Large format KID arrays

Martino CALVO
for the GIS KIDS

Overview

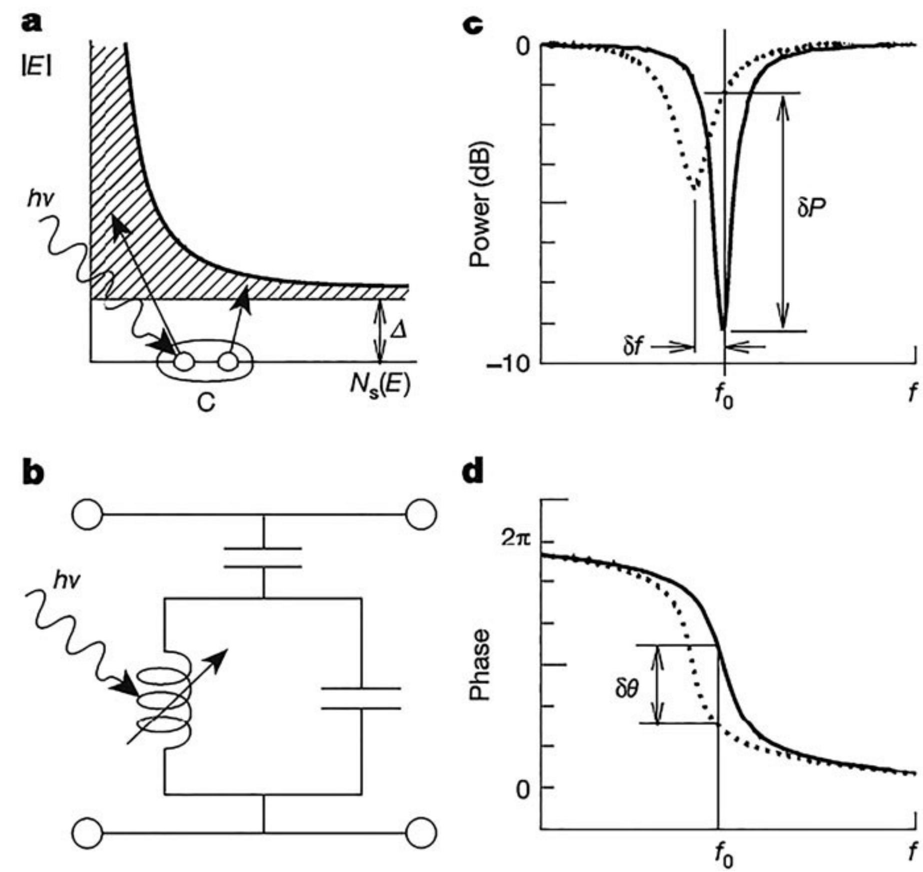
- KID overview (very quick!)
- Main French KID projects: from NIKA to CONCERTO
- Current ongoing developments & future instruments

KID working principle

Core of the device: a ***superconducting resonator***

- SC has *kinetic inductance* : $L_k(n_{cp})$
- Photons break Cooper pairs **(a)**
- Variation in n_{CP} variation in L_k **(b)**
- $f_0 = 1/\sqrt{(LC)}$

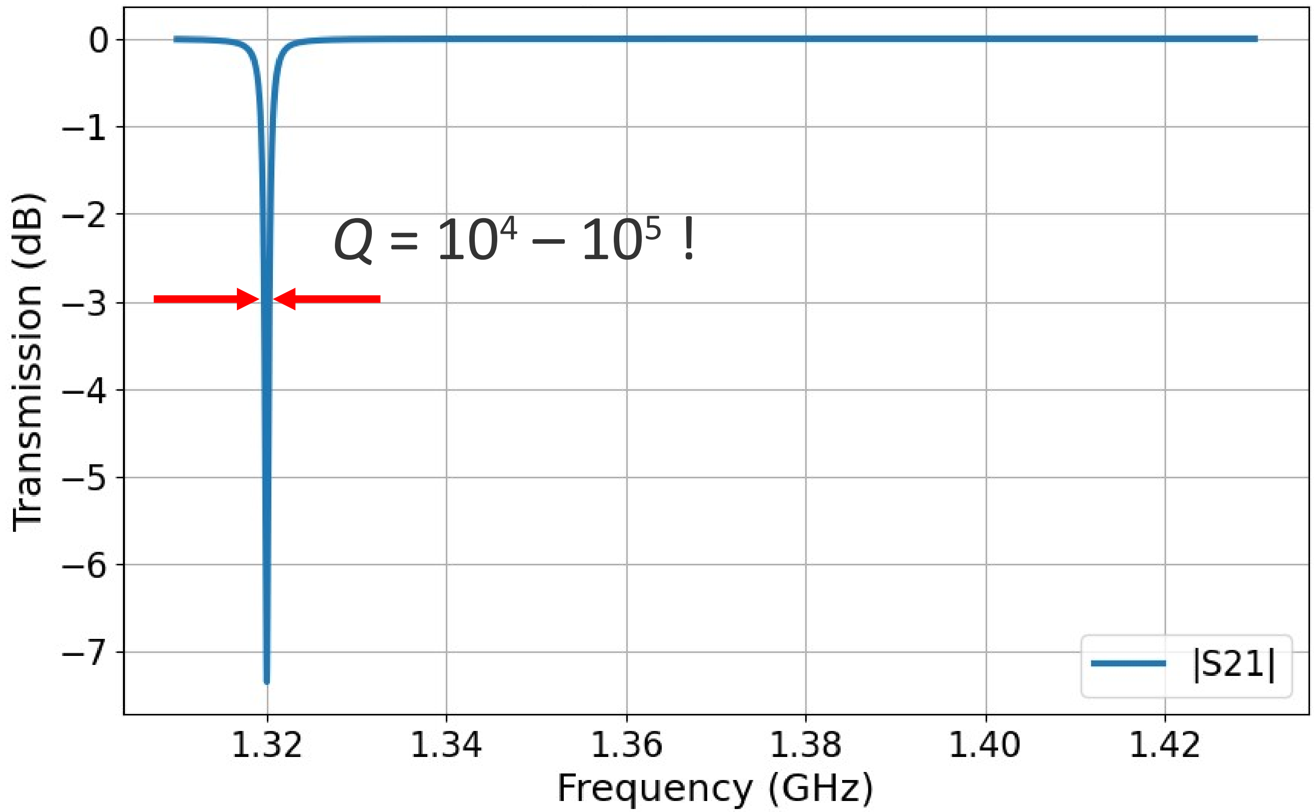
$\Delta L \rightarrow \Delta f_0, \Delta A, \Delta\theta$ **(c, d)**



Day et al., Nature 425 (**2003**) 817

Why KID?

- Frequency Domain Multiplexing for free!



- Easy to fabricate (not always..)
- Non-thermal → fast, reduced T sensitivity..

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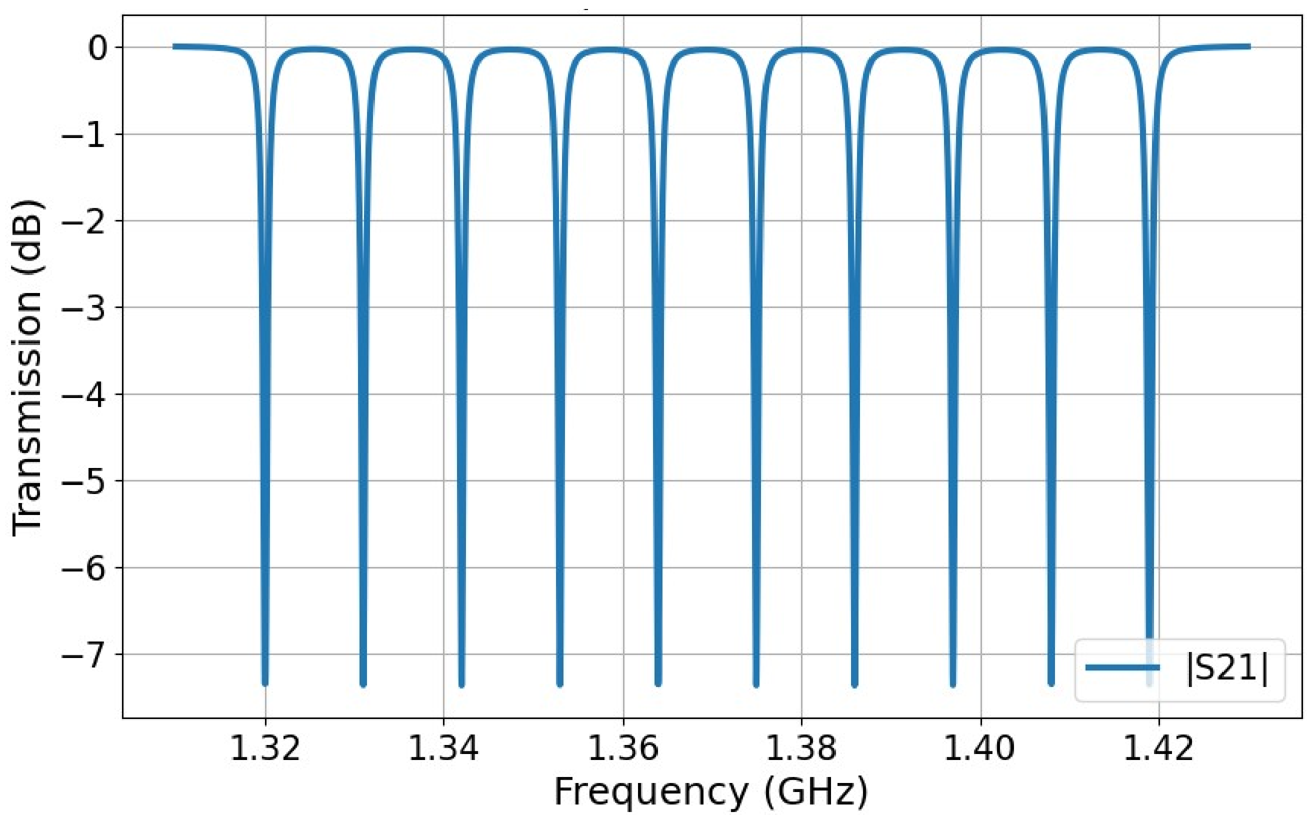

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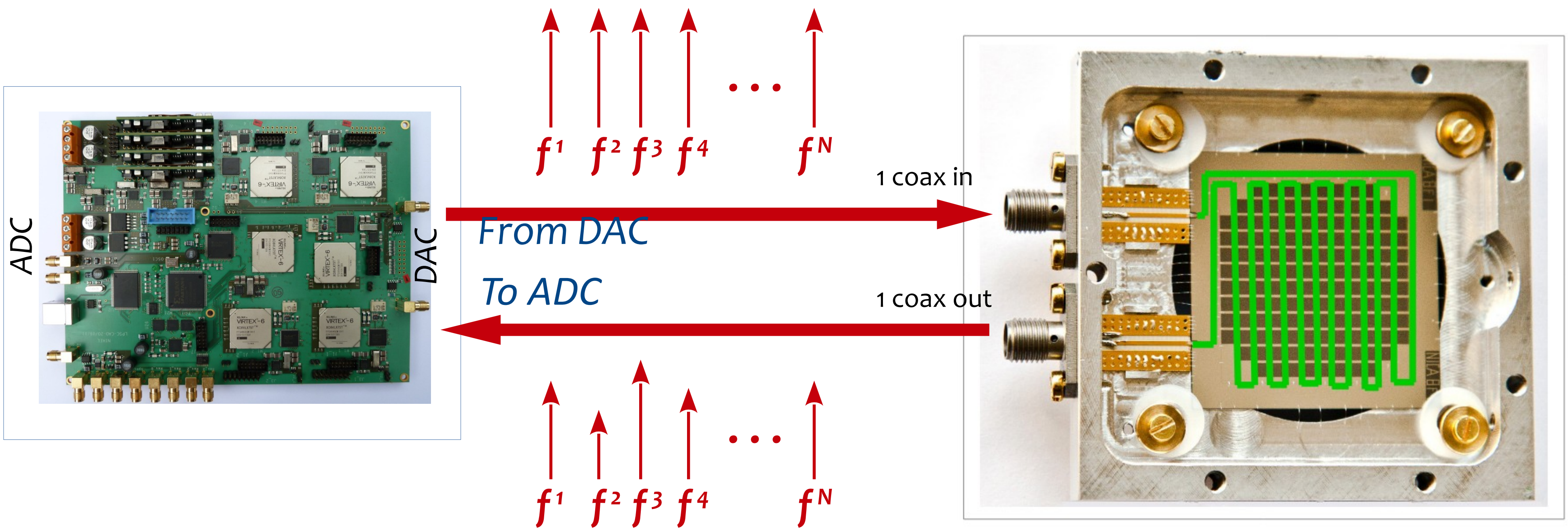

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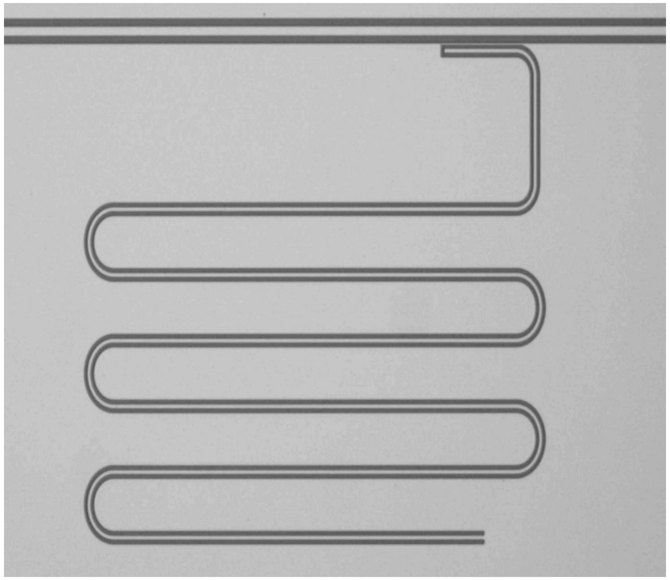
- Non-thermal → fast, reduced T sensitivity..

