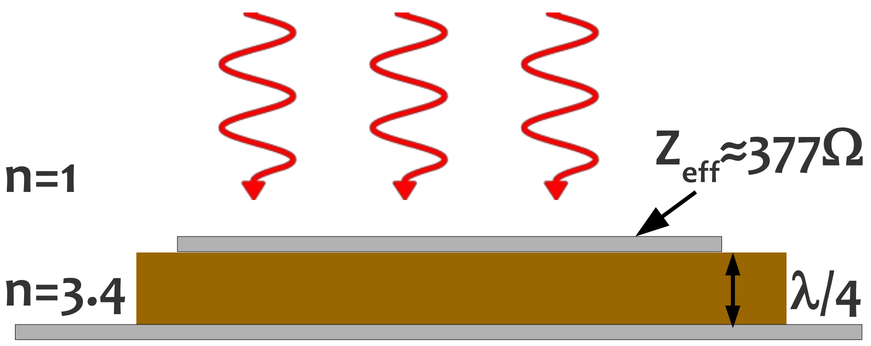
- Basic principle:



LEKID coupling to radiation

- CPW : back-illumination + $\lambda/4$ backshort
- Microstrip : front illumination





LEKID coupling to radiation

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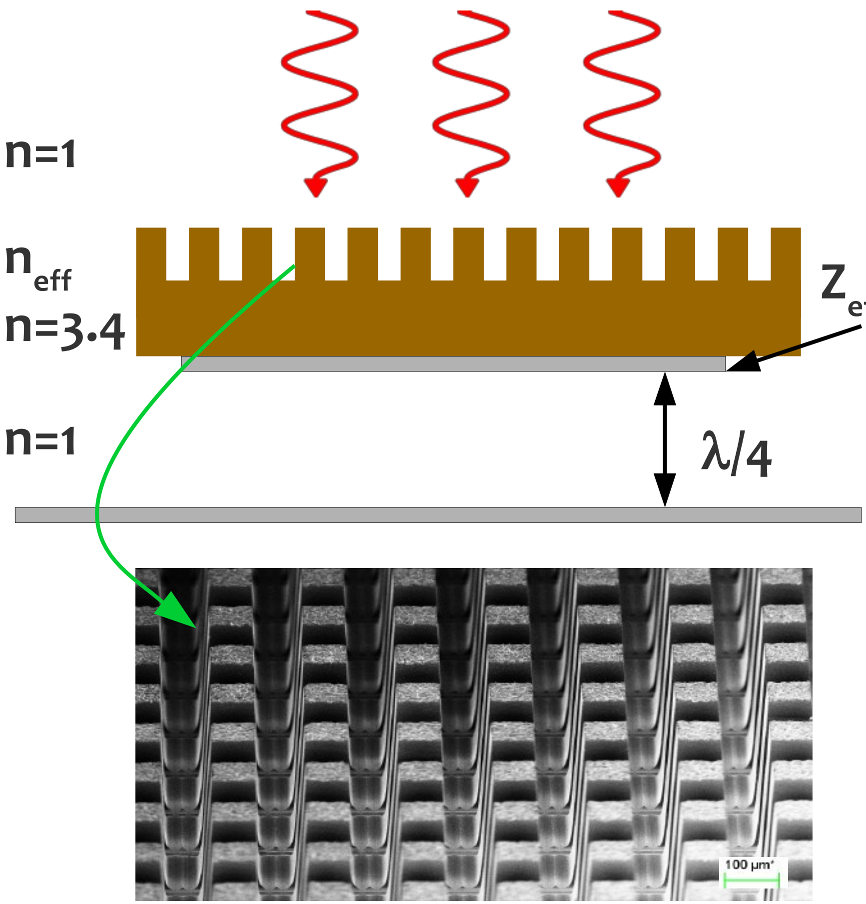
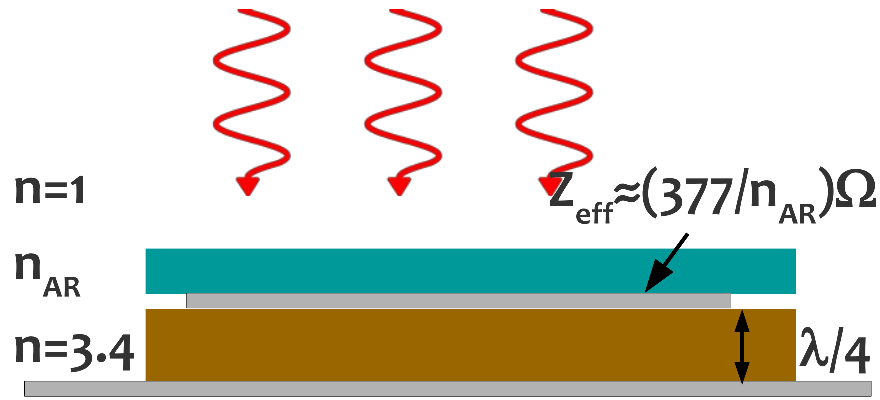
AR coating: integrated



- Microstrip : front illumination

AR coating: external



BI: ideal for large band applications

η > 60% over 100% band

FI: ideal for narrower bandwidths

$\eta_{max} \approx$ 100% at center of 30% band

Lab characterization testbench

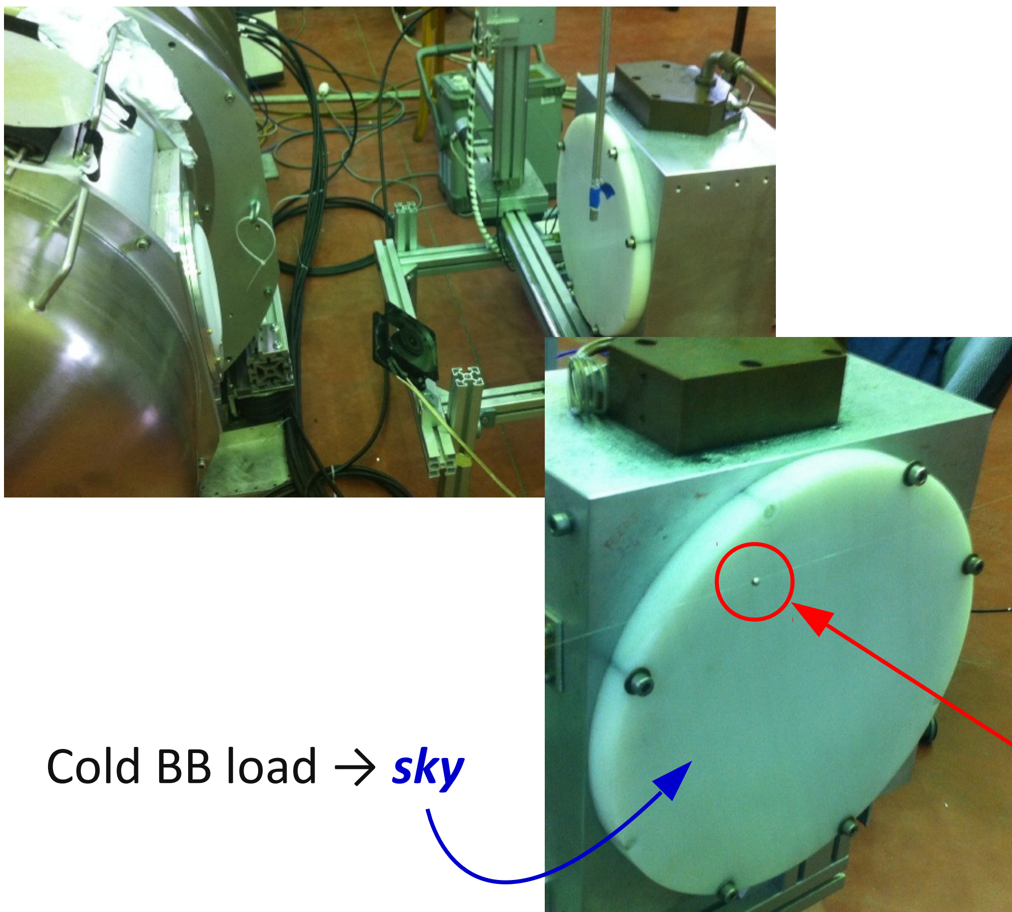
Available tools allow to fully characterize the arrays:

