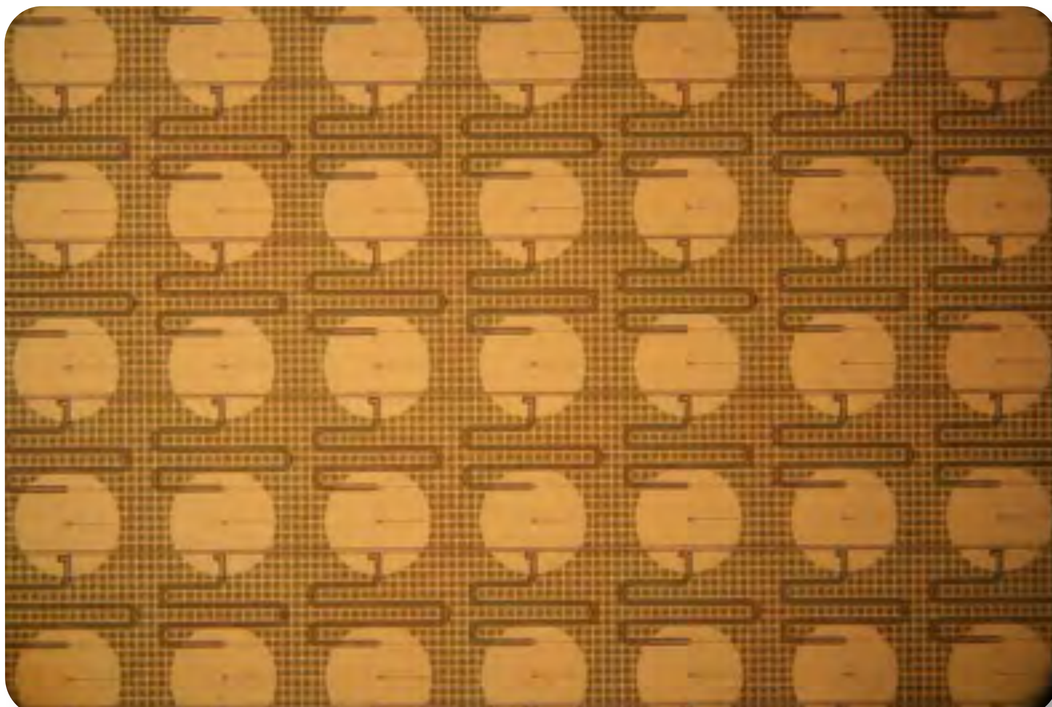
Large format arrays of antenna coupled Kinetic Inductance Detectors for cosmology

J. Baselmans, J. Bueno, O. Yurduseven, N. Llombart, S. Yates,
A. Baryshev, A. Endo, D. Thoen, A. Neto



http://arxiv.org/abs/1609.01952

SRON Netherlands Institute for Space Research
spaceKIDS Kinetic Inductance Detectors for Space
TS THz Sensing Group
TU Delft