KID implementations

Many different kind, but only 2 main 'families'

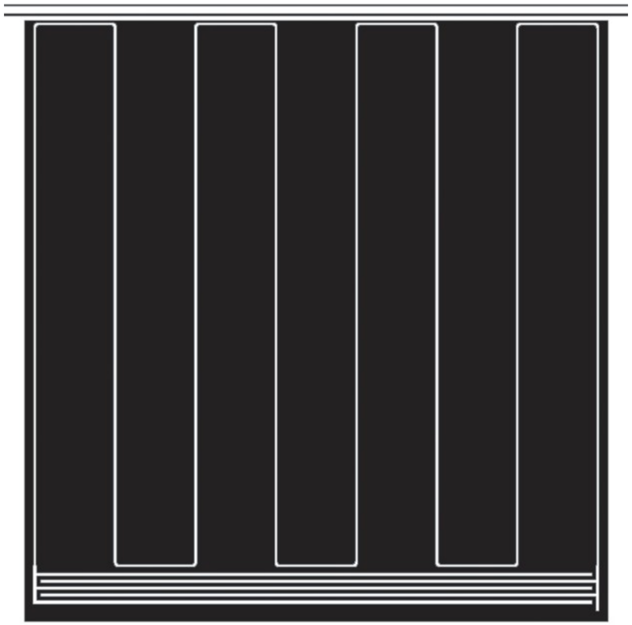
MKID (or 'distributed KID')

- f_0 determined by length
- EM field can be 'contained'
- Ideal for on-chip devices



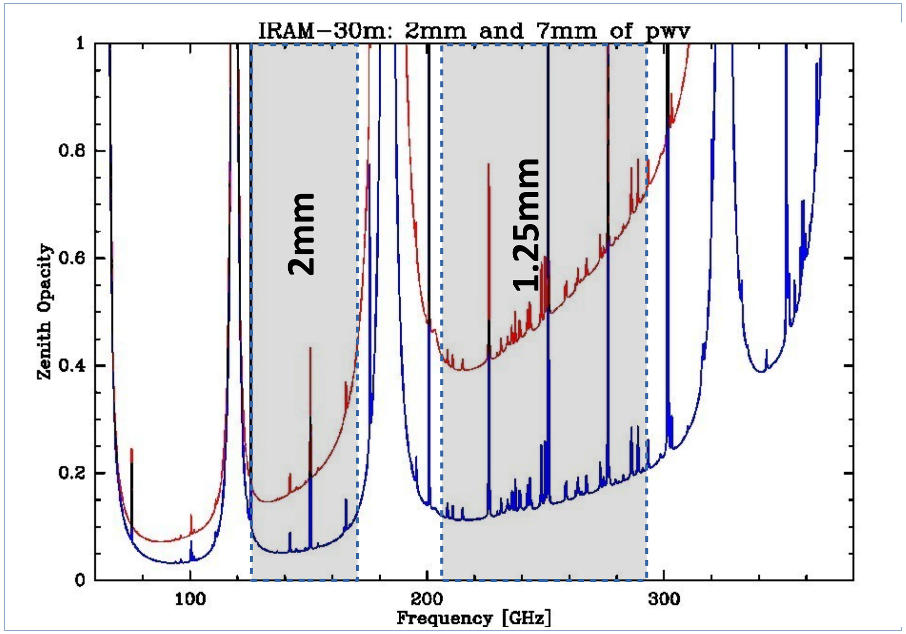
LEKID (Lumped Element KID)

- f_0 determined by L, C
- EM field more 'open'
- **Ideal for filled arrays**



The very beginning: NIKA

Goal: a KID camera for the IRAM 30m telescope



Main contributions from: I. Néel, LPSC, IPAG + IRAM

Planck heritage, + **KIDs**!

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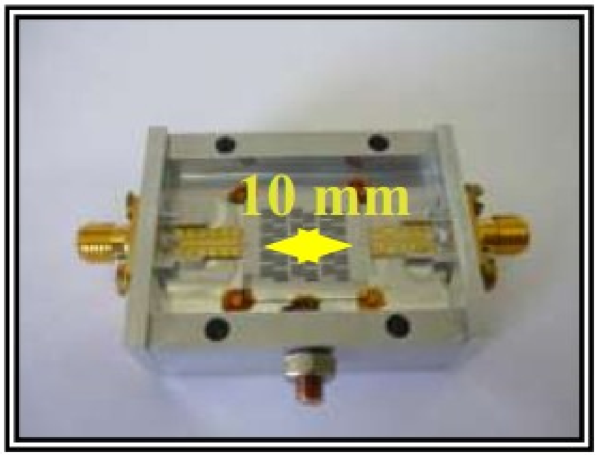
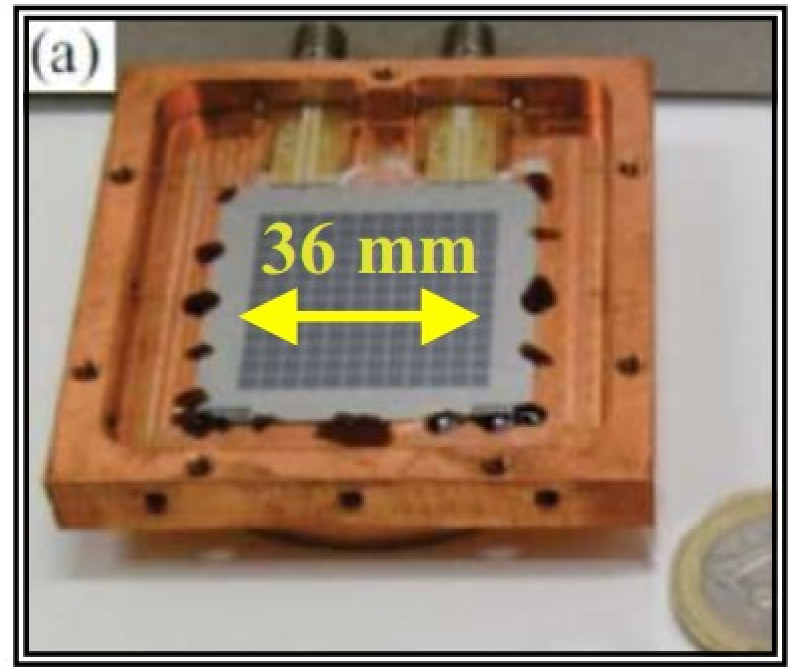
NIKA0 (2009)



x 10

NIKA1 (2010-2013)



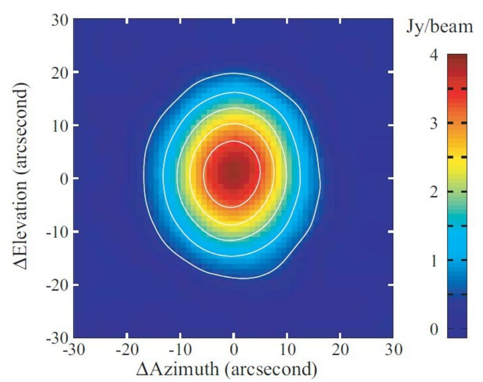
- 30 pixels (2mm)
- First KID camera on sky!

- 300 pixels (2mm+1.25mm)
- First KID camera for astronomers

The very beginning: NIKA

Goal: a KID camera for the IRAM 30m telescope

NIKA0 (2009)

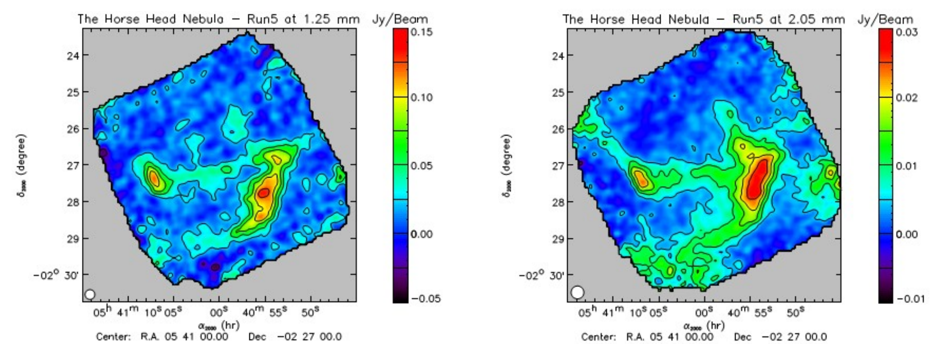


3c345 @ 2mm

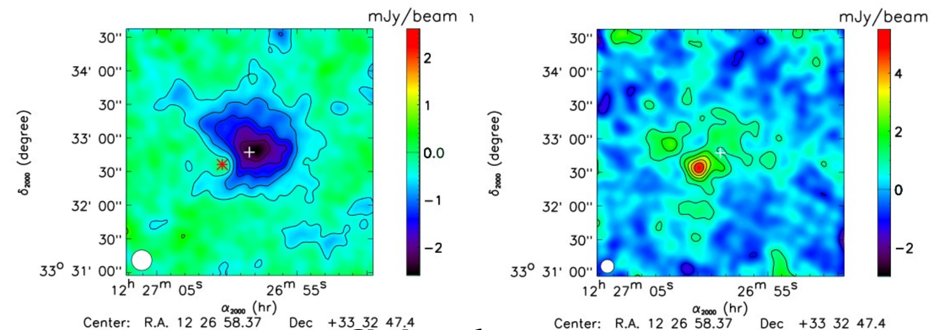
- 'Simple' observations
- **First KID camera on sky**

x 10

NIKA1 (2010-2013)



Horsehead nebula @ 1 and 2mm



CL J1226.9+3332

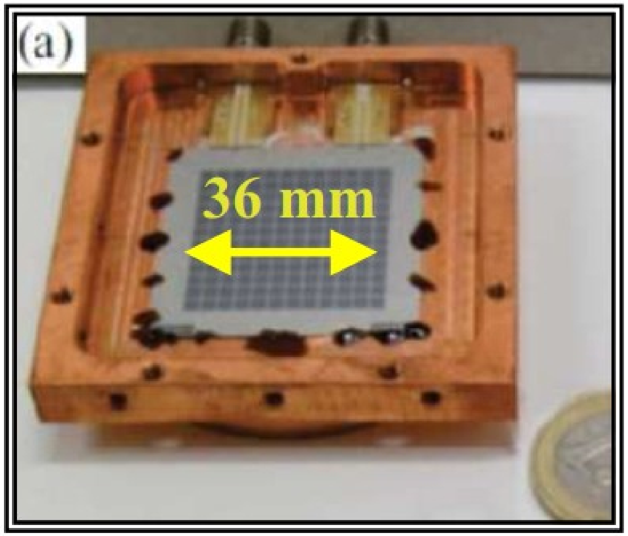
R. Adam et al., A&A 576 A12, 2015

- Science-grade observations

Getting bigger... NIKA2!