- Sky simulator

  beam maps/responsivity

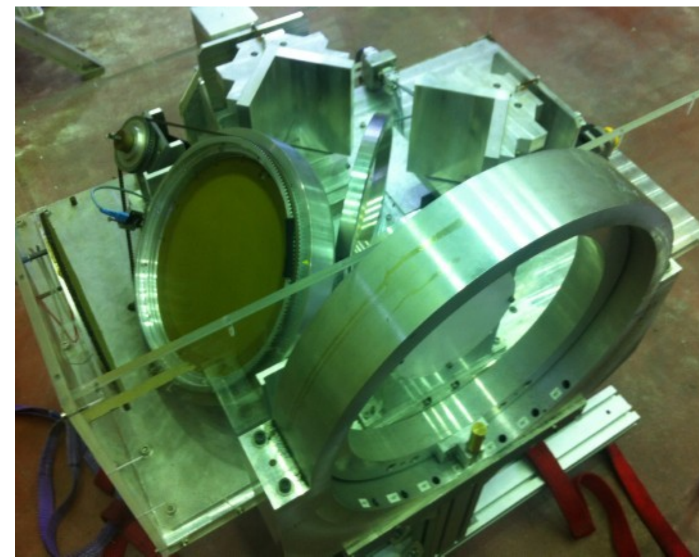
- Martin-Pupplet interferometer

  absorption spectra



Cold BB load → ***sky***

A ***planet*** !

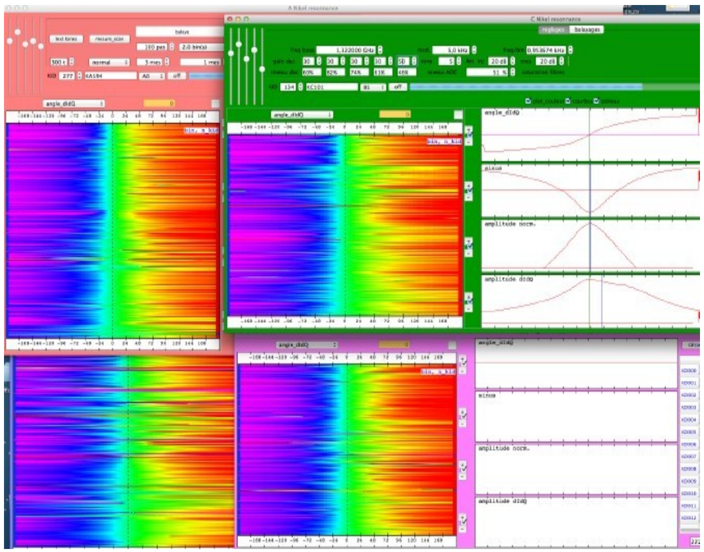


+ radioactive sources
& fast electronics

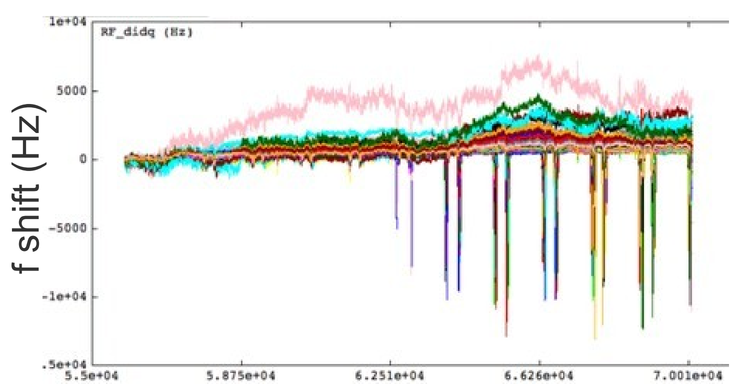
CR impacts!

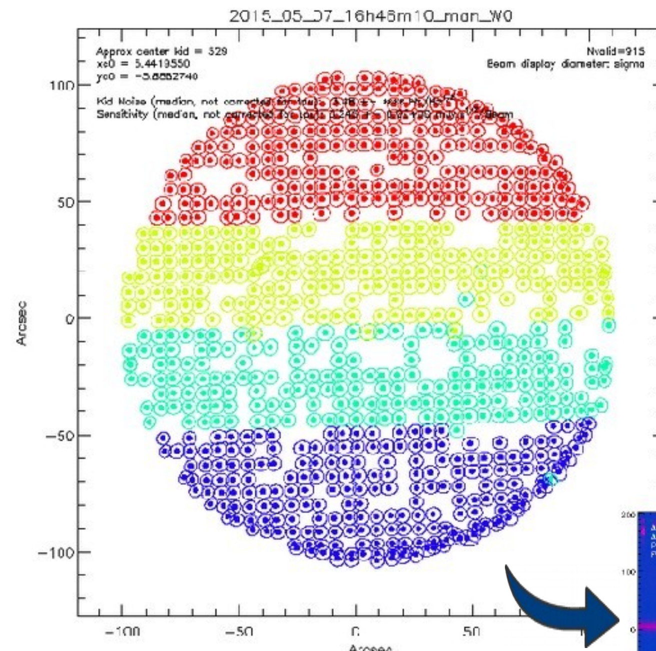
Sample array: NIKA2 2mm

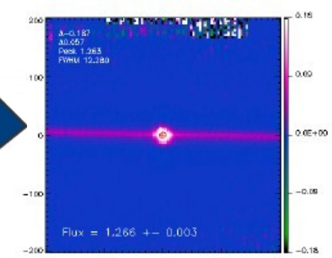
- NIKA2 '**AR11**' array: **1020 pixels**, CPW feedline, AR layer by dicing



4 x 250 pixels, simultaneous readout







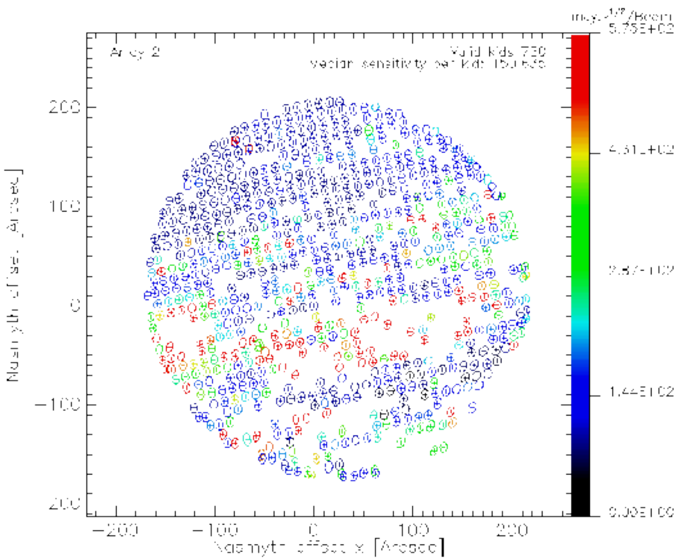
Map of 'planet' (and wire..)

>80% good pixels!