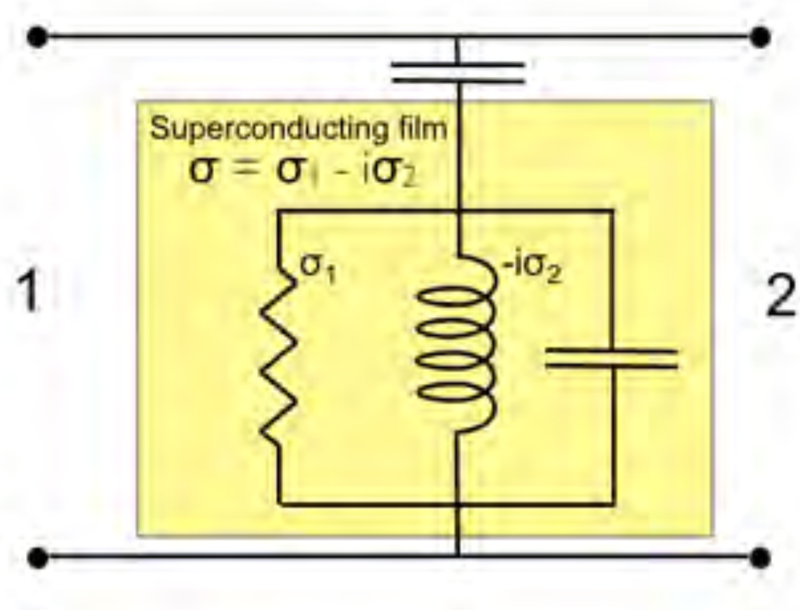
MKID principle of operation

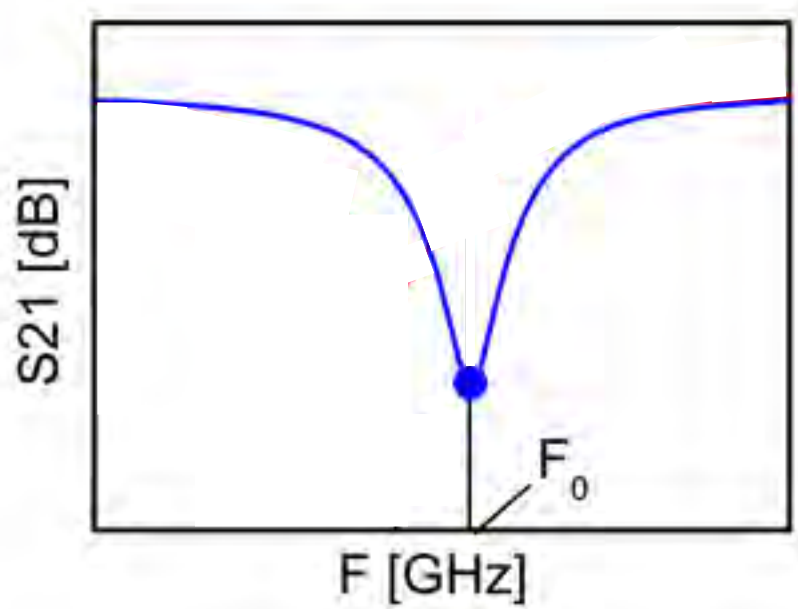
Superconducting film

Inside a microwave resonance circuit

Capable of coupling to radiation

- Q ~10^4 -10^6
- F ~1-10 GHz



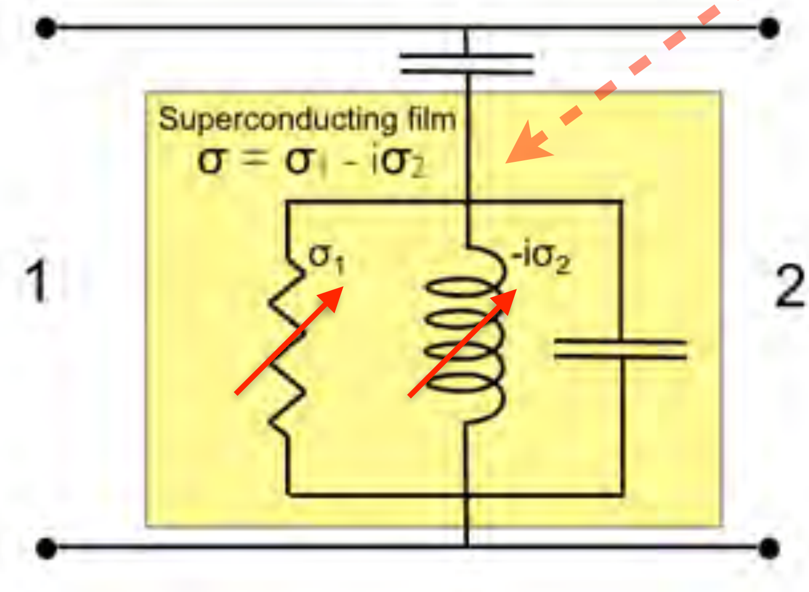


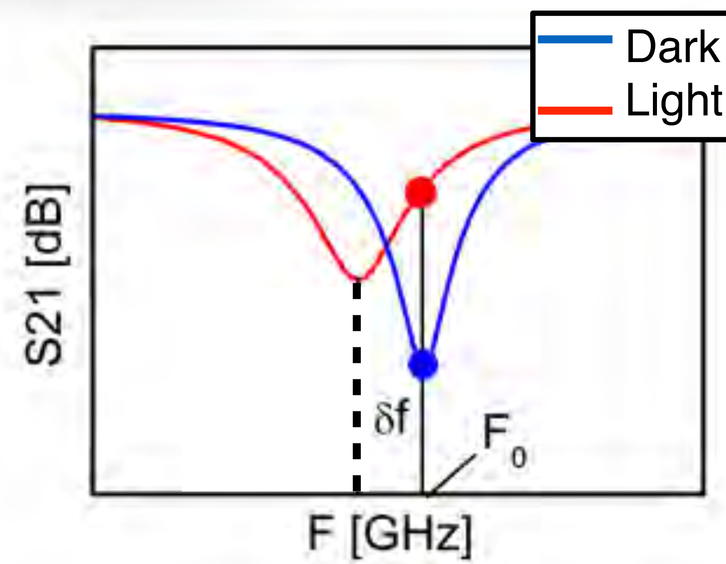
MKID principle of operation

Radiation absorption

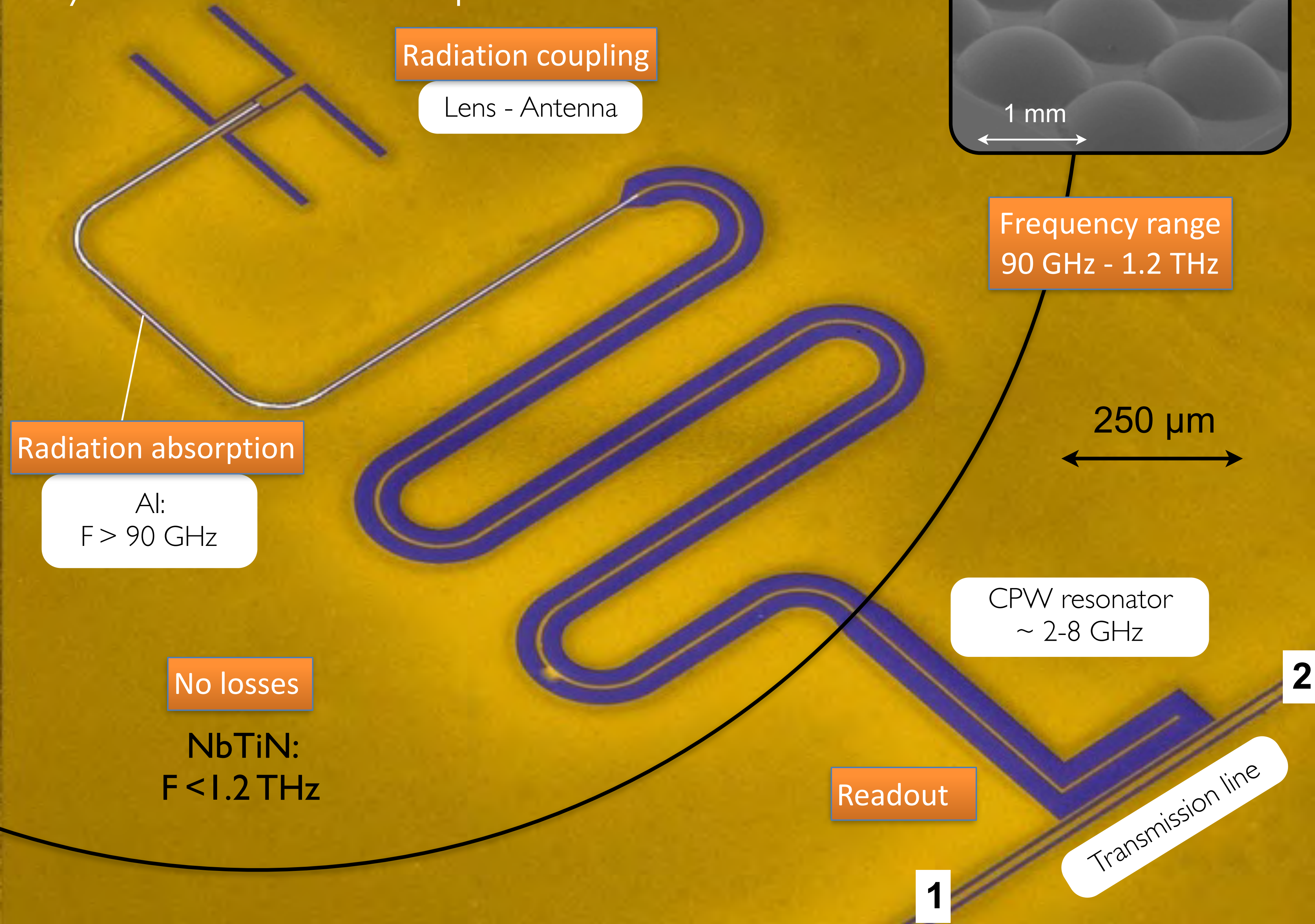
- Changes resonance feature

Can be read out using 1 frequency tone





Hybrid antena coupled MKID