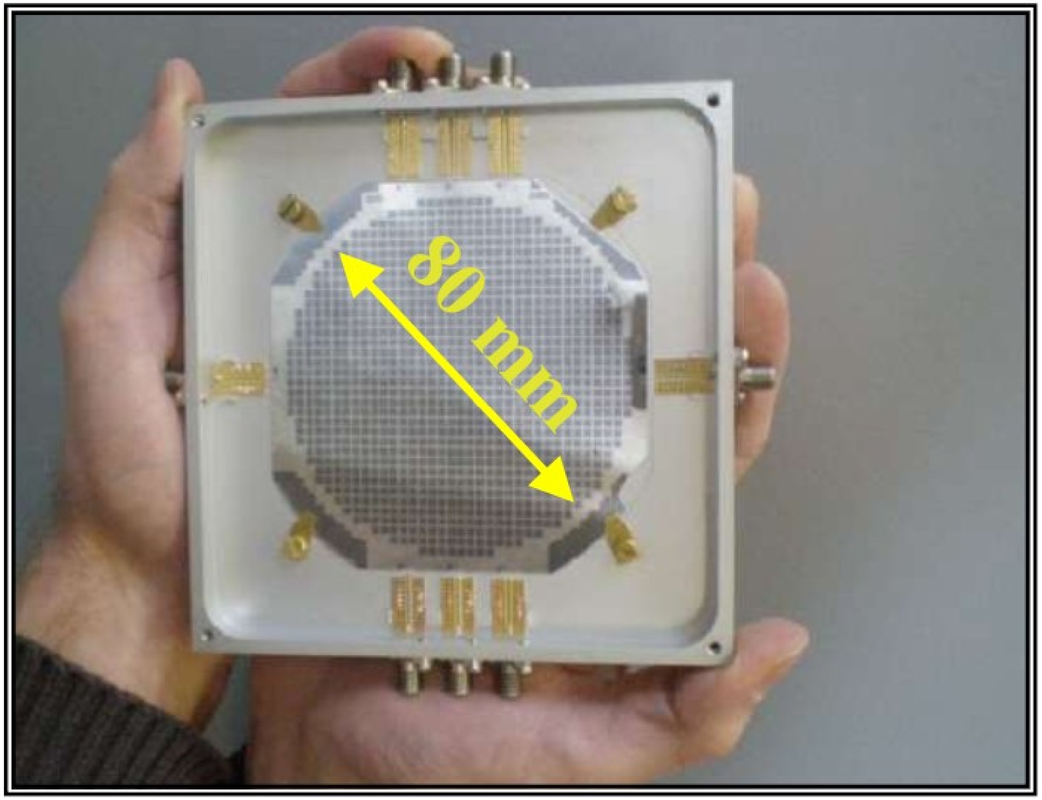
Goal: fill the whole IRAM 30m focal plane! ('only' 6arcmin..)

NIKA1 (2010-2013)



x 10

NIKA2 (2014-2018)

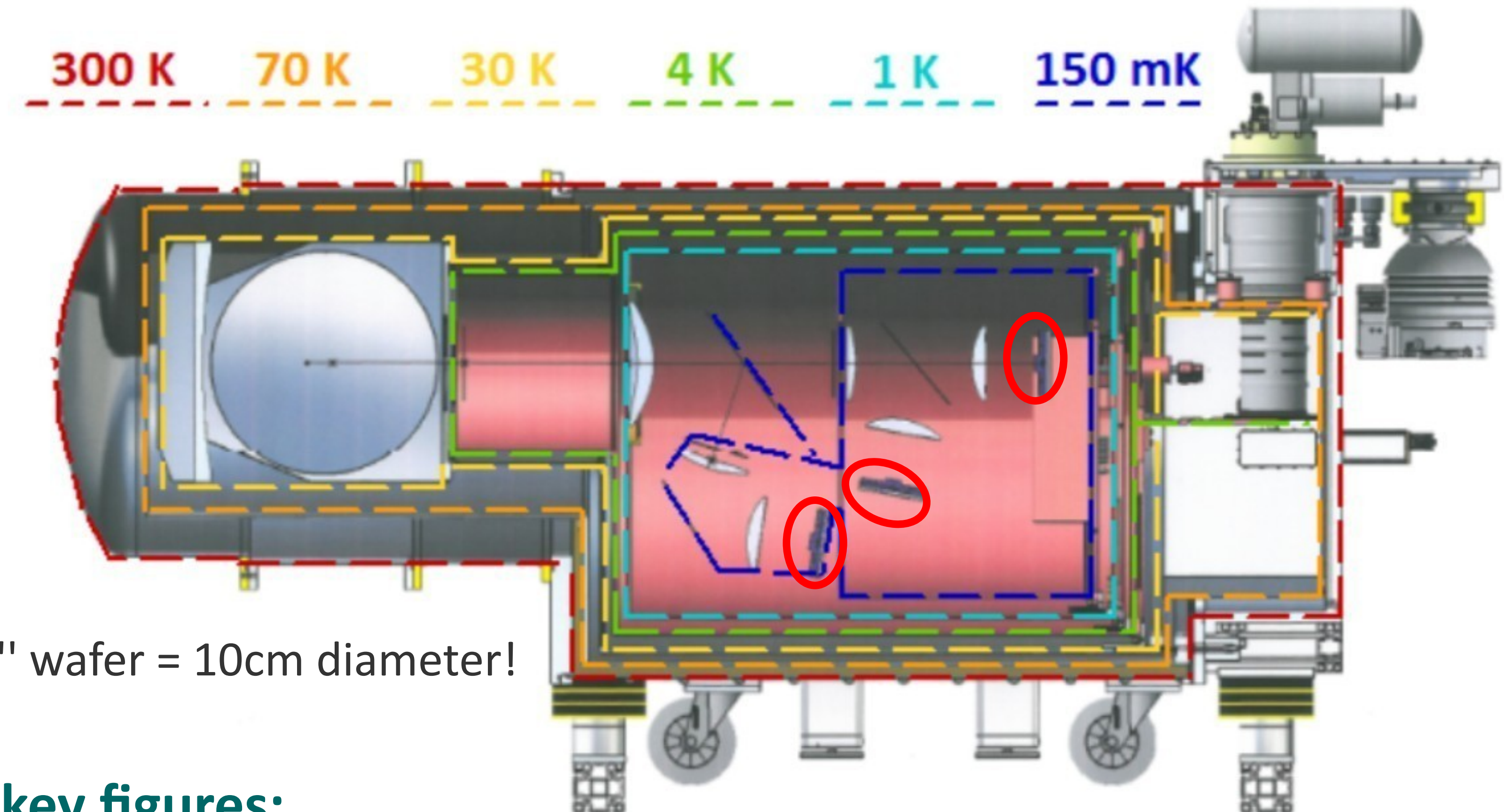


- 300 pixels (2mm+1.25mm)

- 3000 pixels (2mm+2x1.25mm)
- First open access KID camera

Getting bigger... NIKA2!

Not "AtLAST-big", but still..



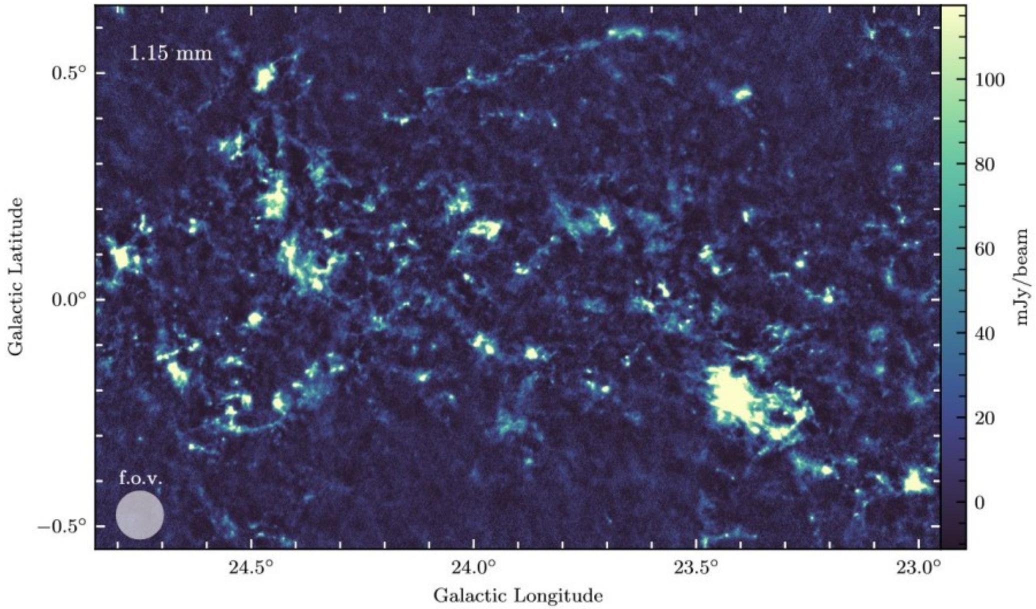
3x **array**, 4'' wafer = 10cm diameter!

NIKA2 key figures:

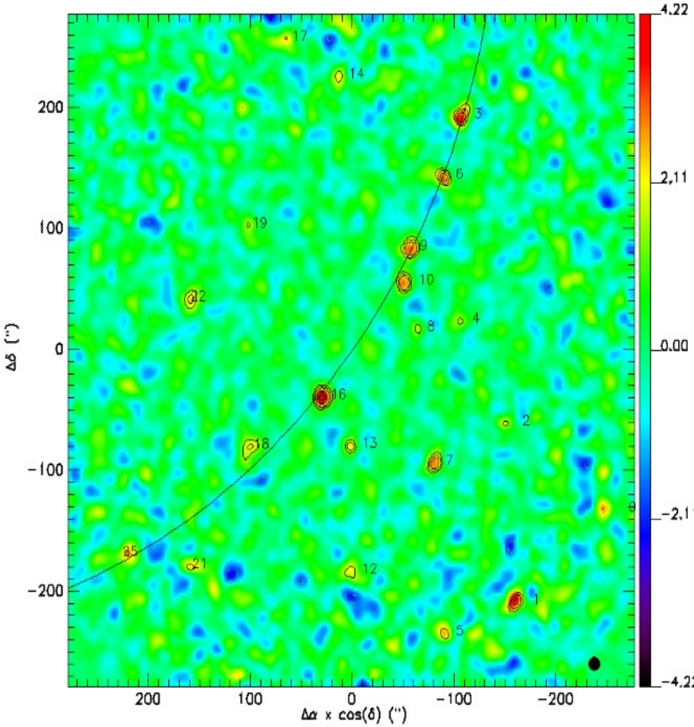
- 1.2 tons, 2.5m long, >3000 pieces
- Double PT
- Full remote operation
- Completely cryogen free

NIKA2 science

NIKA2 observing regularly since 2018



Rigby et al., MNRAS 502-3, 4576 (2021)



Lestrade et al., A&A 667, A23 (2022)

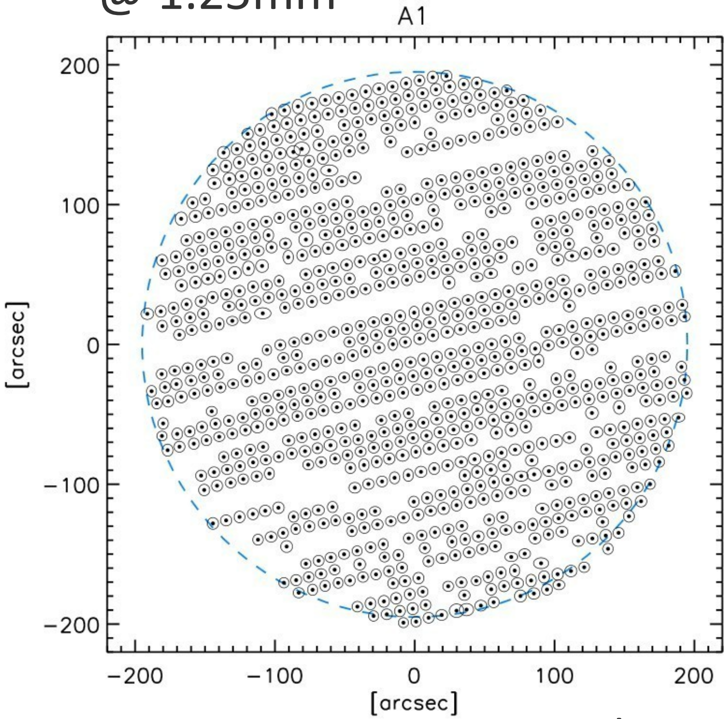
- 100s of cold massive sources discovered
- Insight in early stages of star formation

- Candidate distant SMG in GJ526 field
- A cosmic filament?