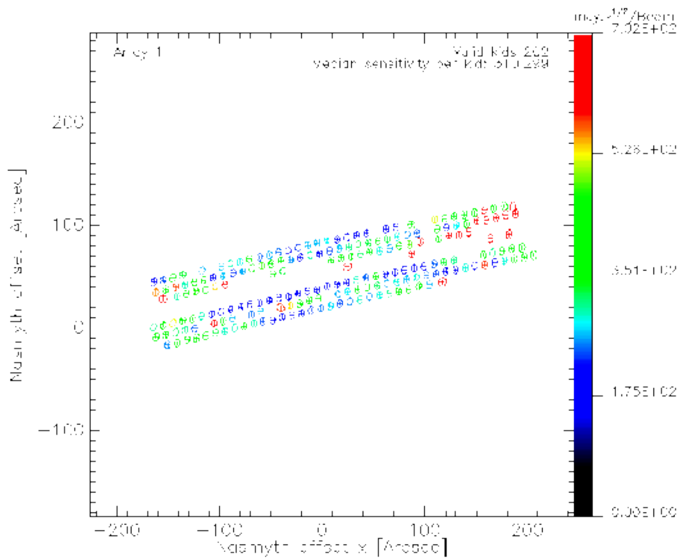
After removal of doubles and bad KID

NIKA2 arrays on the sky

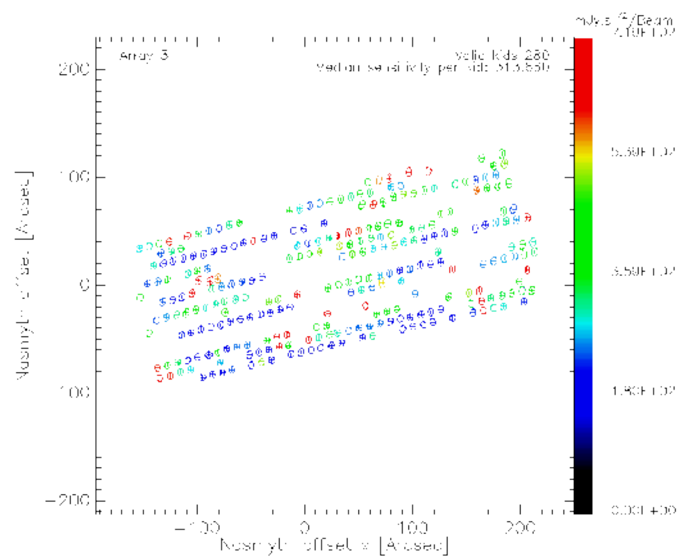
- NIKA2 started observations last October
- For the time being, runs dedicated mainly to commissioning
- Full operation will start next January



2mm



1.25mm V



1.25mm H

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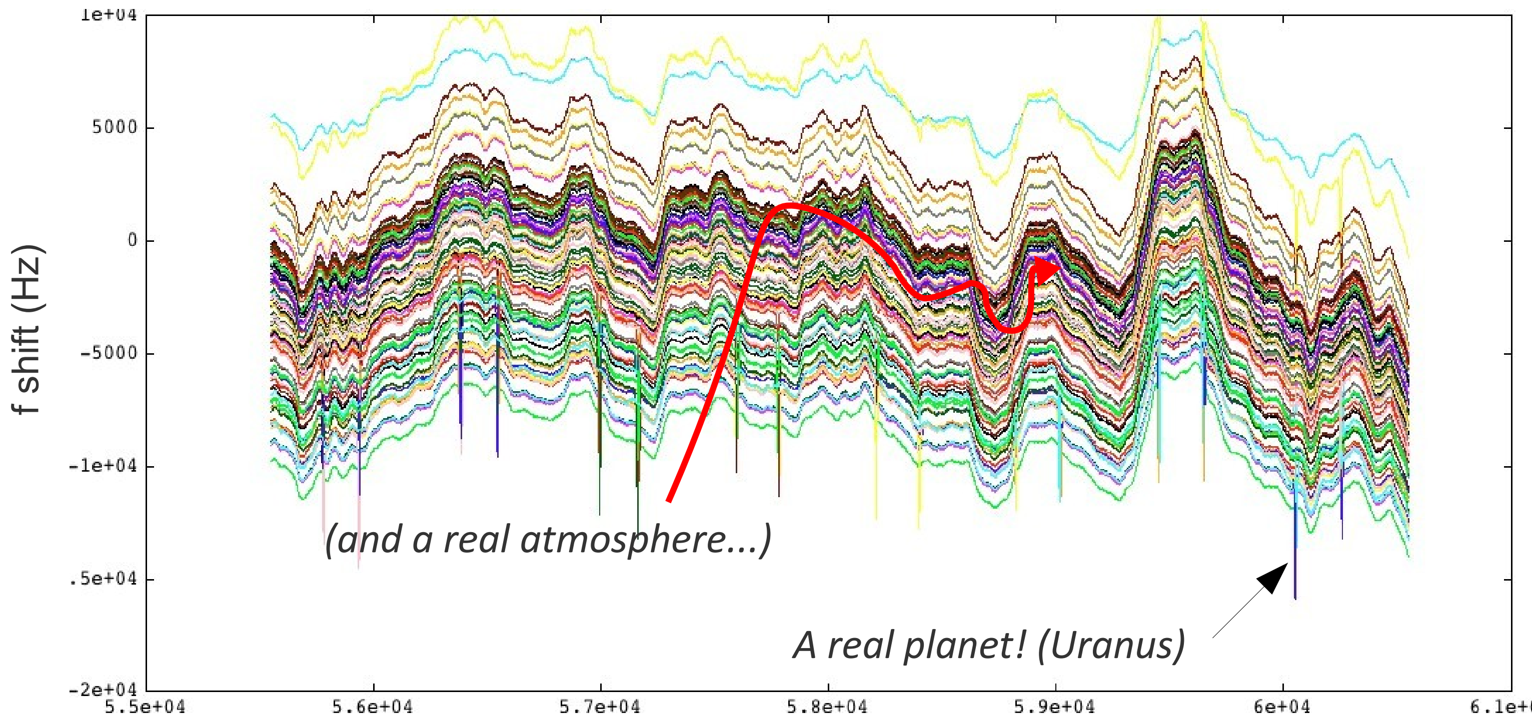
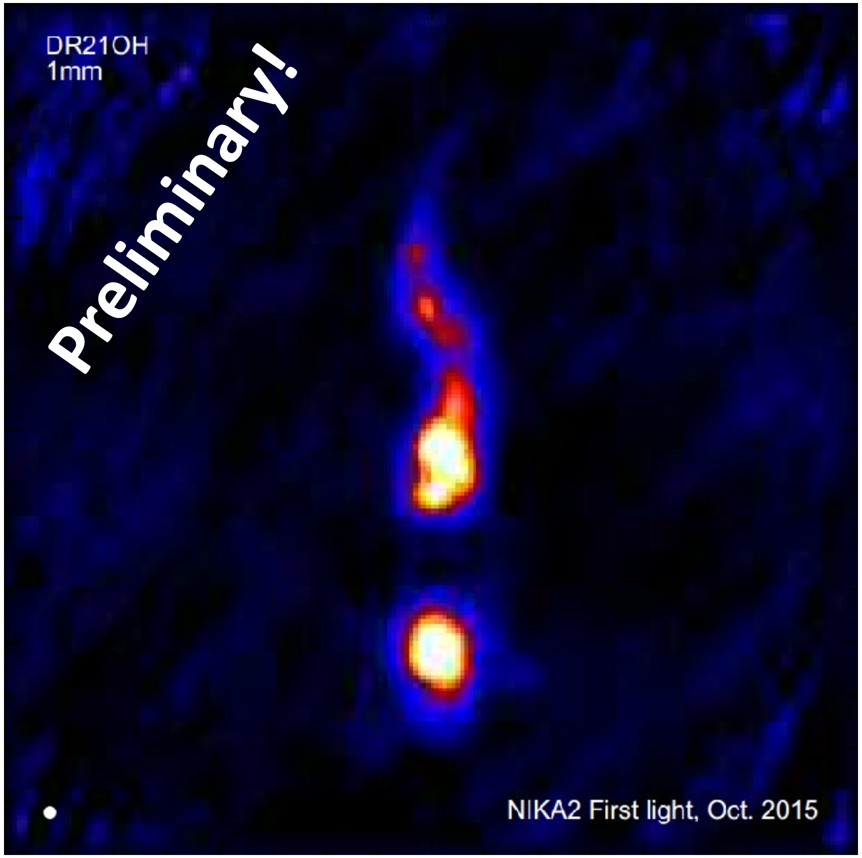
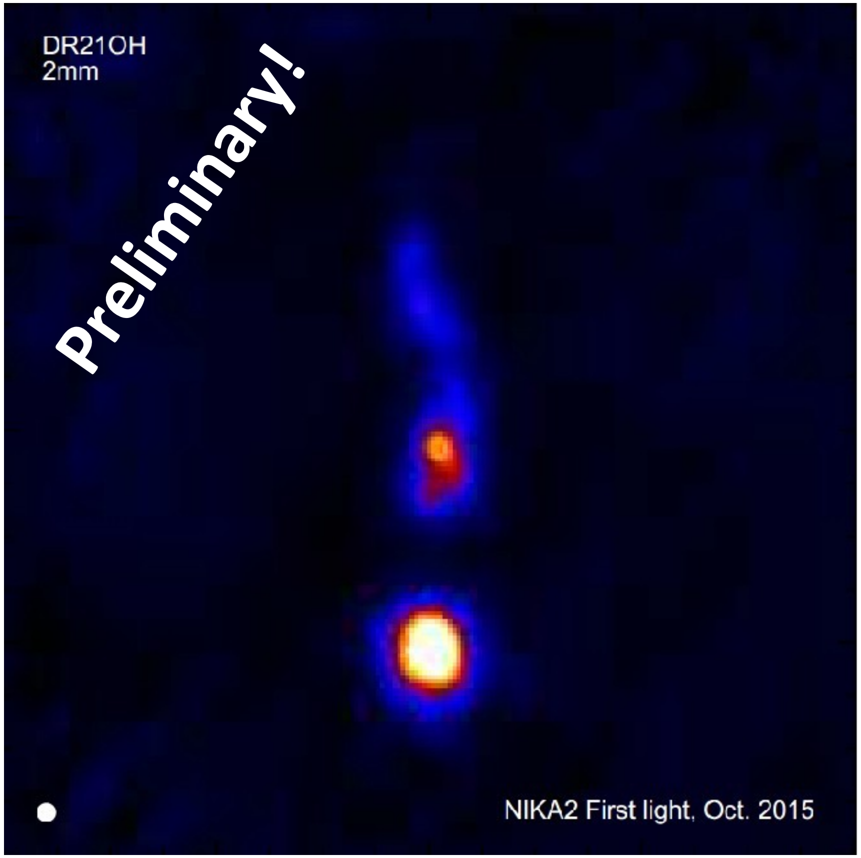