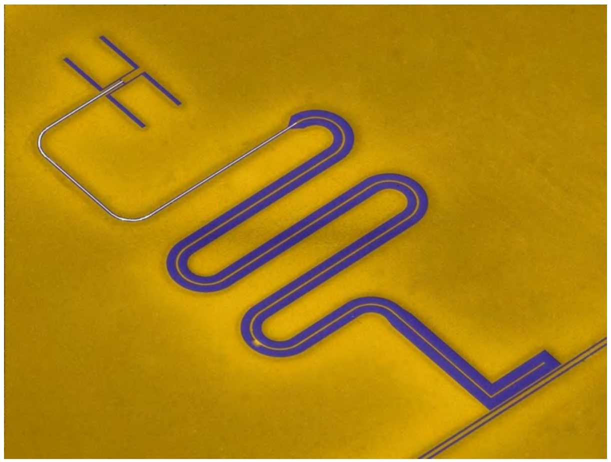


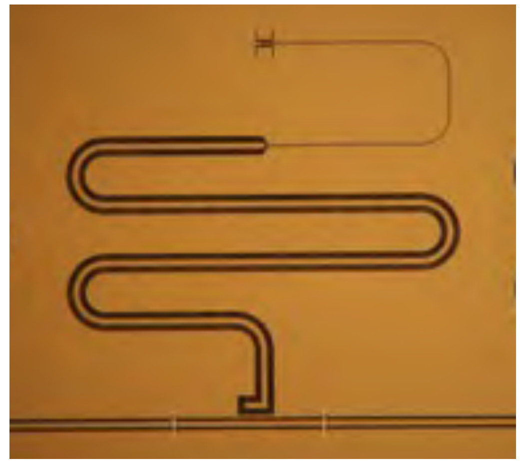
Flexible: Any frequency you want

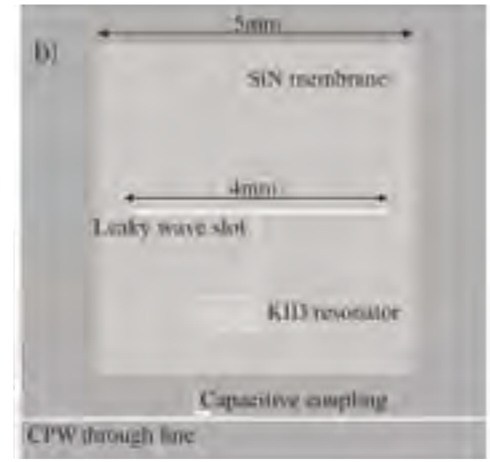
330-400 GHz

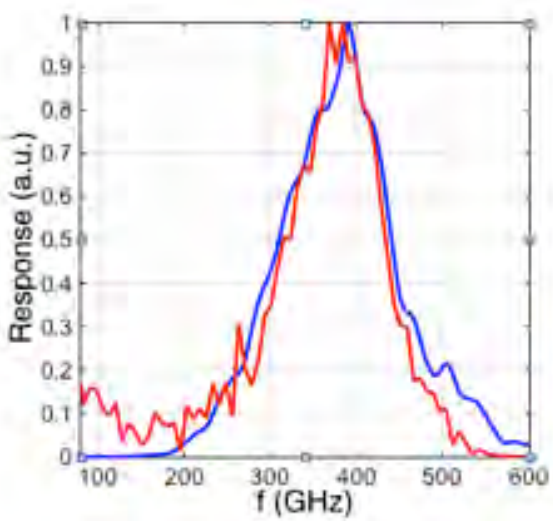
800-950 GHz

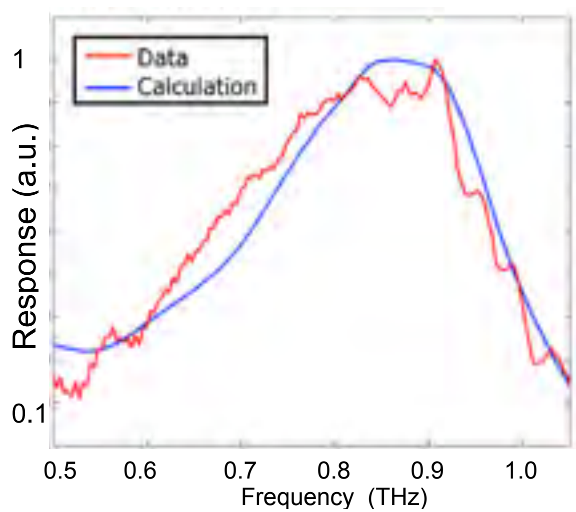
300-1000 GHz

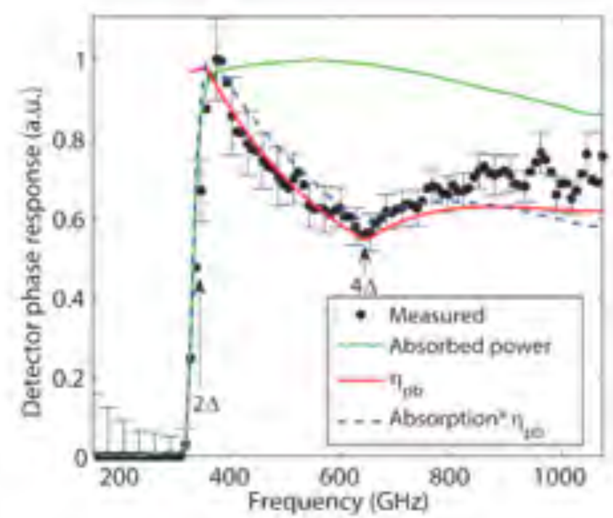




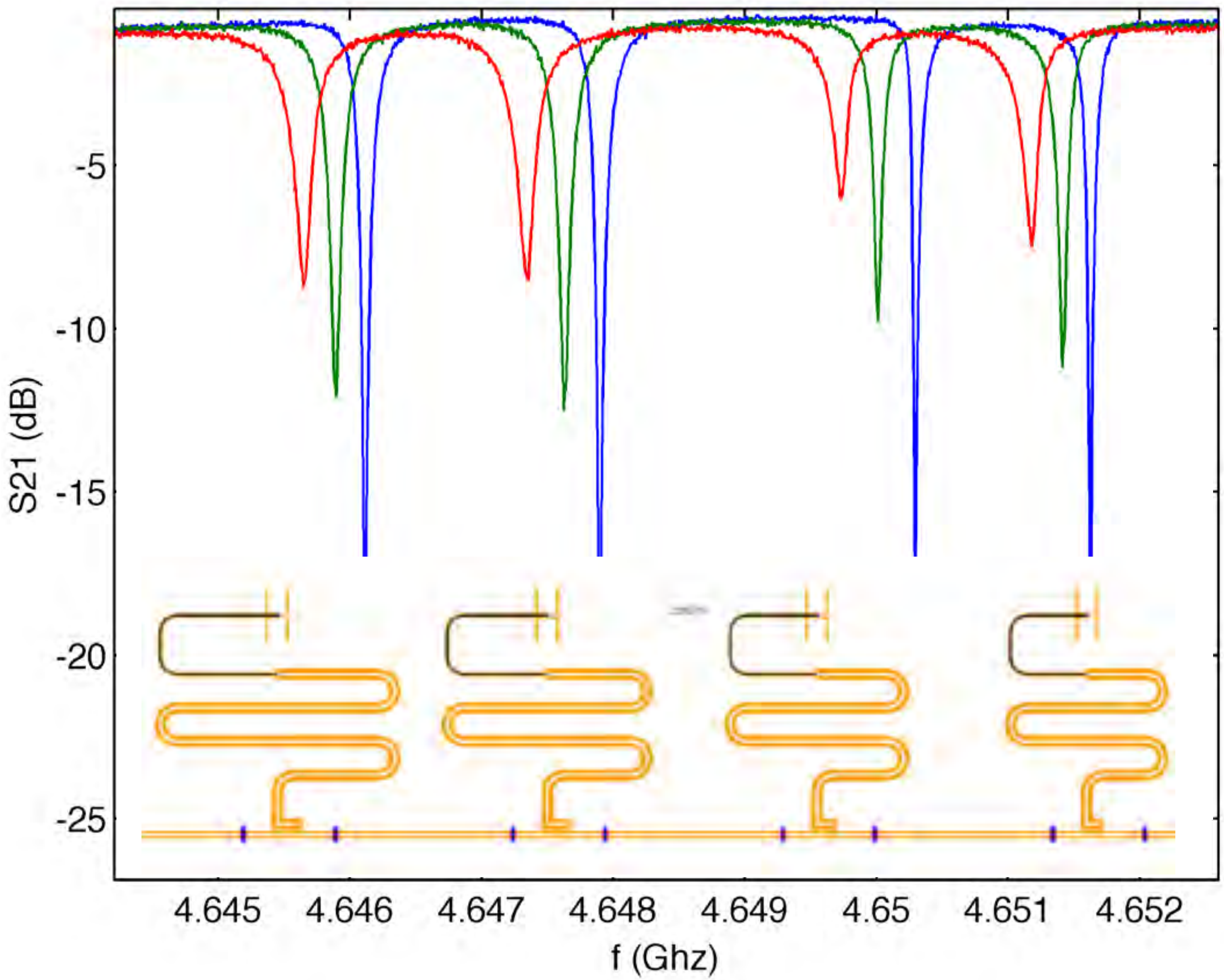




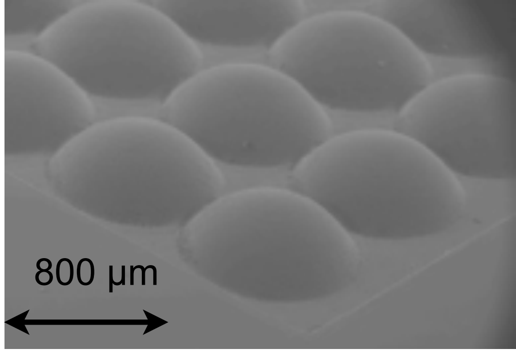


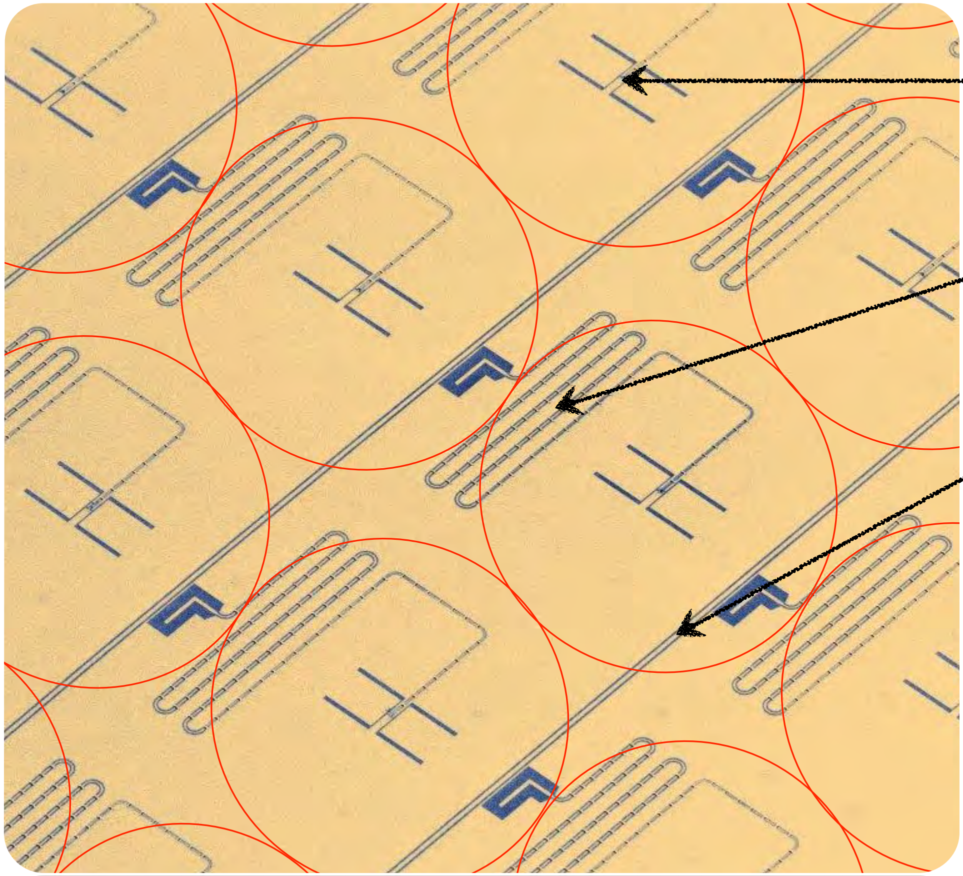


Frequency Domain Multiplexing



KID imaging Array