NIKA2 arrays

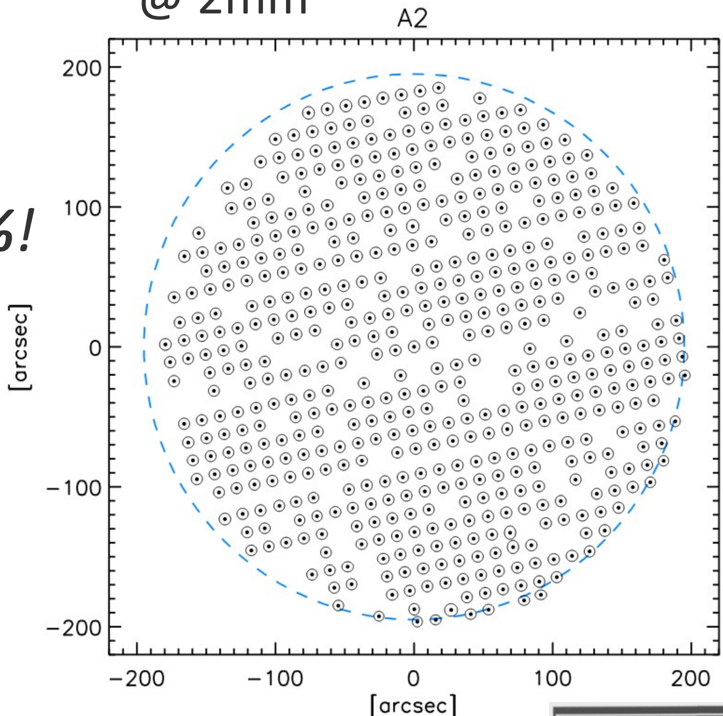
Sample footprint of a NIKA2 arrays

@ 1.25mm



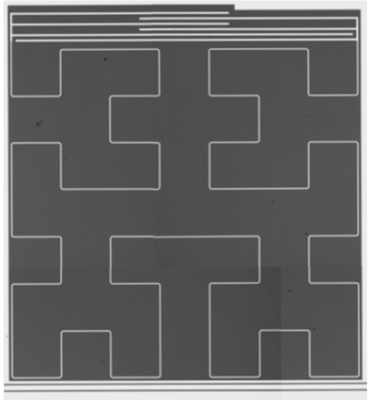
Yield:
70% to 90%!

@ 2mm



Adam et al, A&A 609, A115 (2018)

- Possible thanks to **LEKID** approach *(1-step process)*



NIKA2 arrays

NIKA2 specs (valid <=2025)

Channel	260 GHz 1.15 mm			150 GHz 2 mm
Arrays	A1	A3	A1&3	A2
Number of designed detectors	1140	1140		616
Number of valid detectors[1]	952	961		553
Number of used detectors[2]	660–830	725–780		430–480
FoV diameter [arcmin]	6.5	6.5	6.5	6.5
FWHM [arcsec]	11.3 ± 0.2	11.2 ± 0.2	11.2 ± 0.1	17.7 ± 0.1
Beam efficiency[3] [%]	55 ± 5	53 ± 5	60 ± 6	75 ± 5
rms calibration error [%]	4.5	6.6		5
Model absolute calibration uncertainty [%]	5			
RMS pointing error [arcsec]	<3			
NEFD [$\mathrm{mJy\ s^{1/2}}$][4]			33 ± 2	8 ± 1
Mapping speed [$\mathrm{arcmin^2\ h^{-1}\ mJy^{-2}}$][5]			67–78	1288–1440

Adam et al, A&A 609, A115 (2018)

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Adam et al, A&A 609, A115 (2018)

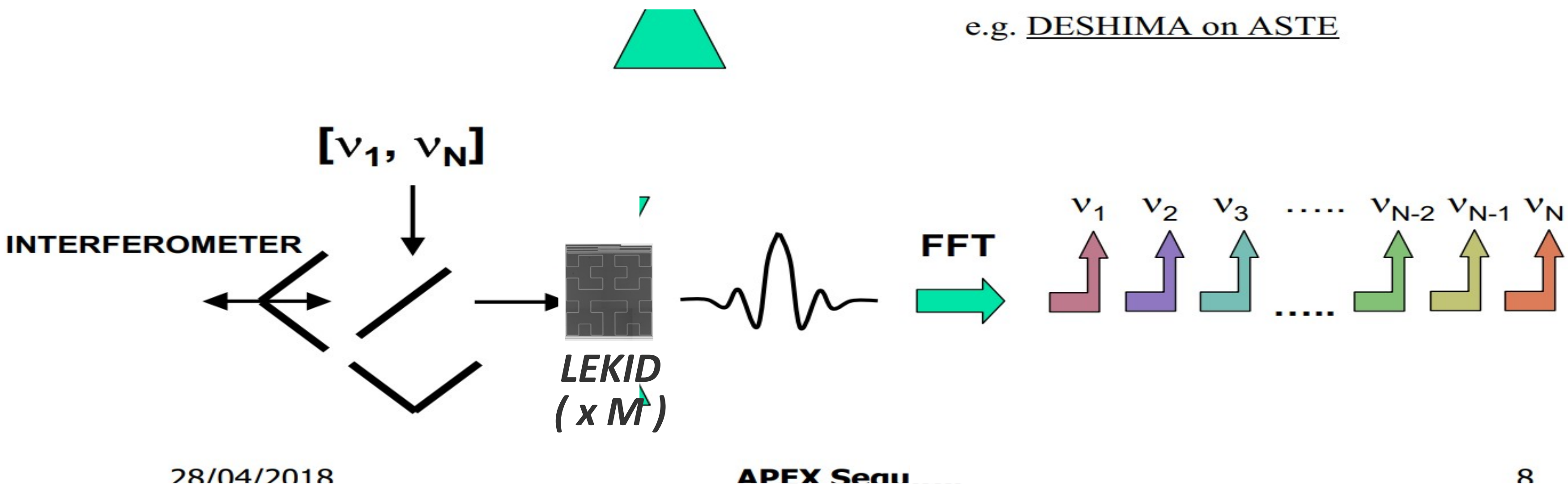
<20 !

(exact value tbc)

- Further improved this spring!
- A champion at mapping the mm sky
- And seed for the birth of **GIS KIDS** → https://gis-kids.cnrs.fr

Going ahead: spectrometry

- LIM → moderate resolution but large focal plane
- One possible option: MP interferometer
- Take advantage of temporal domain (KID are fast)



Pros:

- Adapted to large focal planes
- No strong R&D needed for the detectors

Cons:

- Size (optics)
- Risk of systematics

CONCERTO

- MPI + LEKID array @ **APEX**
- On-sky: 2021-2023

CONCERTO specifications:

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 [#]	2152 | 2152
Angular resolution HF | LF [arcsec]	20-32 | 23-45
Average angular resolution HF | LF [arcsec]	26 | 34
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

Monfardini et al, JLTP 209, 751-757 (2022)

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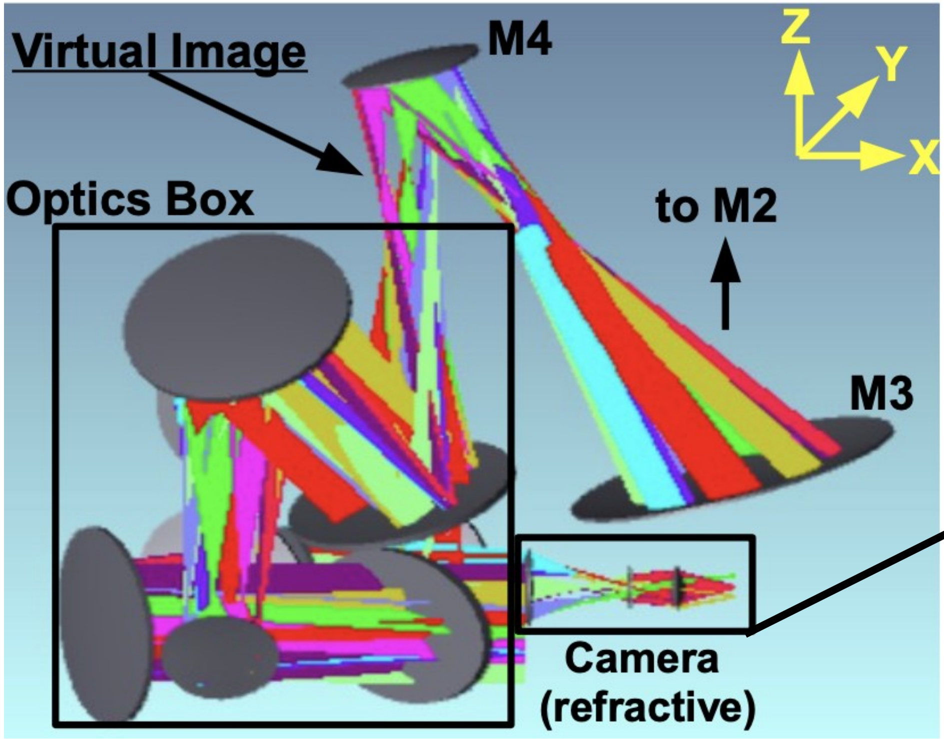
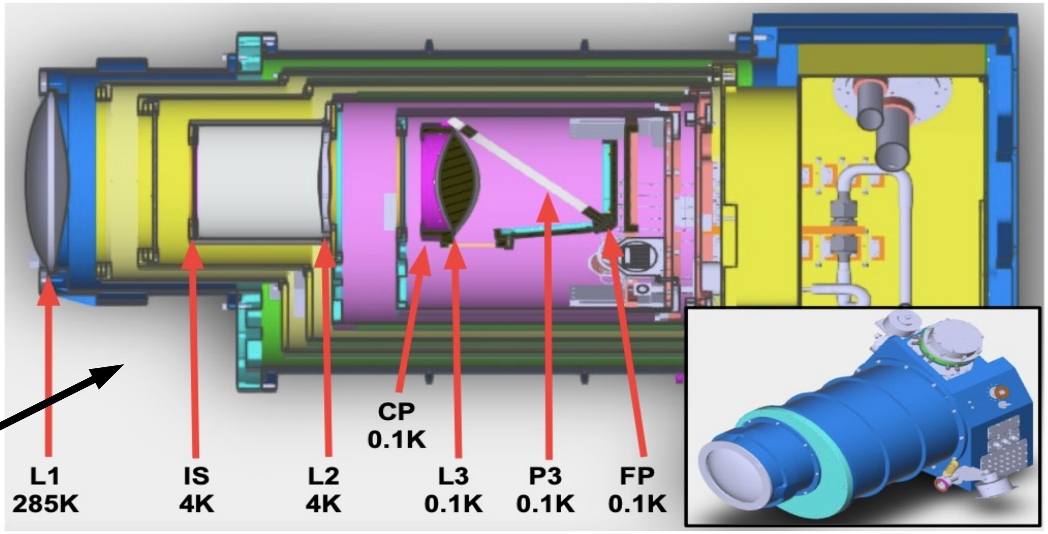
- MPI + LEKID array @ **APEX**
- On-sky: 2021-2023