NIKA2: first light!

- DR21OH star forming region:



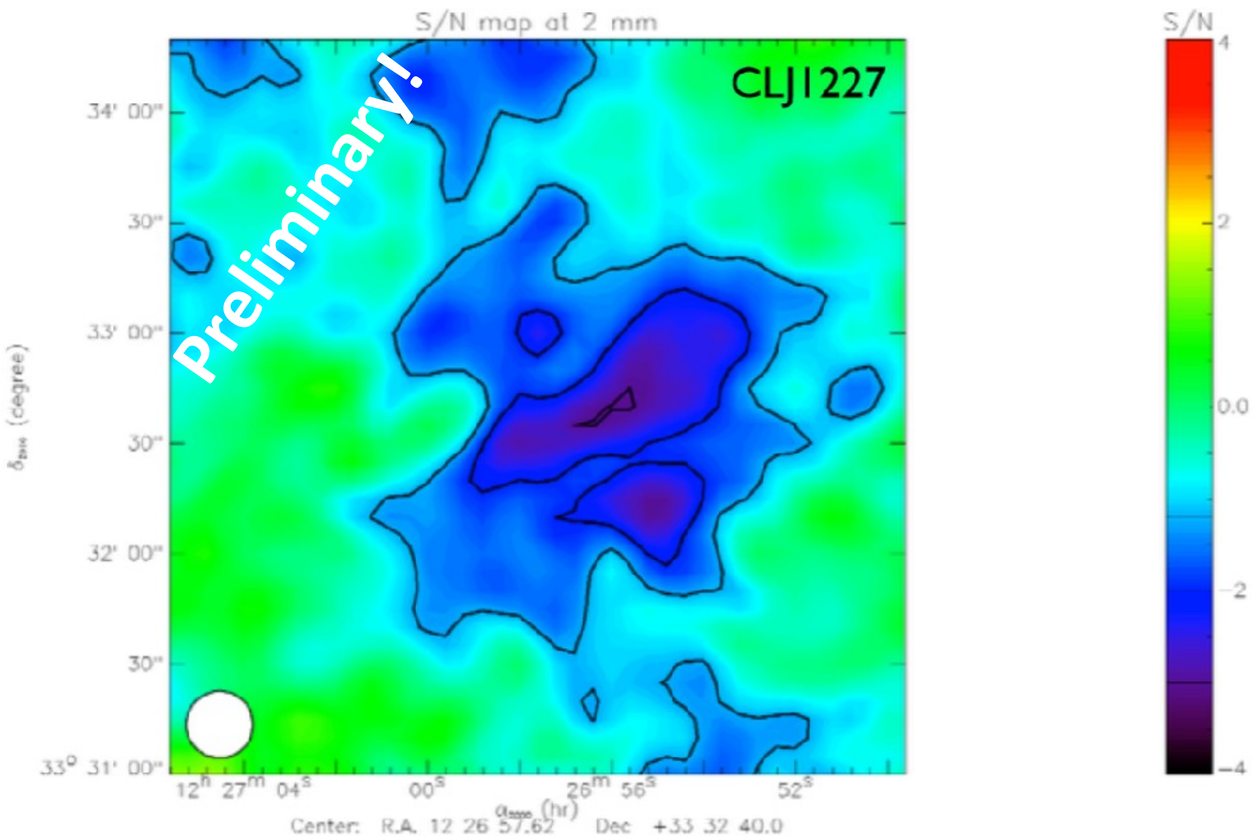


Integration time: 12 min

Credit: N. Ponthieu and NIKA2 collaboration

NIKA2: first light!

- SZ effect in cluster CLJ1227



Integration time: 1h06min

Credit: F. Ruppin and NIKA2 collaboration

What's next?

- NIKA2 is up and running...
- Plenty of good news

  - it works very well! Results (& papers...) on their way.
  - experience for detectors in the **100-300GHz** range
  - time to explore something new!

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  - experience for detectors in the **100-300GHz** range

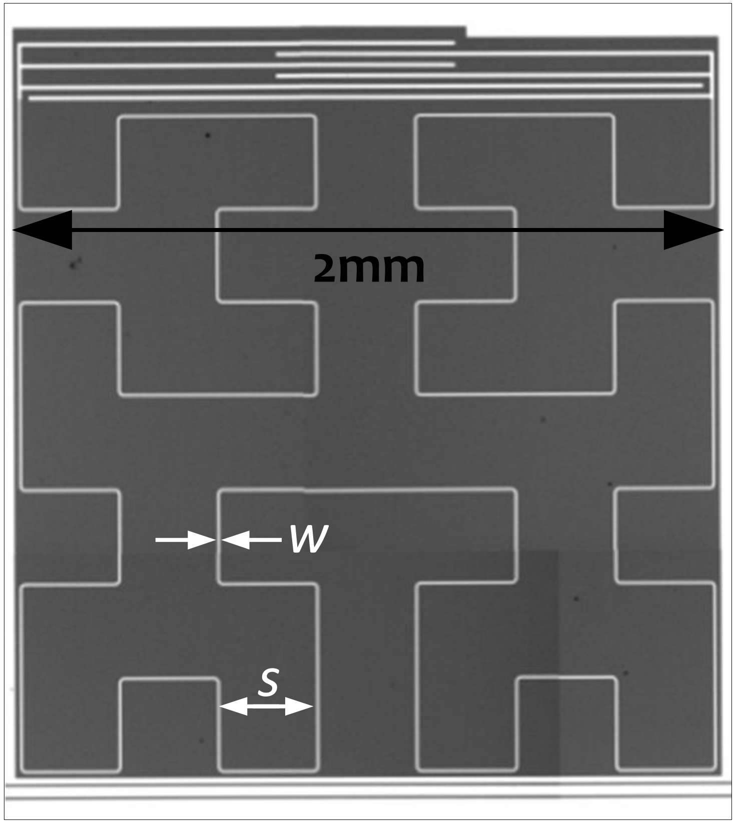
  - time to explore something new!