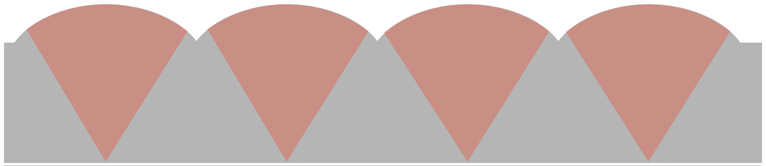


Identical antenna's

Resonators have different length
Different resonance frequencies

1 readout line connecting all pixels

+ Directive beam allows for 4K Lyot stop
- extra complexity (assembly) and cost



Flies eye lens array, 1 lens/pixel

SpaceKIDs

EU FP7 framework project 2012-2015

Develop *MKID* technology towards Space applications

- Build 2 large scale demonstrators (TRL 4-5)

  -> low background demonstrator

The SpaceKIDs low background demonstrator

961 pixels

1 readout chain, 2 coax cables

1 LNA @ 4K (5 mW power)

1 readout system @ 300K

20 mW/pixel for space version

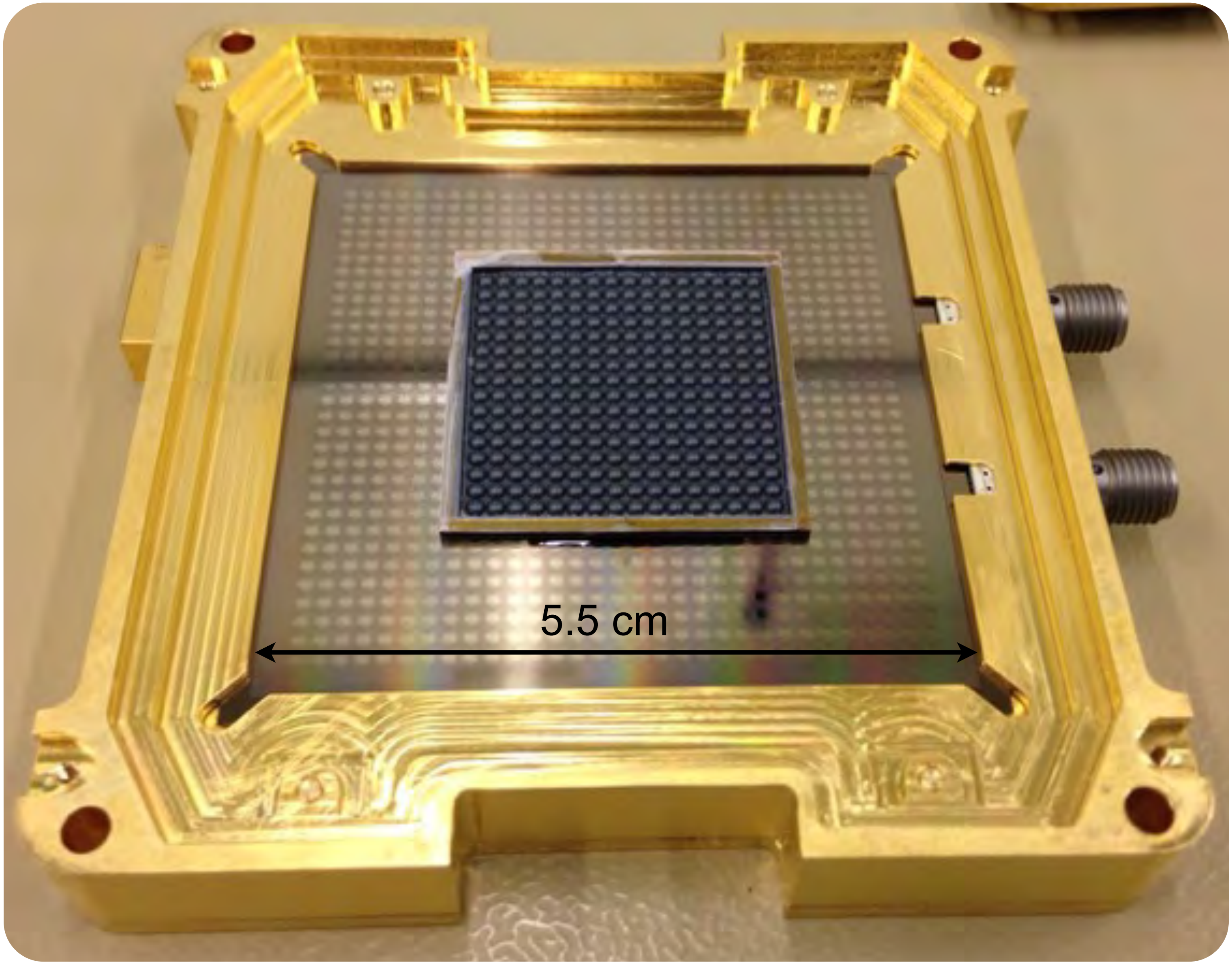
Table 2. Key requirements for the demonstrator system.

	MUX (factor)	λ	$\lambda/\Delta\lambda$	NEP_{det}	Absorption efficiency	dynamic range	Cosmic Ray dead time	Crosstalk	1/f knee	Yield
Baseline	500	350 μm	5	5×10^{-19} W/$\sqrt{\text{Hz}}$	>0.5	> 1000	<30%	<-20 dB	<0.5Hz	>60%
Goal	1000	200 μm	1.5	1×10^{-19} W/$\sqrt{\text{Hz}}$	>0.7	> 10^4	<10%	<-30 dB	<0.1Hz	>70%