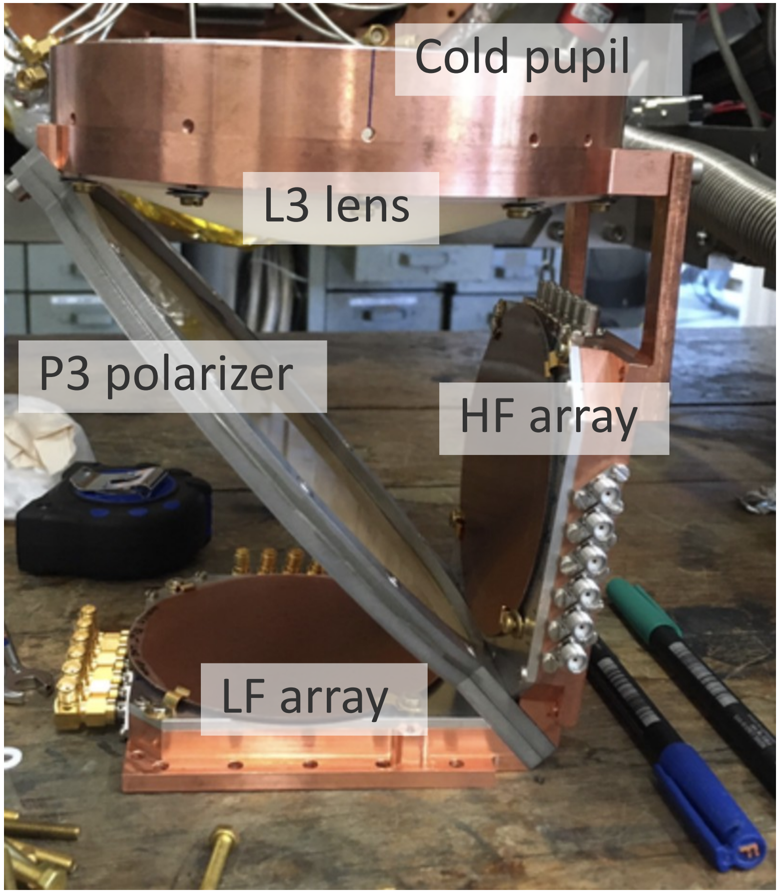


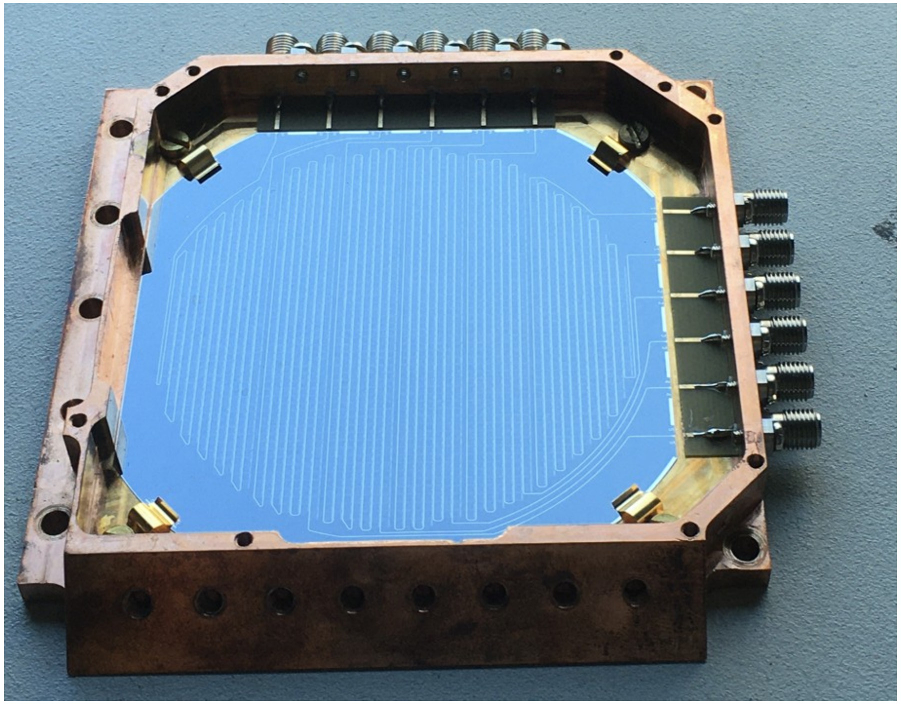


CONCERTO

- MPI + LEKID array @ **APEX**
- A total of ~4000 "spaxels" each with R~100!

(the equivalent of ***400kpixels*** *!)*

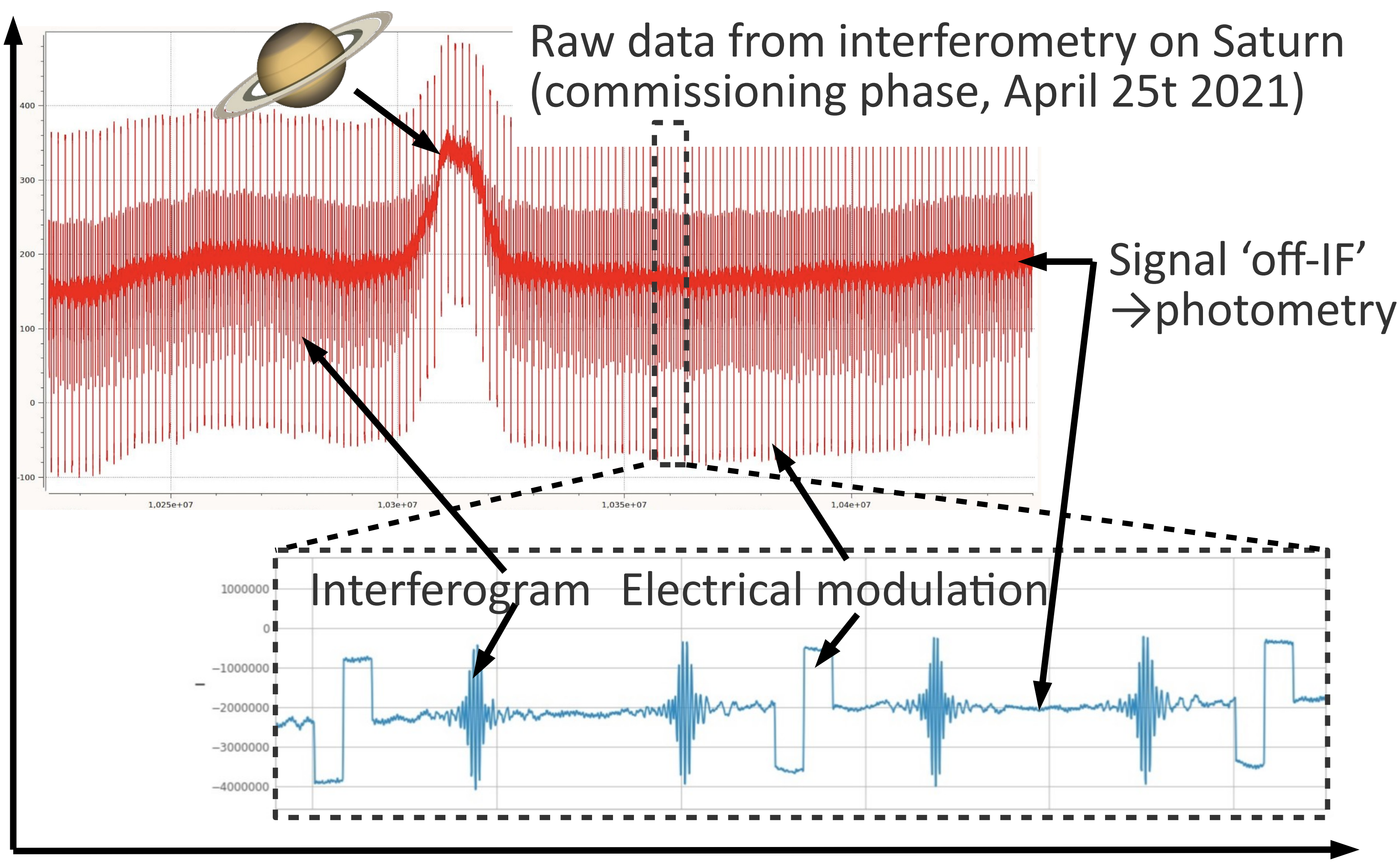




2x 2152 LEKID arrays

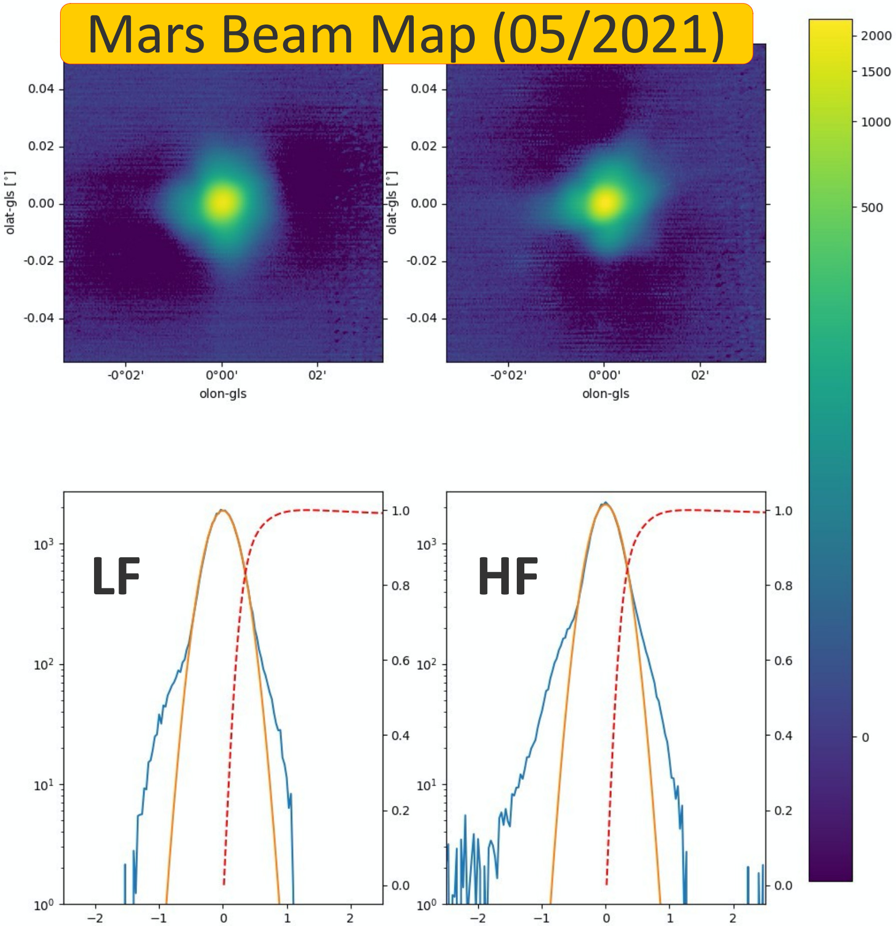
CONCERTO

- The price to pay..



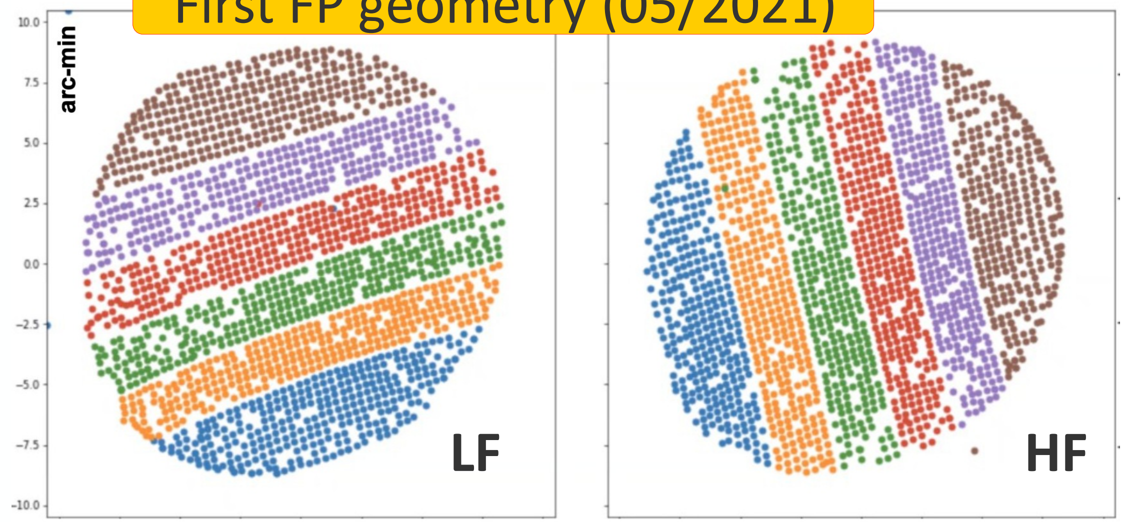
CONCERTO sample results

Mars Beam Map (05/2021)



Good agreement with expectations

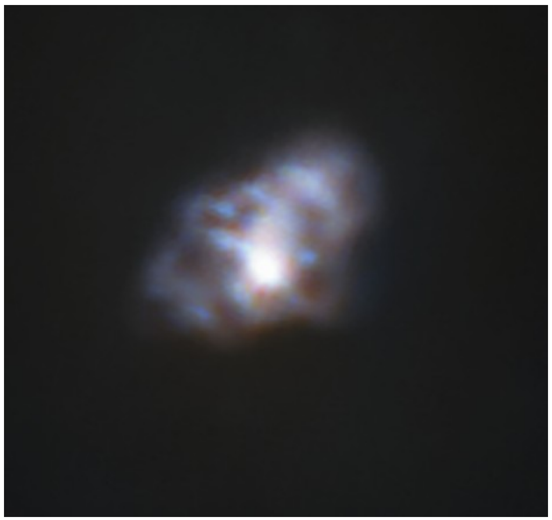
First FP geometry (05/2021)