(luckily enough, choosing ramen is much harder!)

Going to higher frequencies…

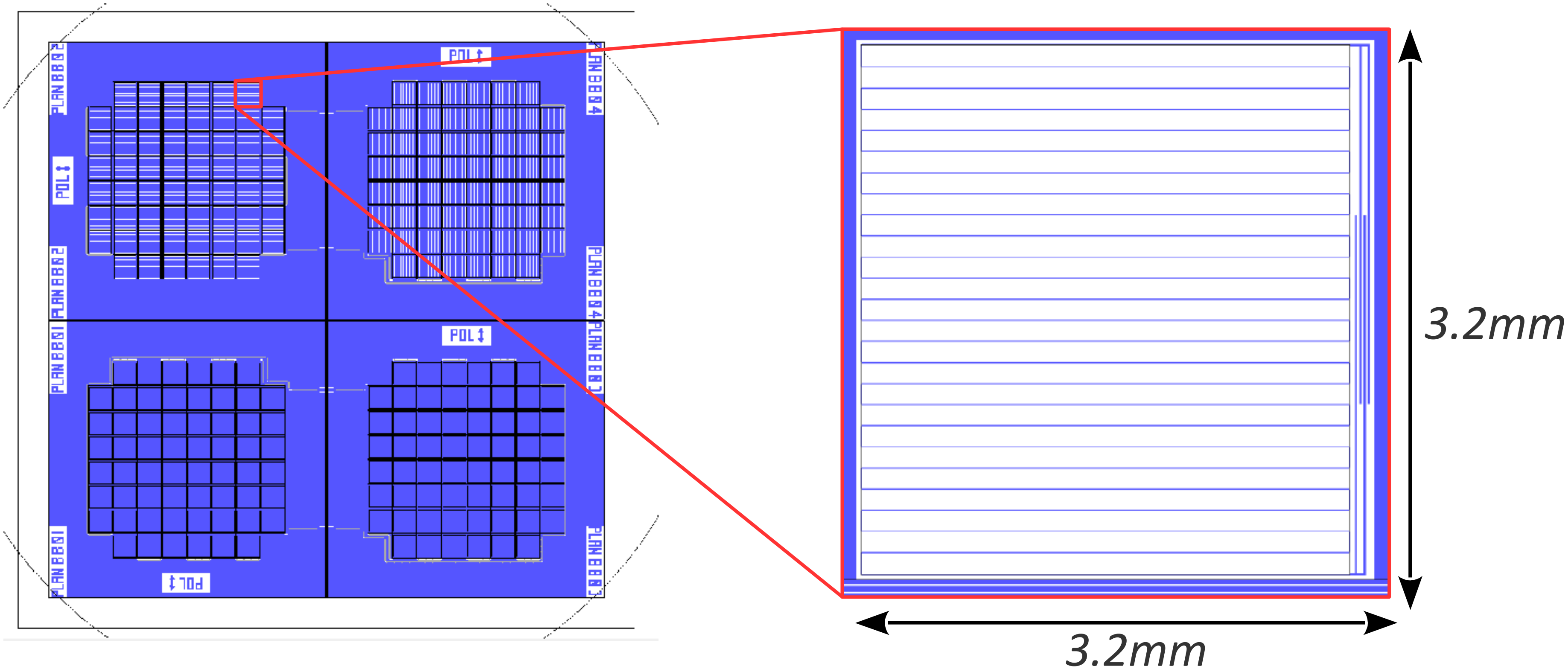
Going to higher frequencies...

- Relatively easy to modify LEKID to cover the 300→600GHz range
- Can keep same technology (eg, materials!)
- In theory, just need to change the geometry a bit: *w, s* << λ



First test mask for high ν LEKID

- First test mask already made
- 4 different sub-arrays of 60 pixels each
- Goal is just a first iteration of the loop design/fabrication/test/feedback!

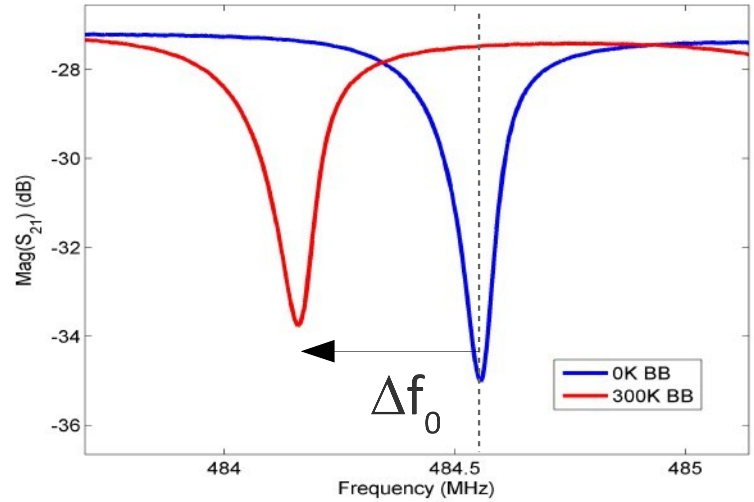


Teaser: pixel size and meander type are **not** chosen at random!

First results

Note #1: must increase stray-light rejection (as of now likely the limiting factor to our sensitivity!)

Note #2: optical path not yet in final configuration so power per pixel is a rough estimate



$\Delta P \approx 100pW$ $\Delta f_0 \approx 400kHz$

First results

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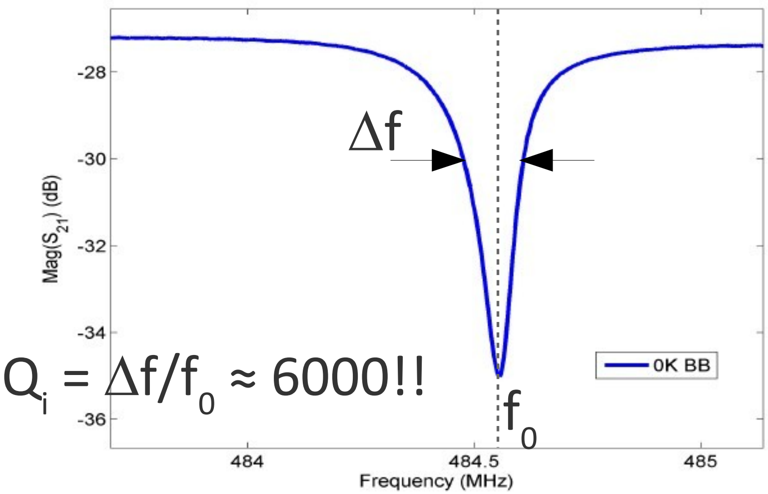
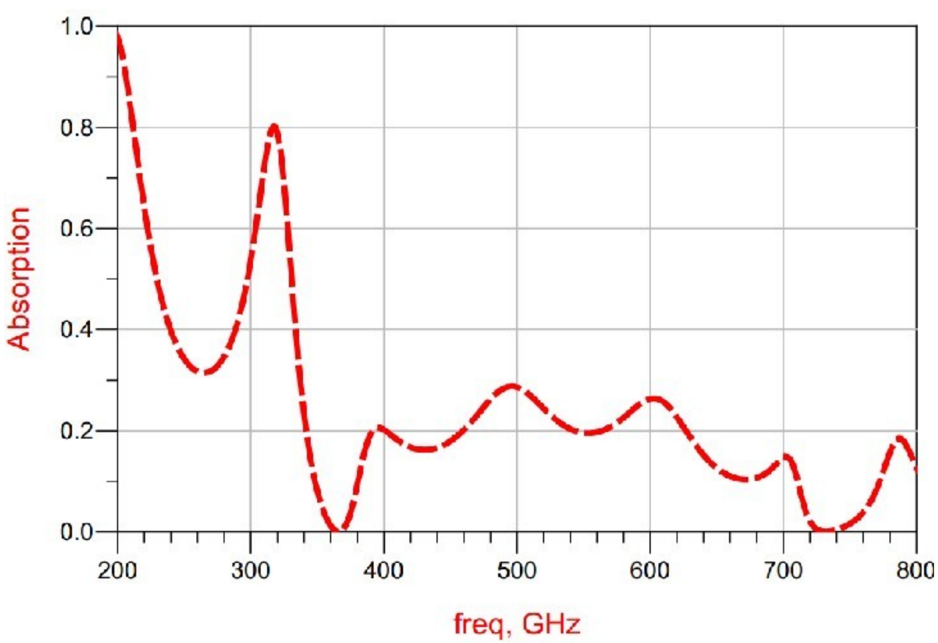
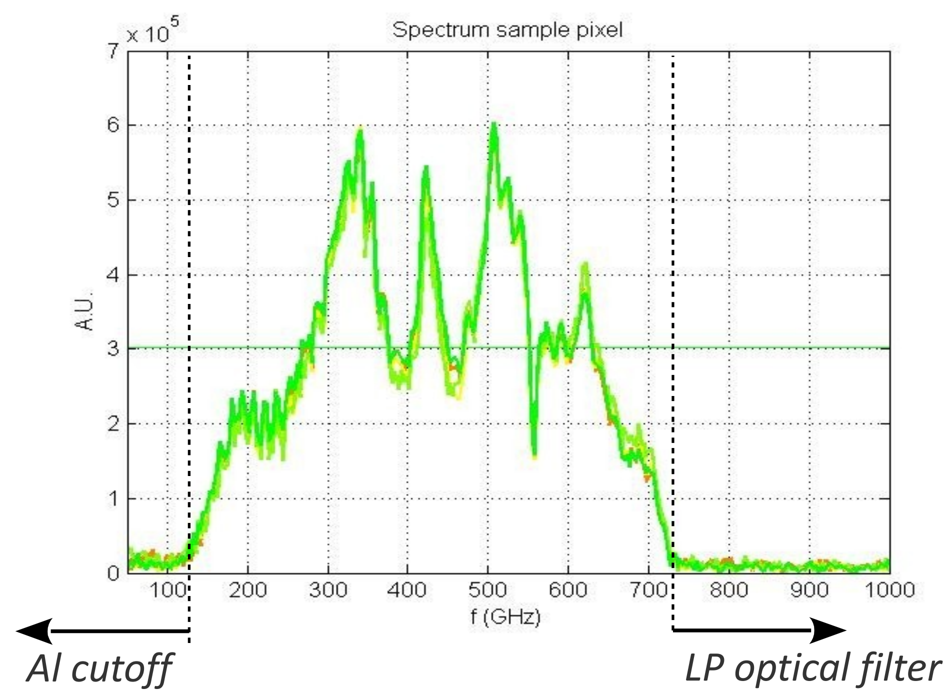