spaceKIDS
Kinetic Inductance Detectors for Space

SEVENTH FRAMEWORK PROGRAMME

916 pixel, 850 GHz demonstrator



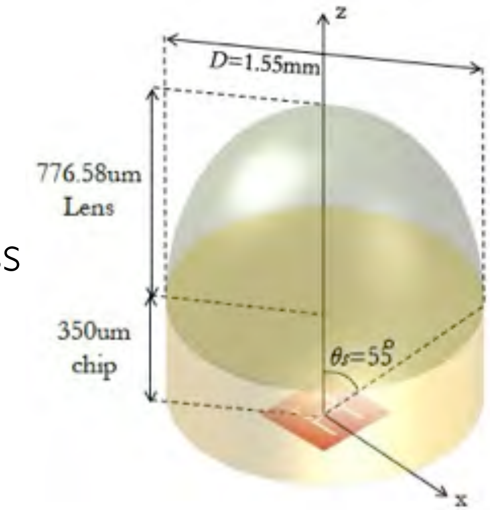
Lens - antenna coupling

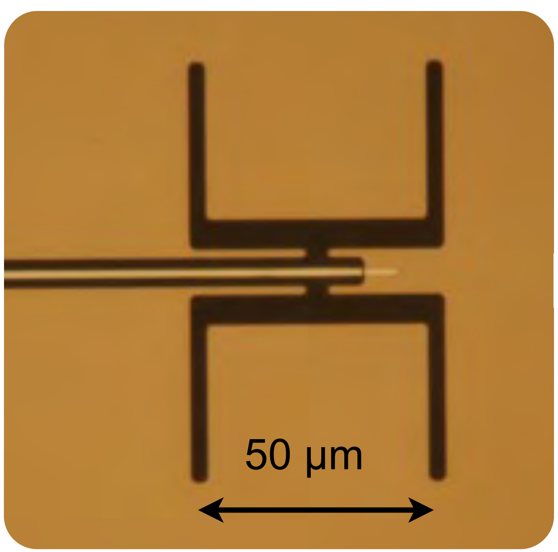
Twin slot antenna + Si lens (850 GHz)

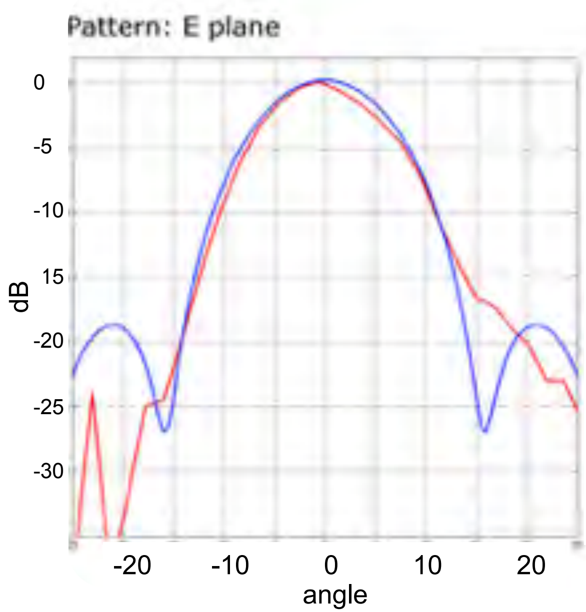
- Sapphire C plane substrate (birefringent)
- Si lens
- Superconducting materials with significant thickness

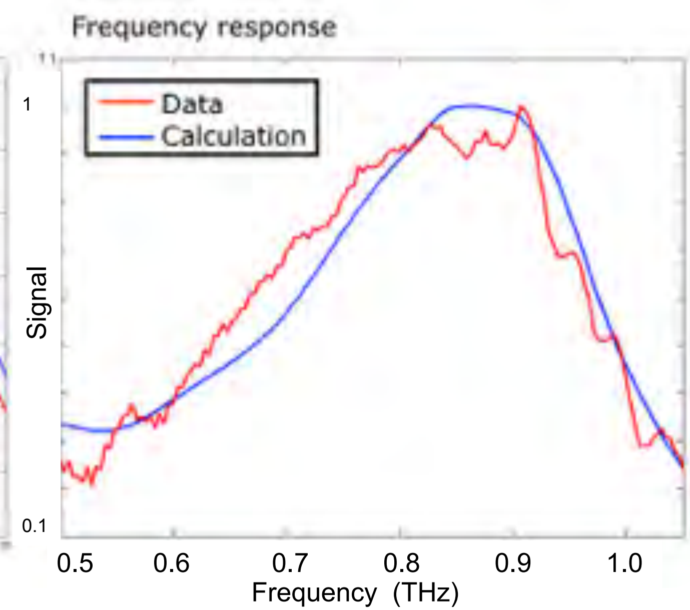
Very good match simulations - experiment