>90% pixels detected
>70% valid KID used

CONCERTO sample results

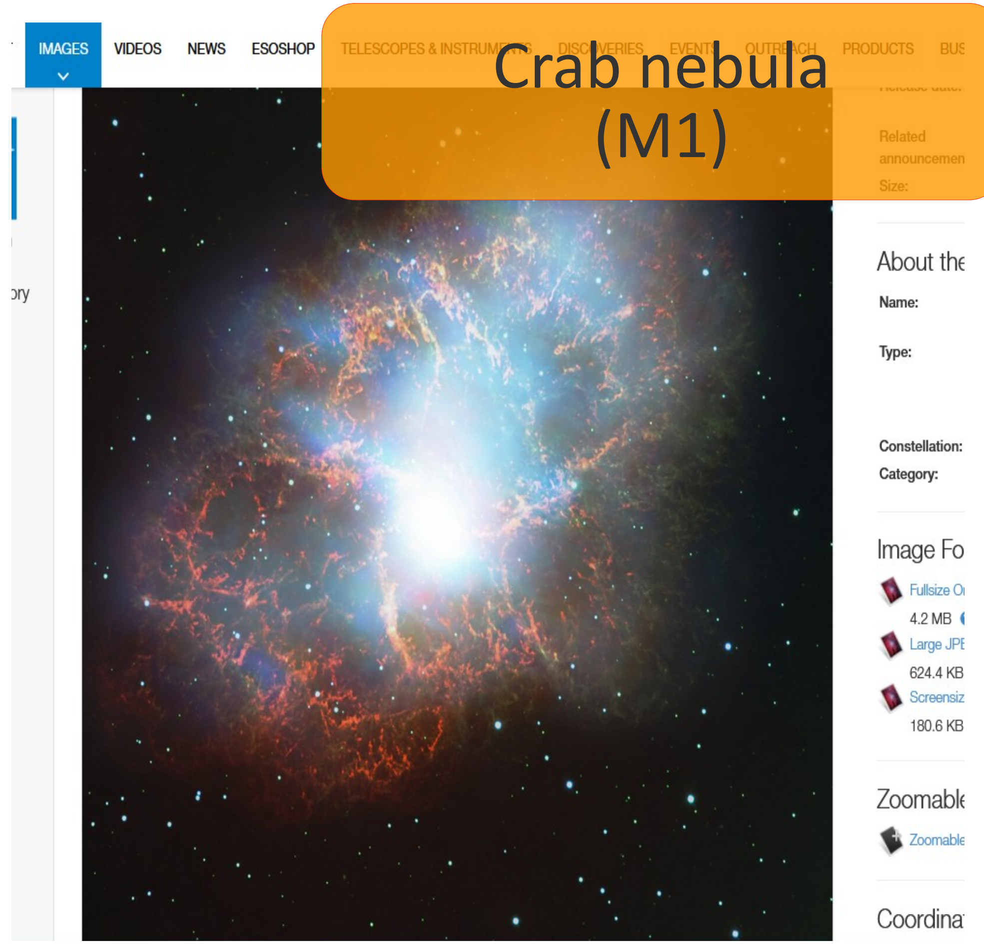
https://www.eso.org/public/announcements/ann21010/



CONCERTO
LF (blue) + HF (red)

10' x 10' field
2.5min integration time

Crab nebula
(M1)



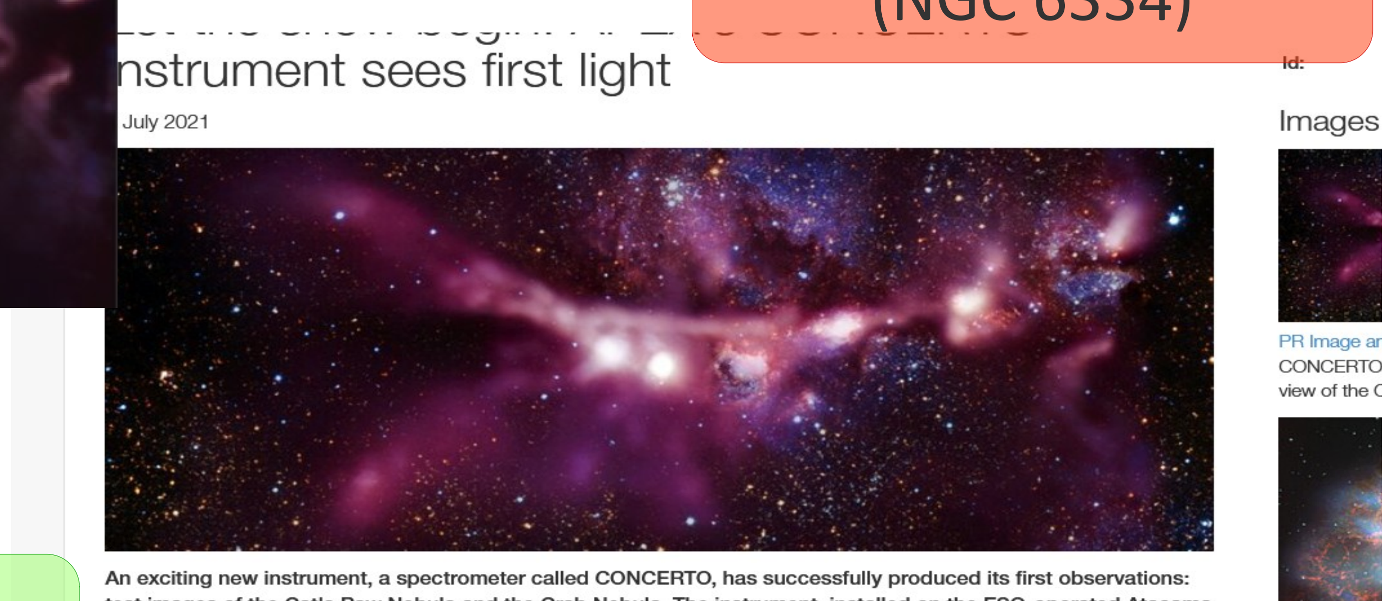
CONCERTO + visible from FORS 2 (VLT)

CONCERTO sample results

https://www.eso.org/public/announcements/ann21010/

CONCERTO
LF (blue) + HF (red)

Cat’s paw nebula
(NGC 6334)



37’ x 25’ field
16min integration time

CONCERTO + near-IR from VISTA (Paranal)

CONCERTO: spectroscopy!

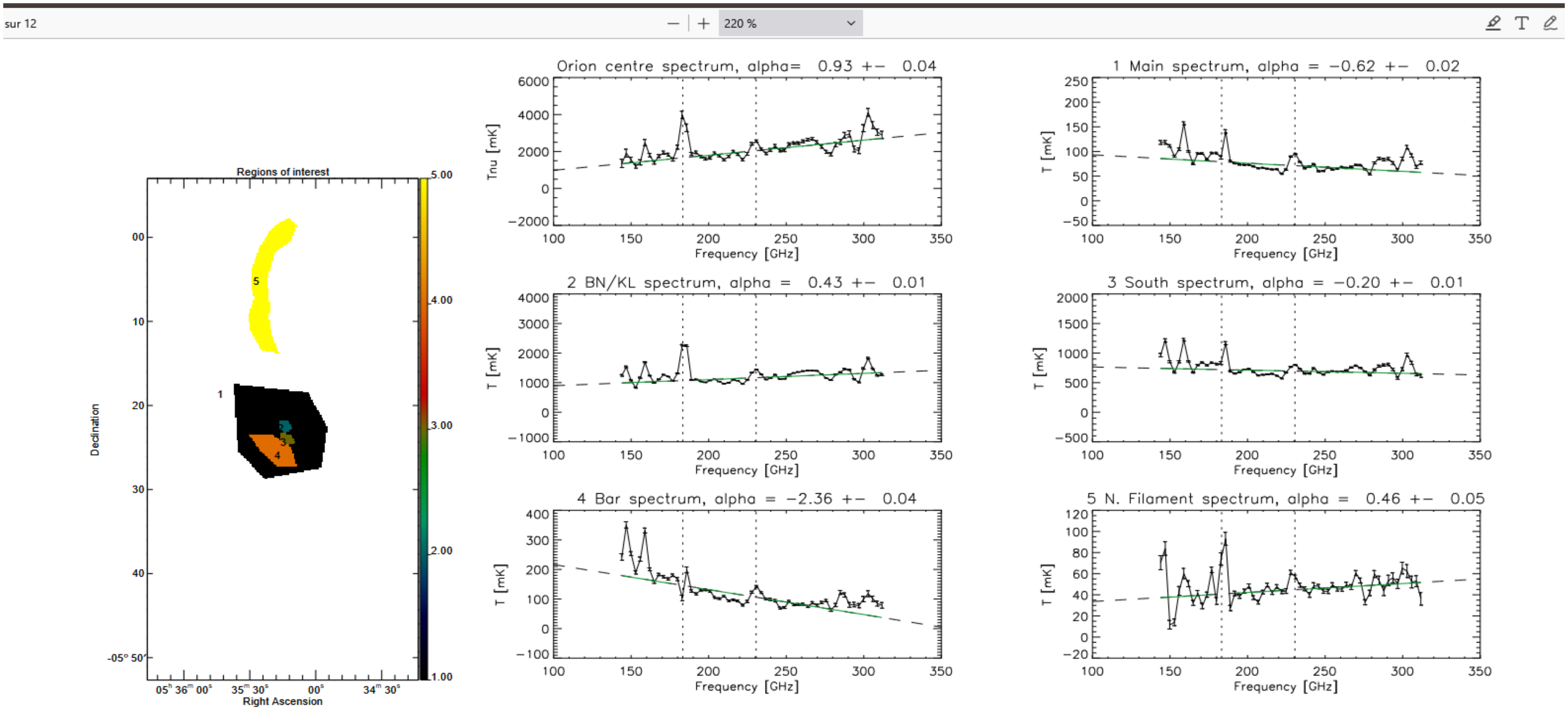
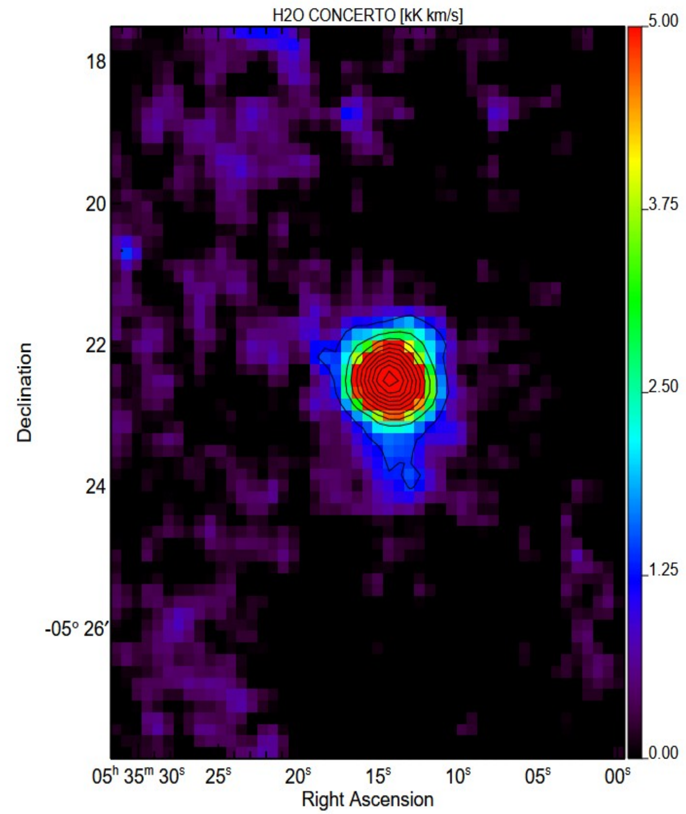


Fig. 5. Spectrum of selected regions in Orion. The left figure shows the selected regions in equatorial coordinates and their labelling. The average

Désert et al, submitted to A&A (04/25, arXiv:2504.20487)

- Studying dust emission in Orion nebula

CONCERTO: spectroscopy!



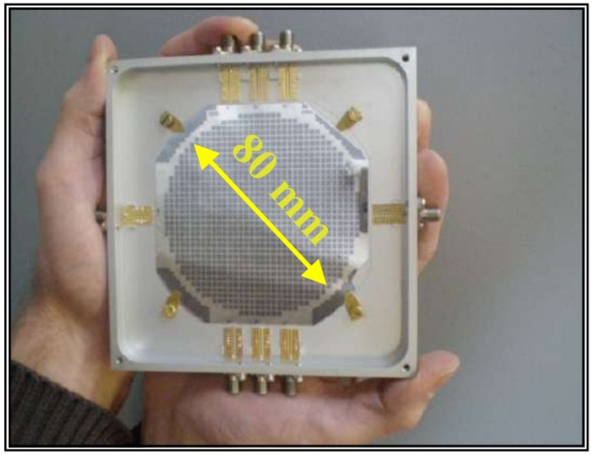
Désert et al, submitted to A&A (04/25, arXiv:2504.20487)

- Studying dust emission in Orion nebula
- And: mapping water!