First results

- Current design is not yet optimized to maximize absorption...
- ...but already achieved a *very* large band!
- More data needed for an 'absolute' value of absorption efficiency (need to consider HDPE lenses, BB power, atmosphere...)





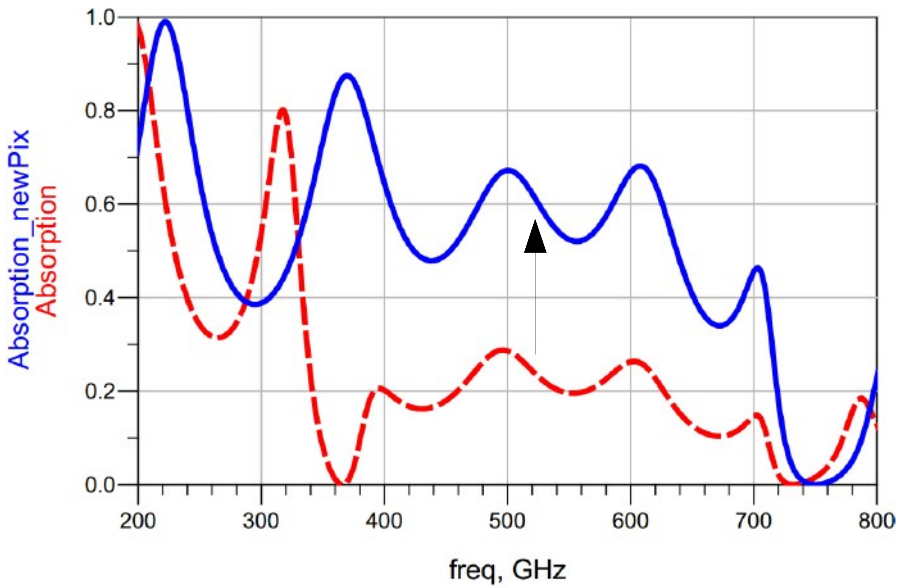
New mask design

- Already designed a second generation pixel (denser meander)

Increase absorption by a factor ≈3 (if we believe in simulations!)

Resonances are at very low frequencies (a pro?)

Denser meander means longer lines → need to check *yield*!



Next steps:

- Improve baffling and optics of dedicated test cryostat
  - Show sensitivity under representative background load
- Test new materials (eg lower ε_{eff} wafer)

Going to lower frequencies…

Going to lower frequencies...

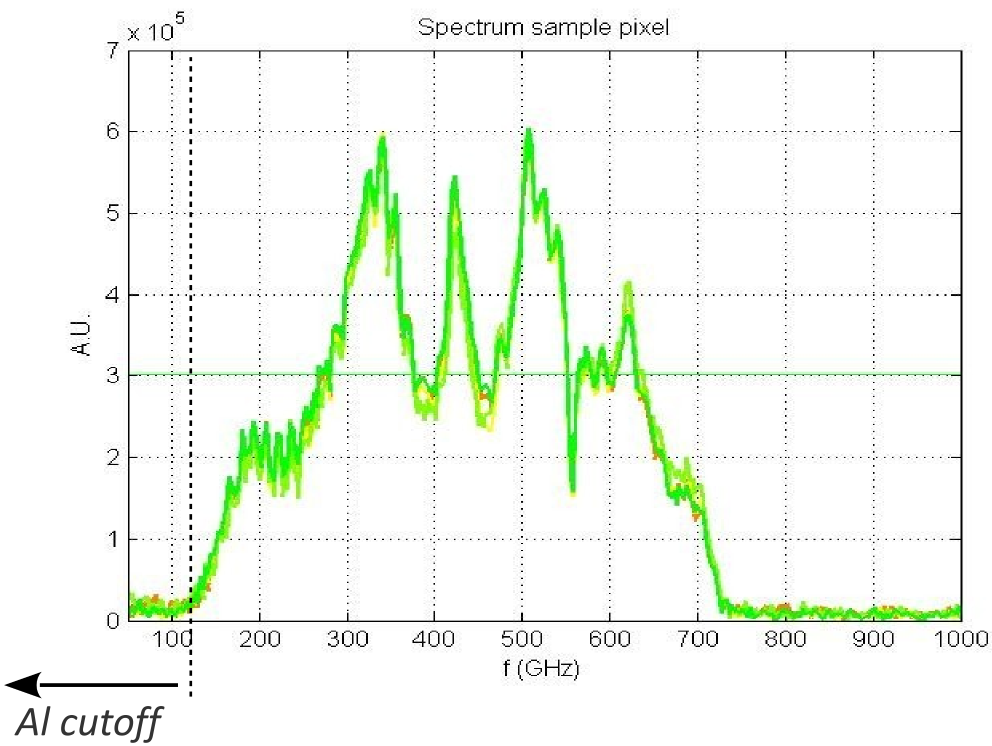
- Not as straightforward… KID are pair-breaking detectors!