- Taper efficiency = 0.8

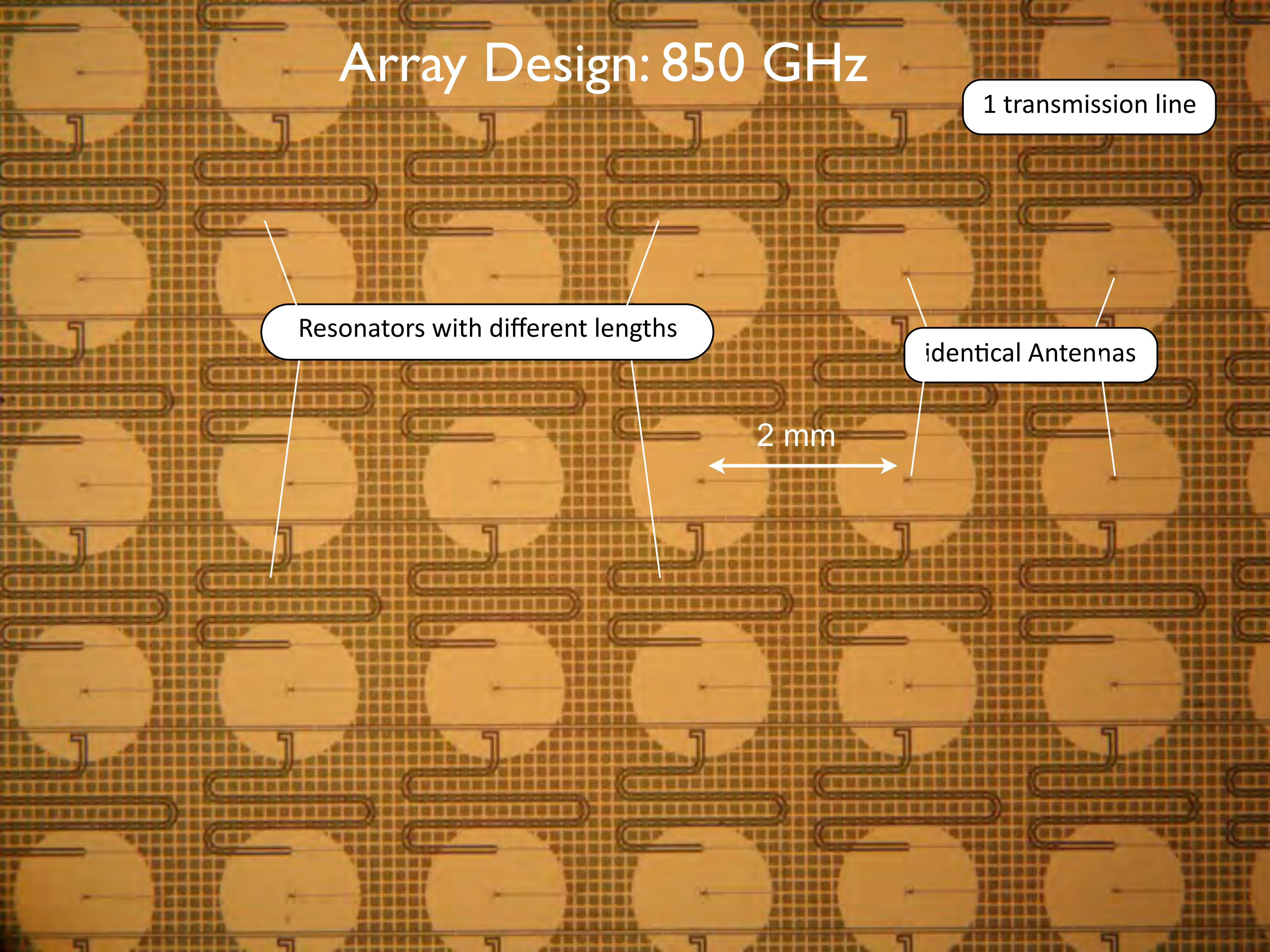




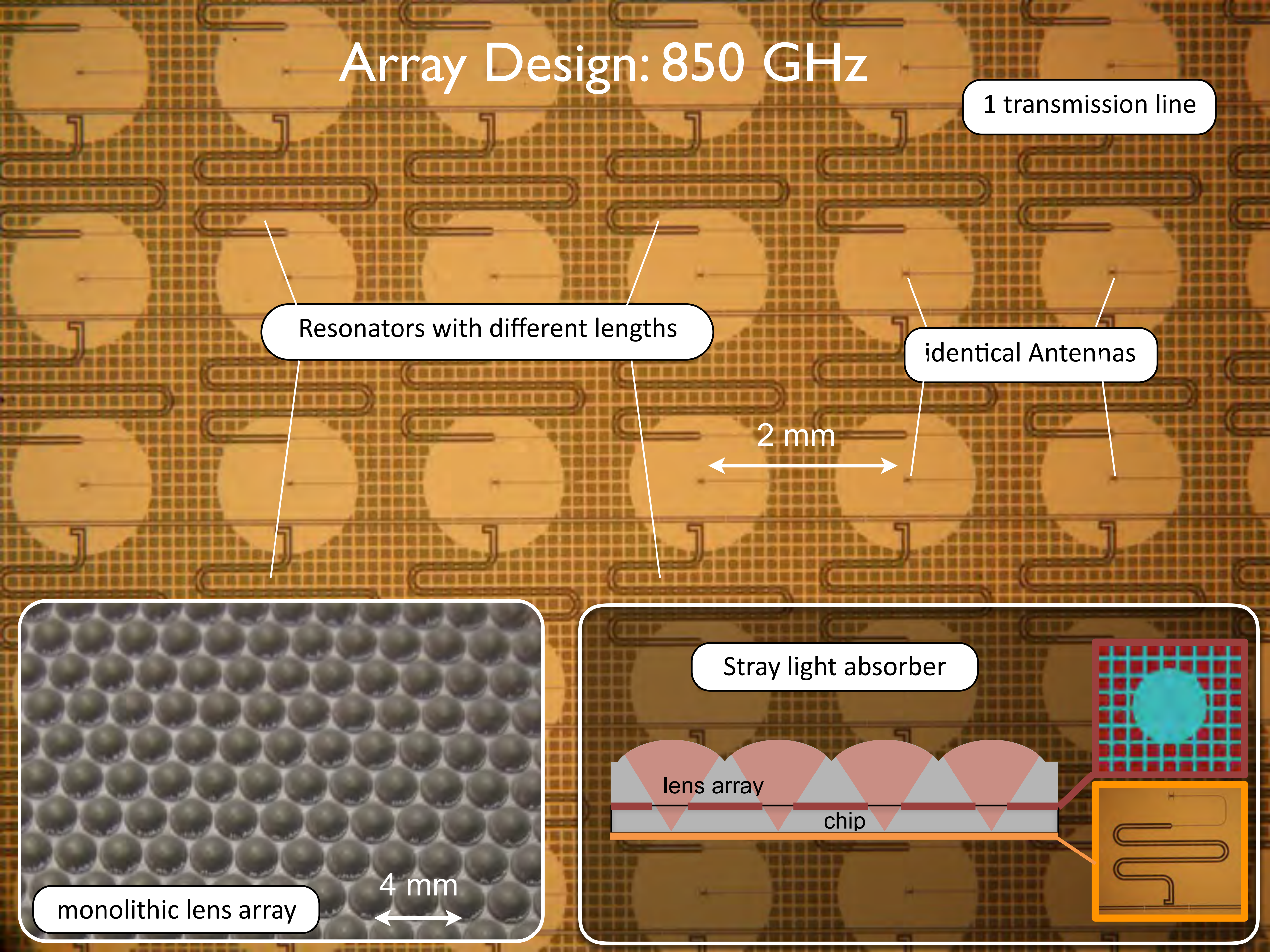




Array Design: 850 GHz

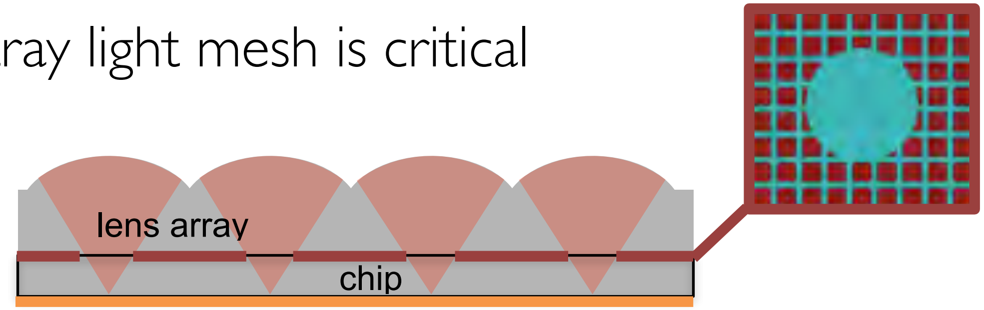