What next? *(R&D)*

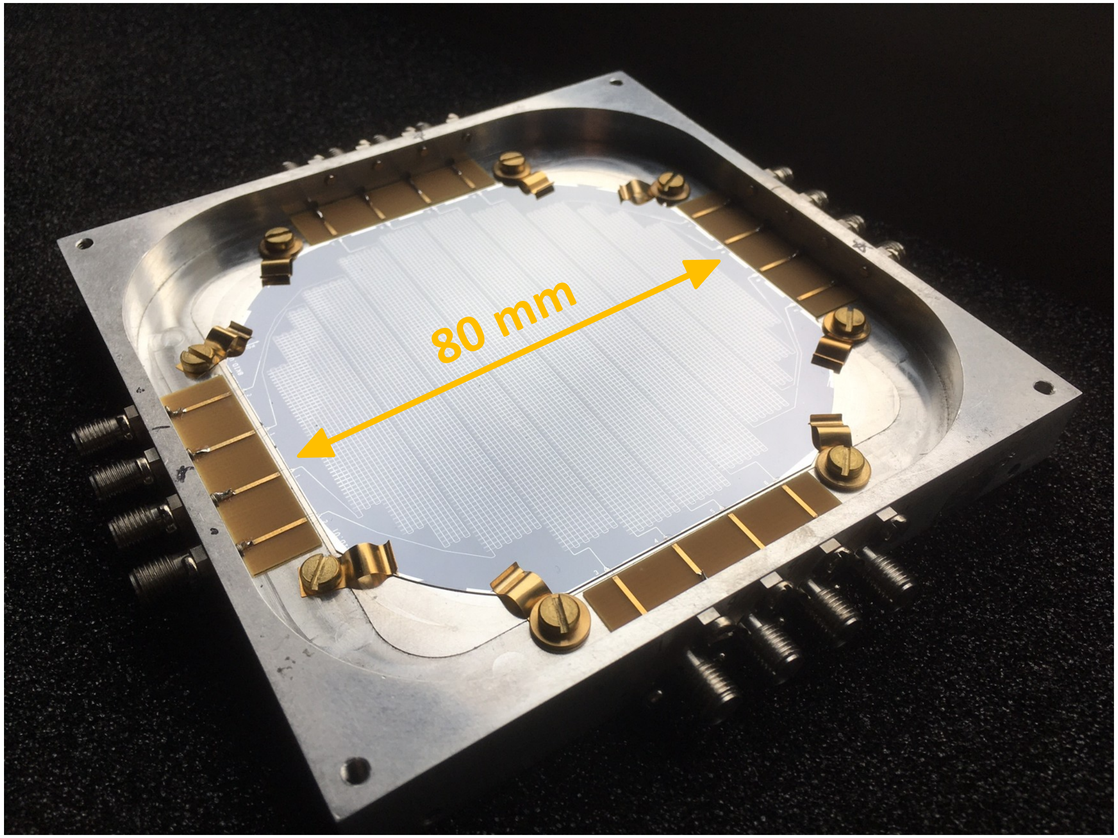
Increasing pixel count

- 8000 pixel array tested



x 4

(pixel count)



- Electronics must follow (/is following)

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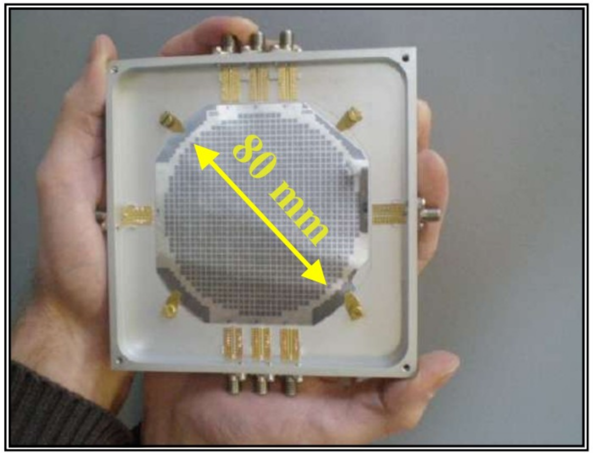

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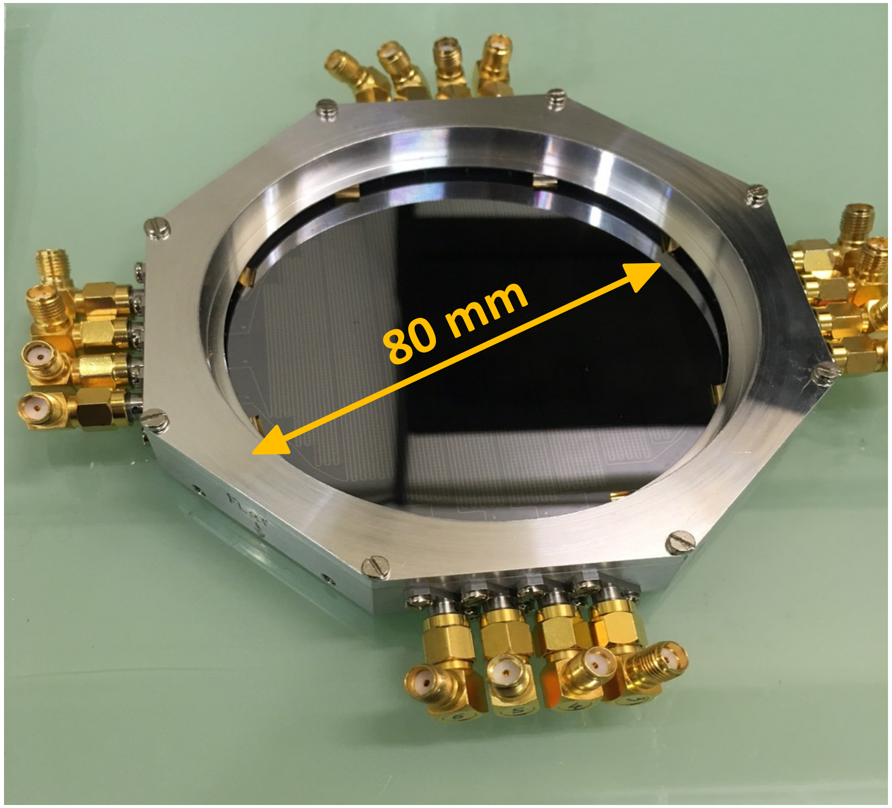
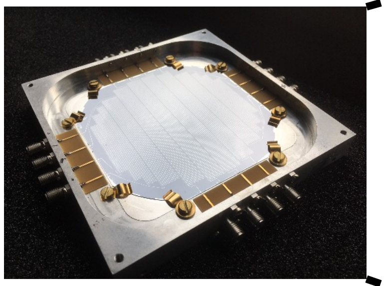


- Electronics must follow (/is following)

What next? *(R&D)*

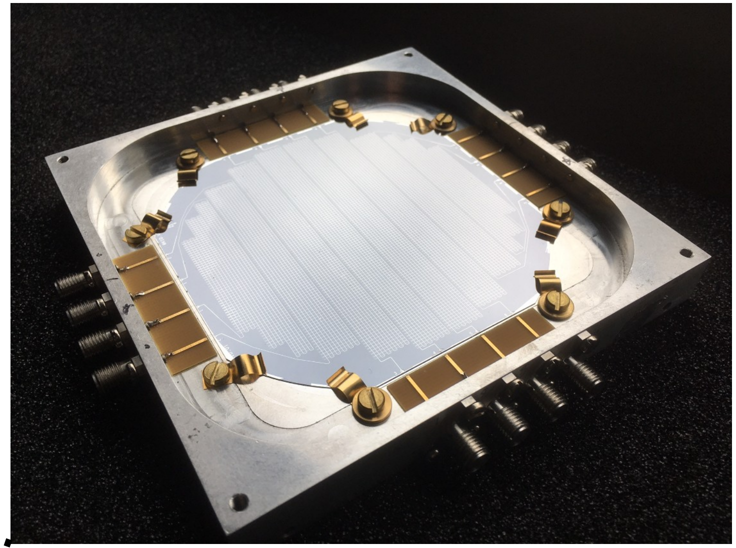
Increasing pixel count

- 8000 pixel array tested
- Longer term: 8” technology (CPER under way)



x 4

(wafer size)

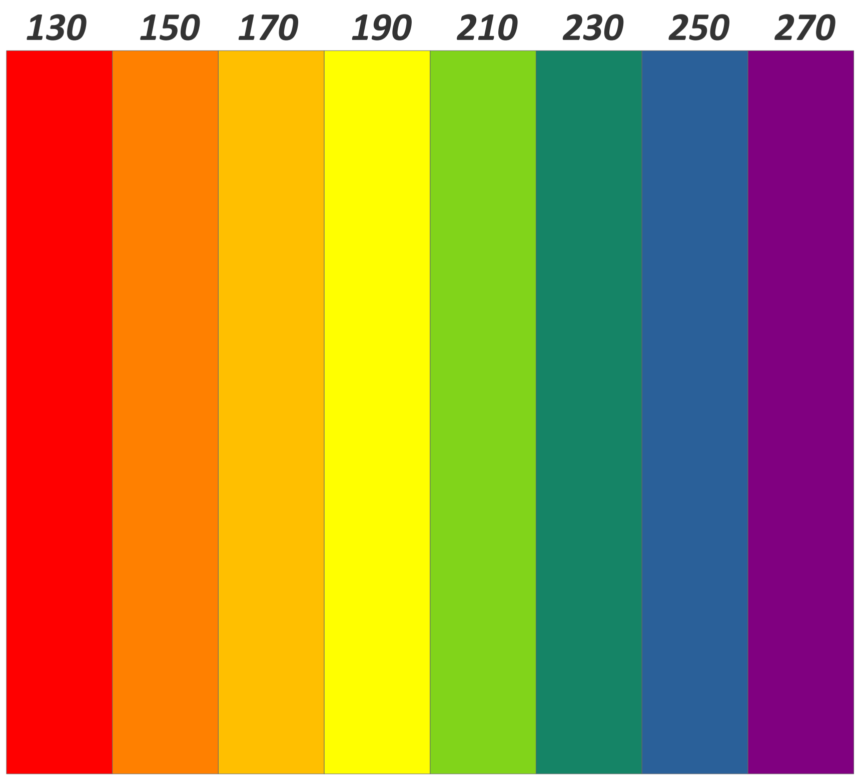


- Bigger wafer → more pixels
- Improved thickness uniformity
- New dedicated machine hosted at new IRAM cleanrooms

What next? *(R&D)*

Alternative low/mid R spectrometers solutions

- Fabry-Perot spectrometer with no moving parts
- Array divided in sub-bands by dedicated multi-λ filter