$$E_{cp} = 3.5 k_b T_c$$

$$E_{\gamma} = h\nu$$

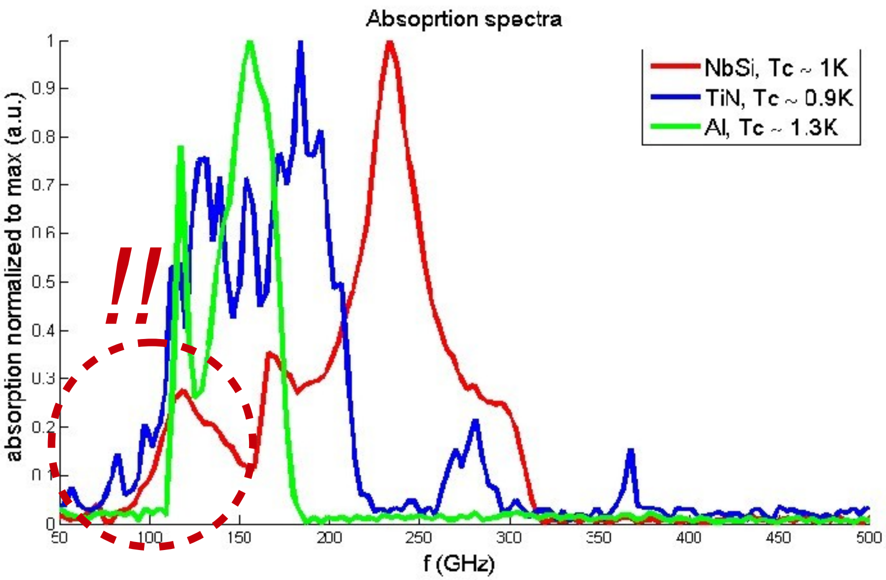
$$\nu_{gap} \approx T_c \cdot 73\ \text{GHz}$$

- Thin Aluminum ok only above ≈ 100GHz!



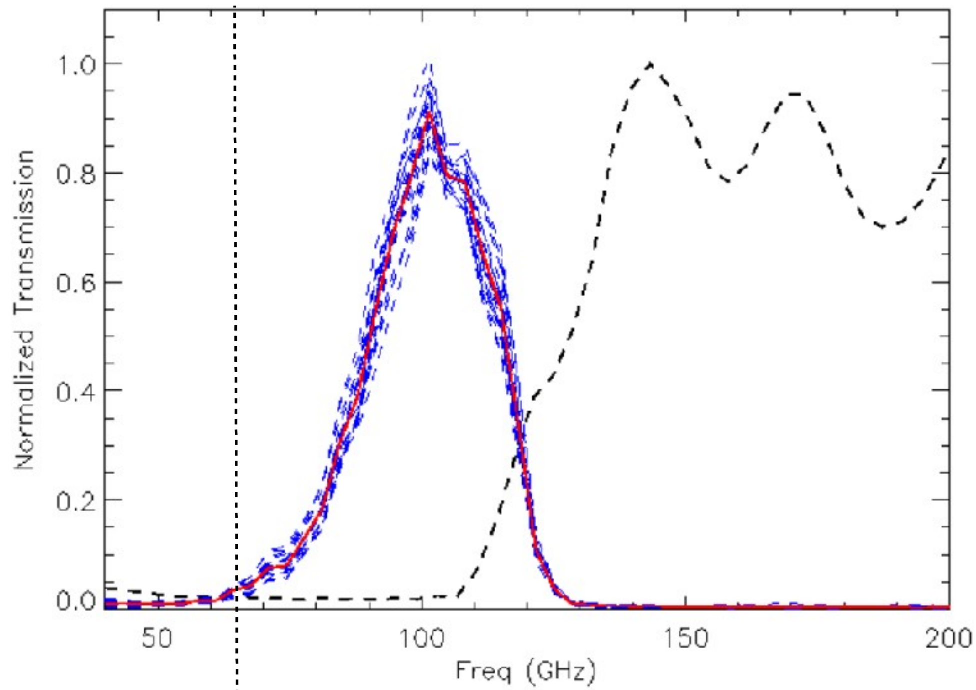
Going to lower frequencies...

- Not as straightforward... KID are pair-breaking detectors!
- $\nu_{gap} \approx T_c \cdot 73$ GHz
- Thin Aluminum ok only above ≈100GHz!
- Plenty of other materials available, but beware of their properties!
- Example: Ti_xN_{1-x}, Nb_xSi_{1-x}...
- Ti_xN_{1-x}: NEP worse under lower background!
- *Maybe* Ti/TiN?



Bi-layer LEKID for low ν applications

- Bi-layers have been widely used (for example for TES!)
- Proximity effect gived T_c intermediate between 2 materials
- Example : **Ti/Al**!
- Different tests made, best results for **Ti_{10nm}/Al_{25nm}**



$\nu_{cutoff} \approx 65GHz \longrightarrow T_c \approx 0.9K$

A. Catalano et al., ***A&A***, 580 (2015) A15

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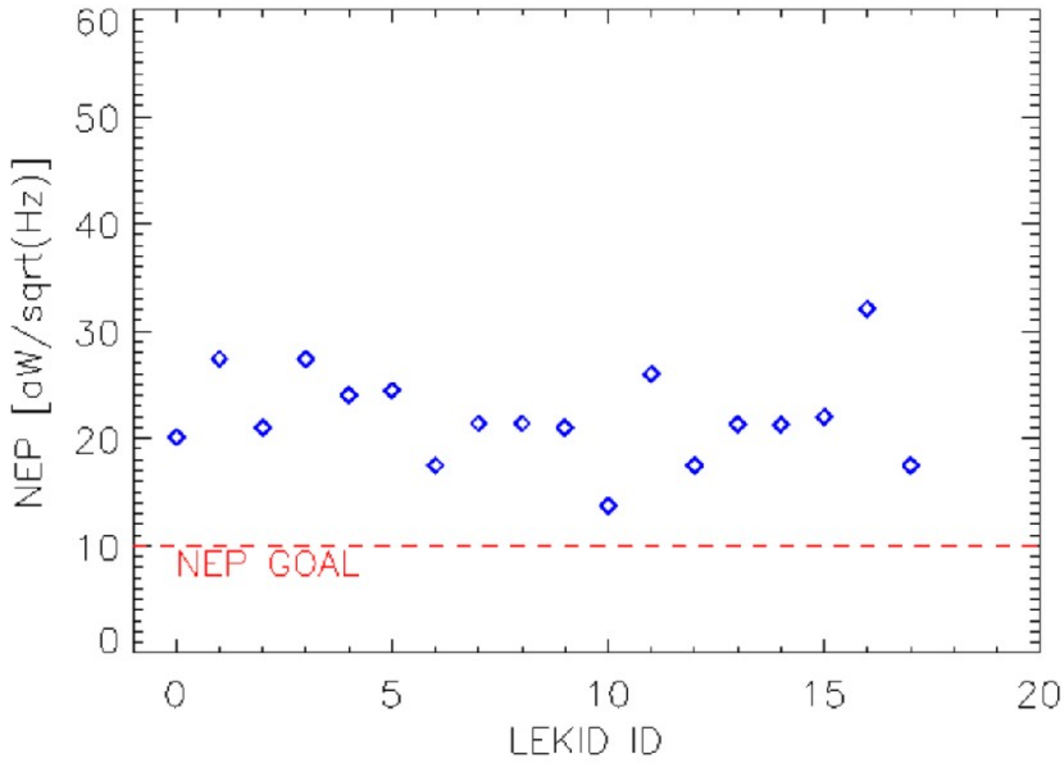


A. Catalano et al., ***A&A***, 580 (2015) A15

Getting ready for space!

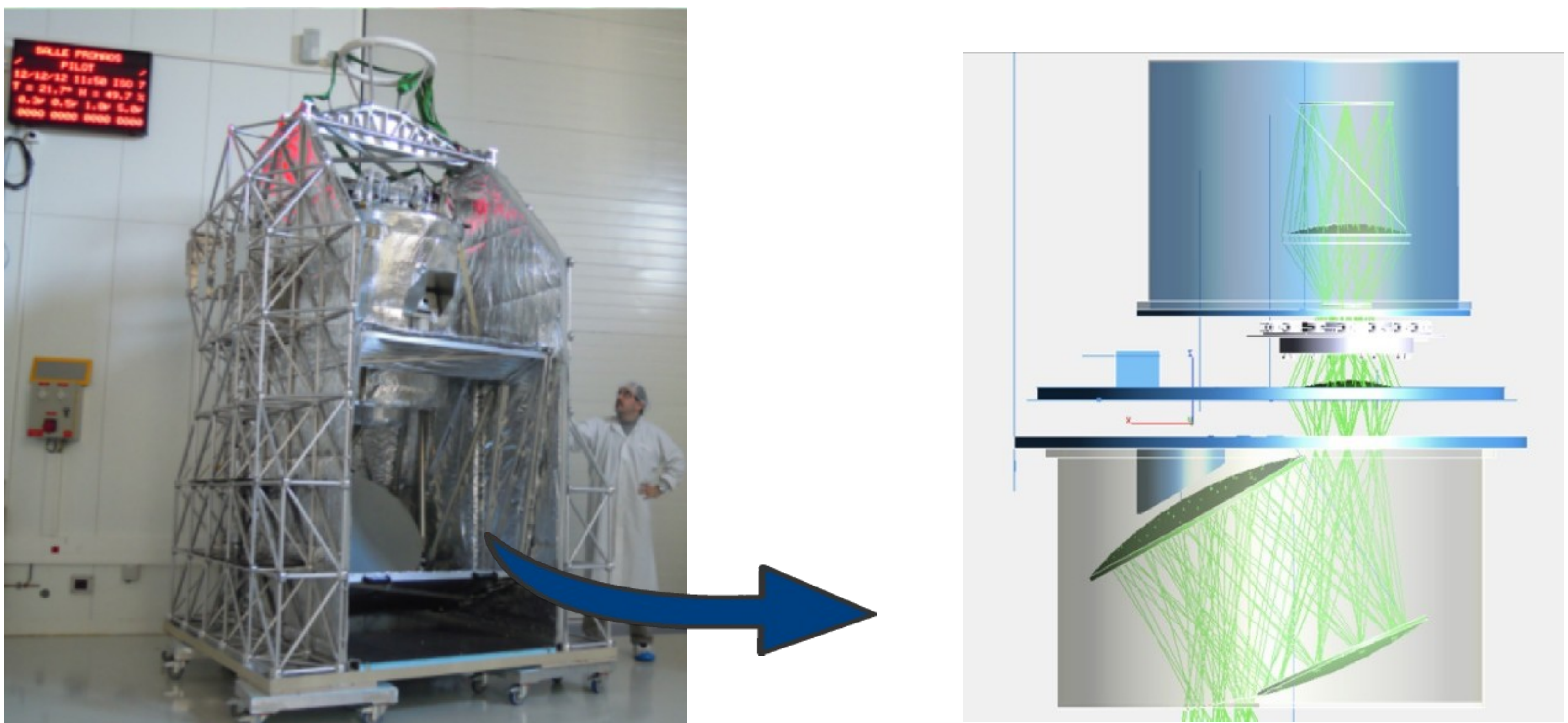
- So far so good… But are KID really ready for space?
- Try to ask ESA! (And I guess JAXA/NASA...)
- Basically, no technology can be flown if it didn't fly before (??)

Getting ready for space!

- So far so good… But are KID really ready for space?
- Try to ask ESA! (And I guess JAXA/NASA...)
- Basically, no technology can be flown if it didn't fly before (??)
- Is there a workaround?
- Demonstrate the technology using a **balloon!**

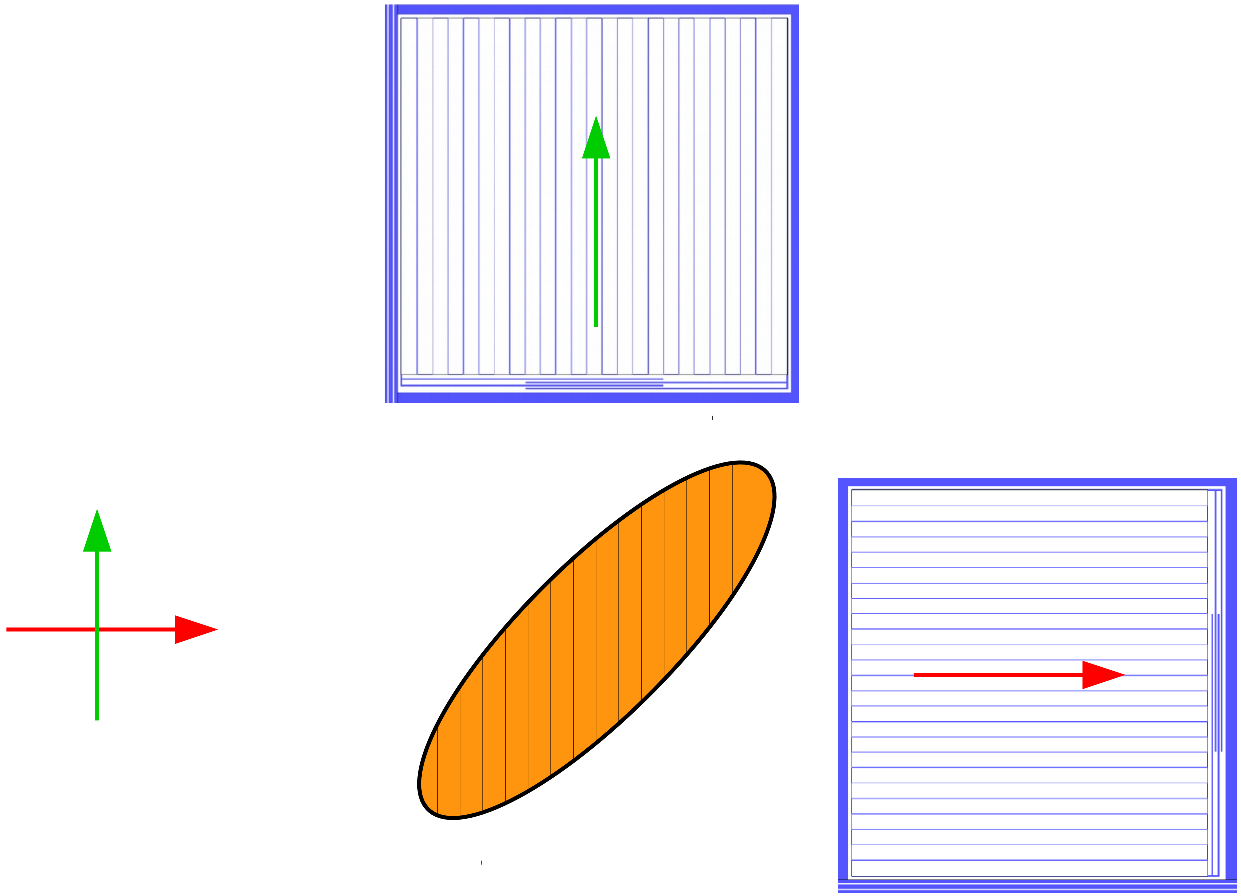
The PlanB / B-SIDE project

- PlanB: a French **KID-based balloon experiment**
- Follow-up of the PILOT project
- Main goal is to measure the *polarized emission of foregrounds*



PlanB / B-SIDE overview

- Field of view : 3°
- Dual-polarization (cold 45° polarizer)
- Rotating HWP at 4K



PlanB / B-SIDE overview

- Field of view : 3°
- Dual-polarization (cold 45° polarizer)
- Rotating HWP at 4K
- Resolution @ 550GHz: between 3' and 6'
- 2x 500-1000 pixels
- MUX ratio of 250
- Flight: 24hrs in April 2018 from Australia

→ *BICEP2 field*

PlanB / B-SIDE goals

- Accurate measurements of foreground polarization
- Allow clean-up of existing datasets
- **Demonstrate performance of KID in space-like conditions!**

- KID NEP in-flight under low optical load

- Effect of CR (glitches!)

- Low-consumption readout electronics

- Any unexpected surprises?

- and a bonus: Closed Cycle Dilution Refrigerator!

Conclusions

- Lots of experience gained thanks to the NIKA2 project
- Work has already started to widen the band of operation of our detectors
- The situation looks promising for both high (>300GHz) and low (<100GHz) frequencies
- The PlanB/B-SIDE balloon project can be a key step to demonstrate the suitability (and 'readiness'!) of KID arrays for space-based missions
- ***Happy to collaborate!***

Thank you!