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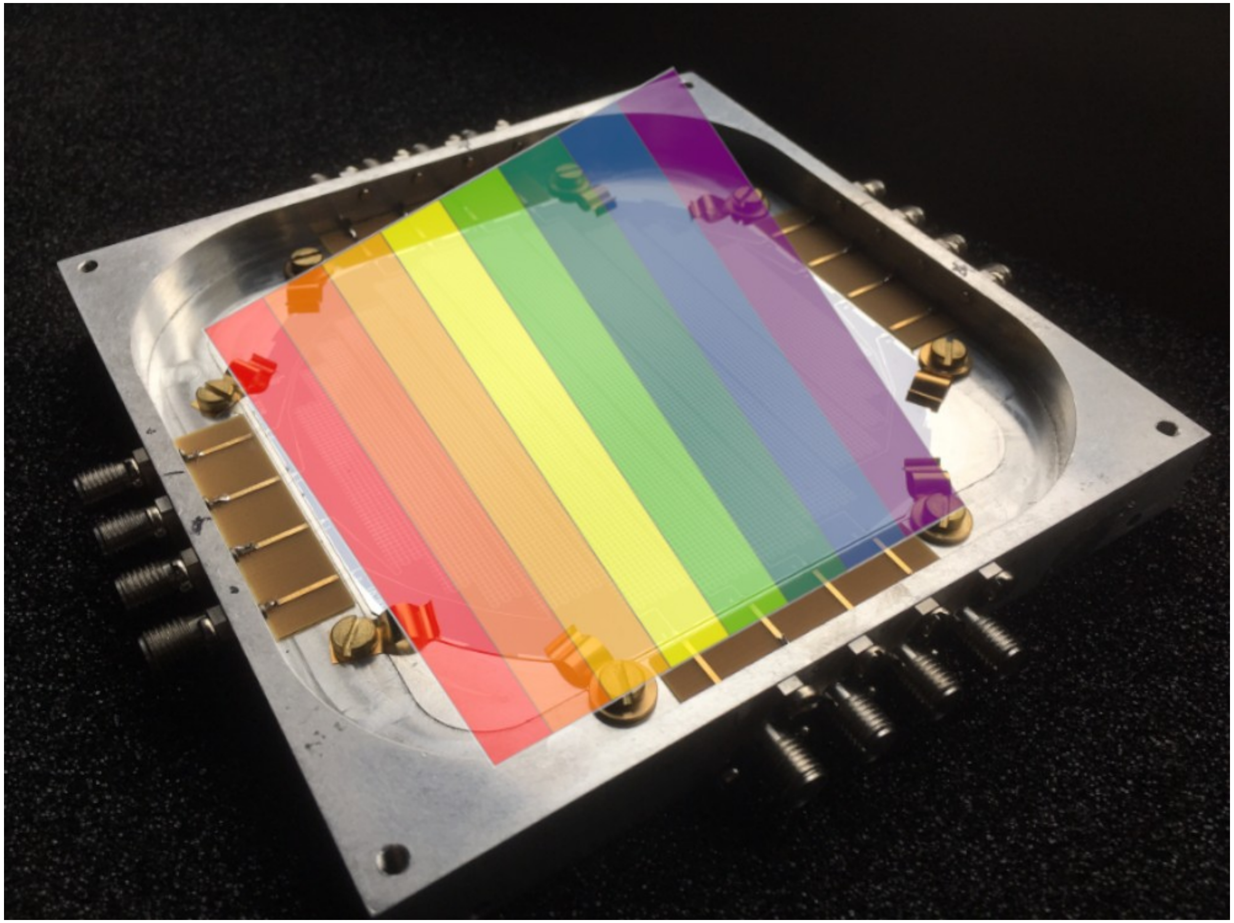
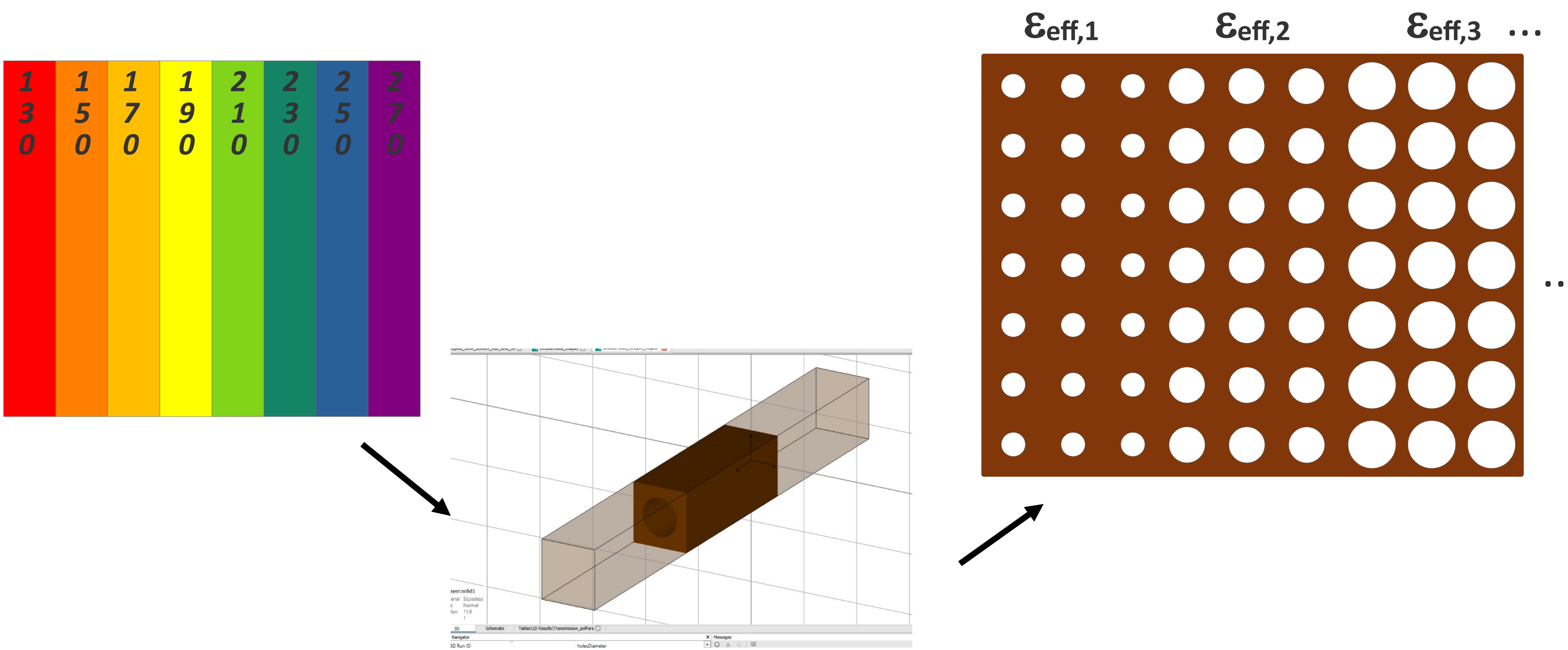


What next? *(R&D)*

Alternative low/mid R spectrometers solutions

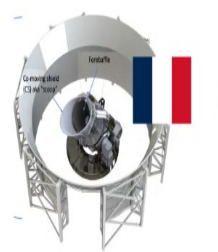
- Fabry-Perot spectrometer with no moving parts
- Array divided in sub-bands by dedicated multi-λ filter
- Achieved by dielectric constant engineering

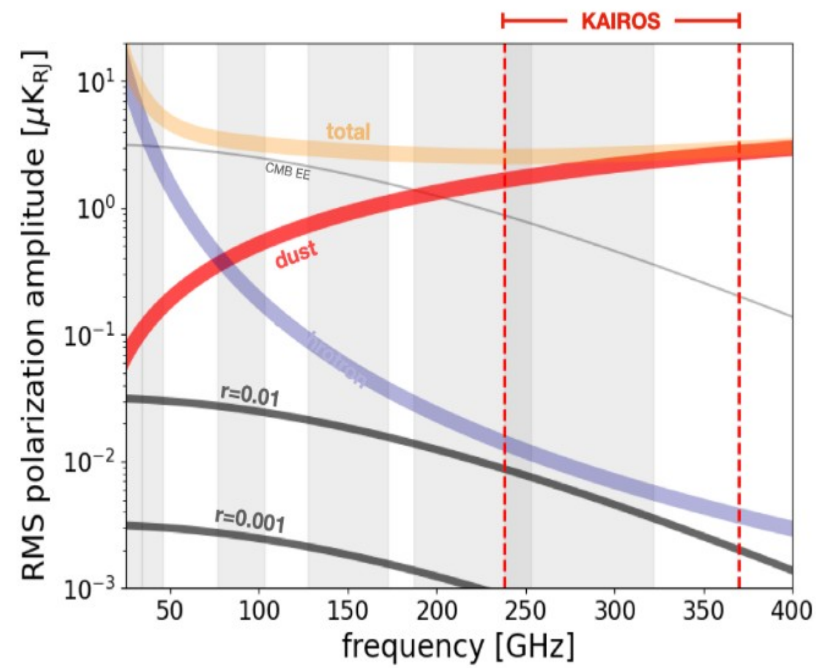


What next? *(Projects)*

KAIROS, a new SAT for SO?

- High frequency SAT for SO
- Looking for funds..

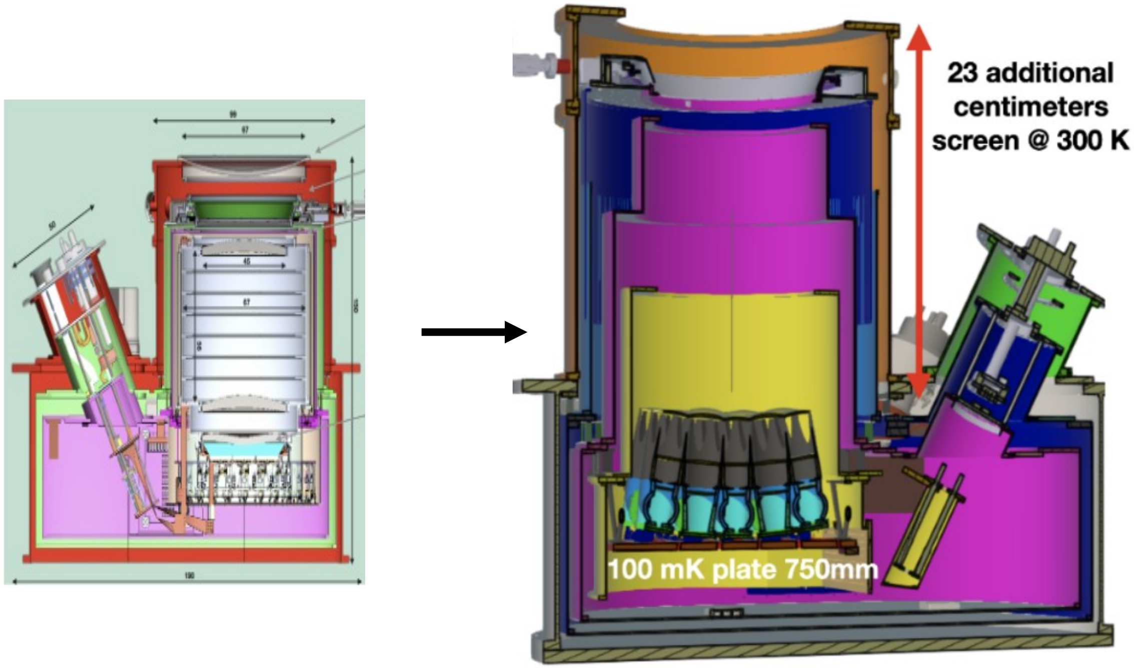


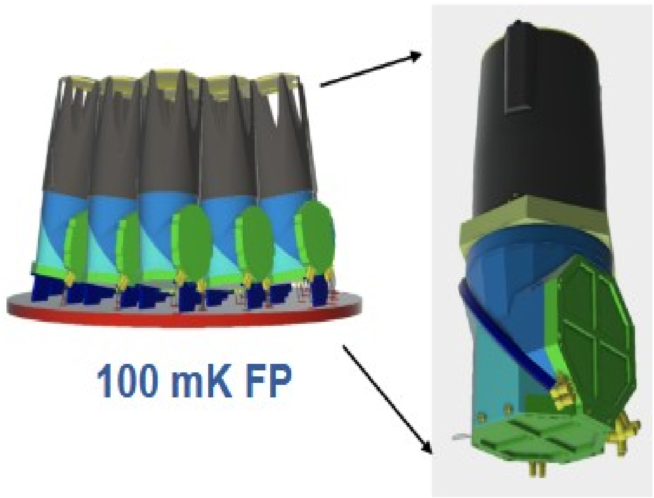


What next? *(Projects)*

KAIROS, a new SAT for SO?

- High frequency SAT for SO
- Will host a total of **~30000** LEKID





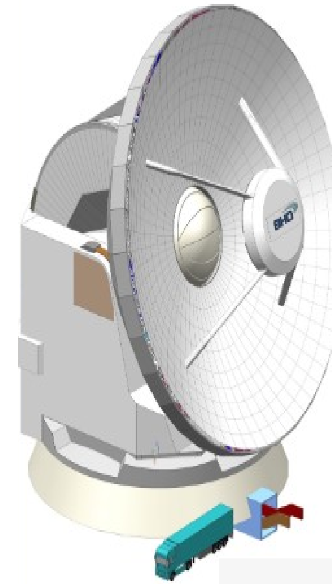
19 x 2 x 800
LEKID!

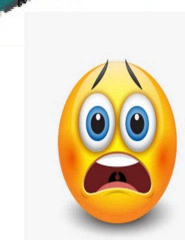
- Pushing towards the 100kpixel level!

Conclusions

- AtLAST is a great project (in all senses..)

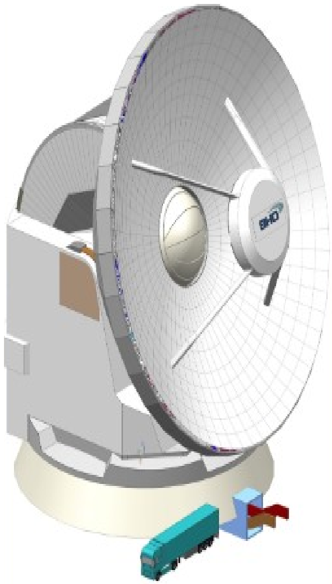
x 2





Conclusions

- AtLAST is a great project (in all senses..)
- In France, a lot of experience on large format KID arrays
- GIS KIDS: dedicated multi-lab collaboration on KID
- On-going work is already naturally pushing in the AtLAST direction
- So a lot of potential to explore!



Thank you!