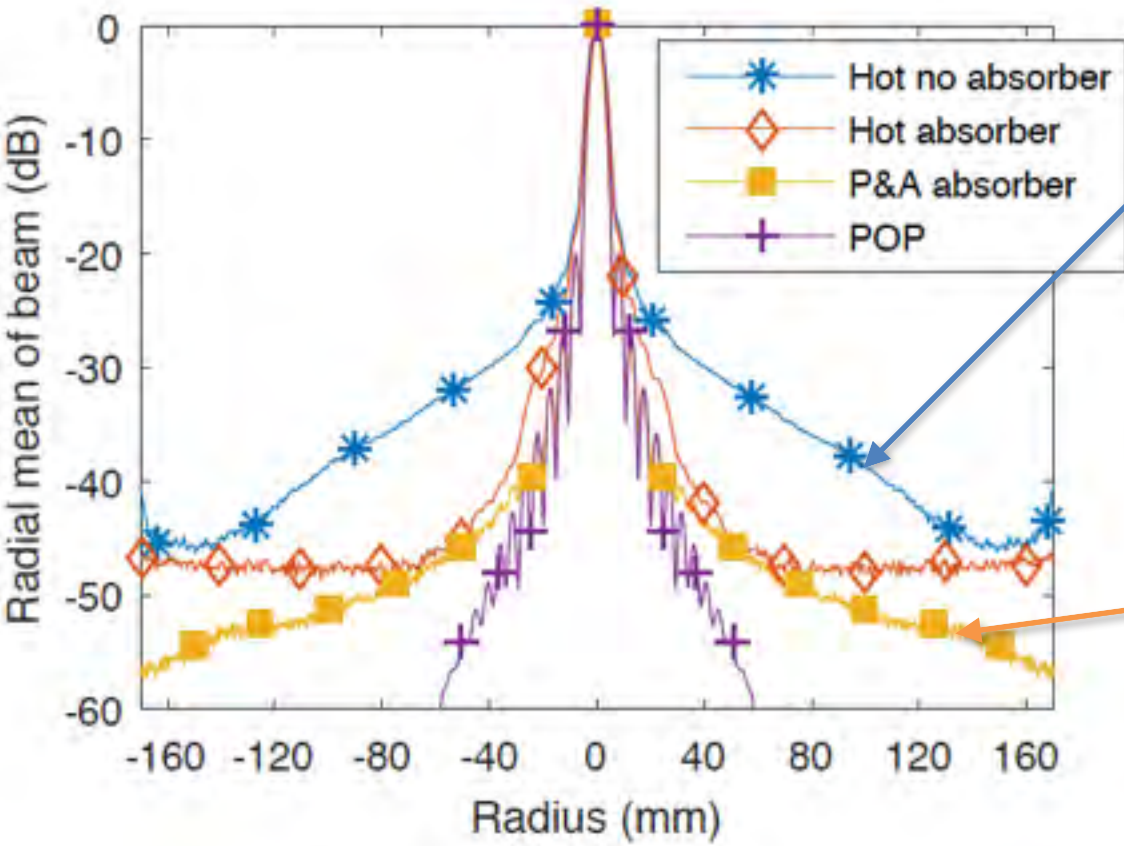
Array Design: 850 GHz

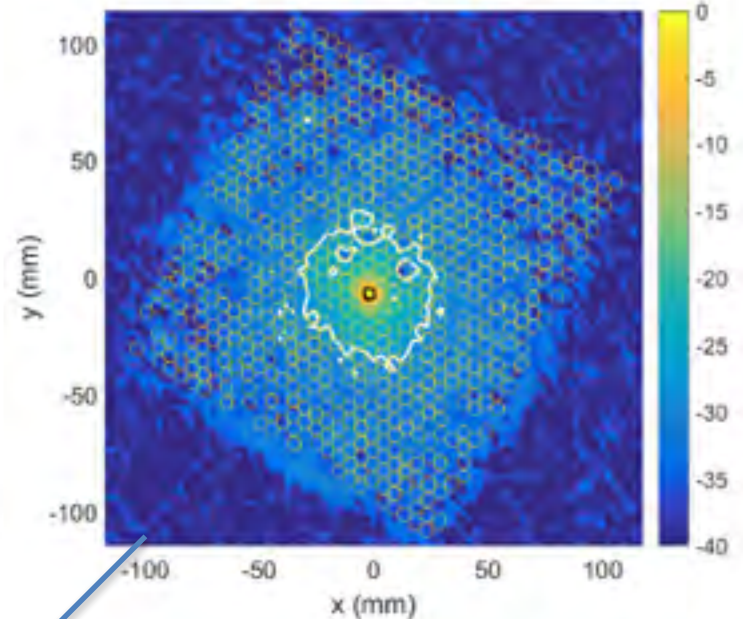


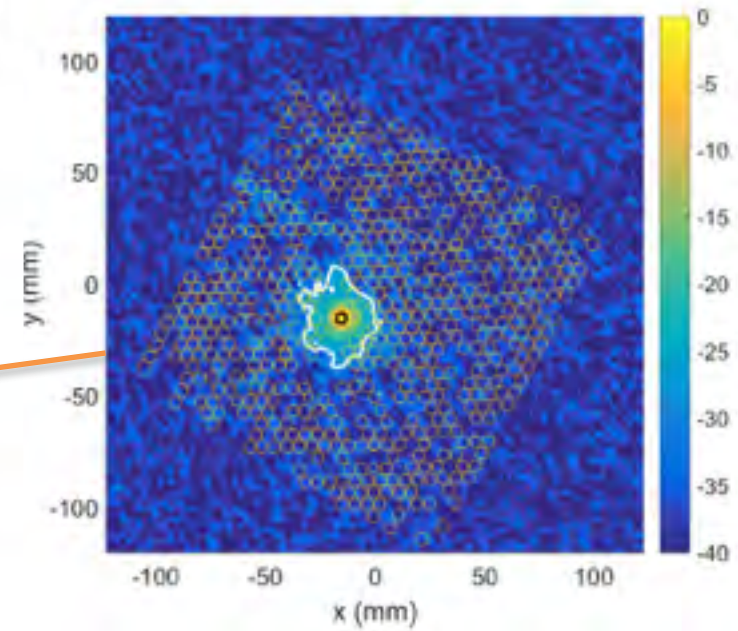
High fidelity imaging

Stray light mesh is critical



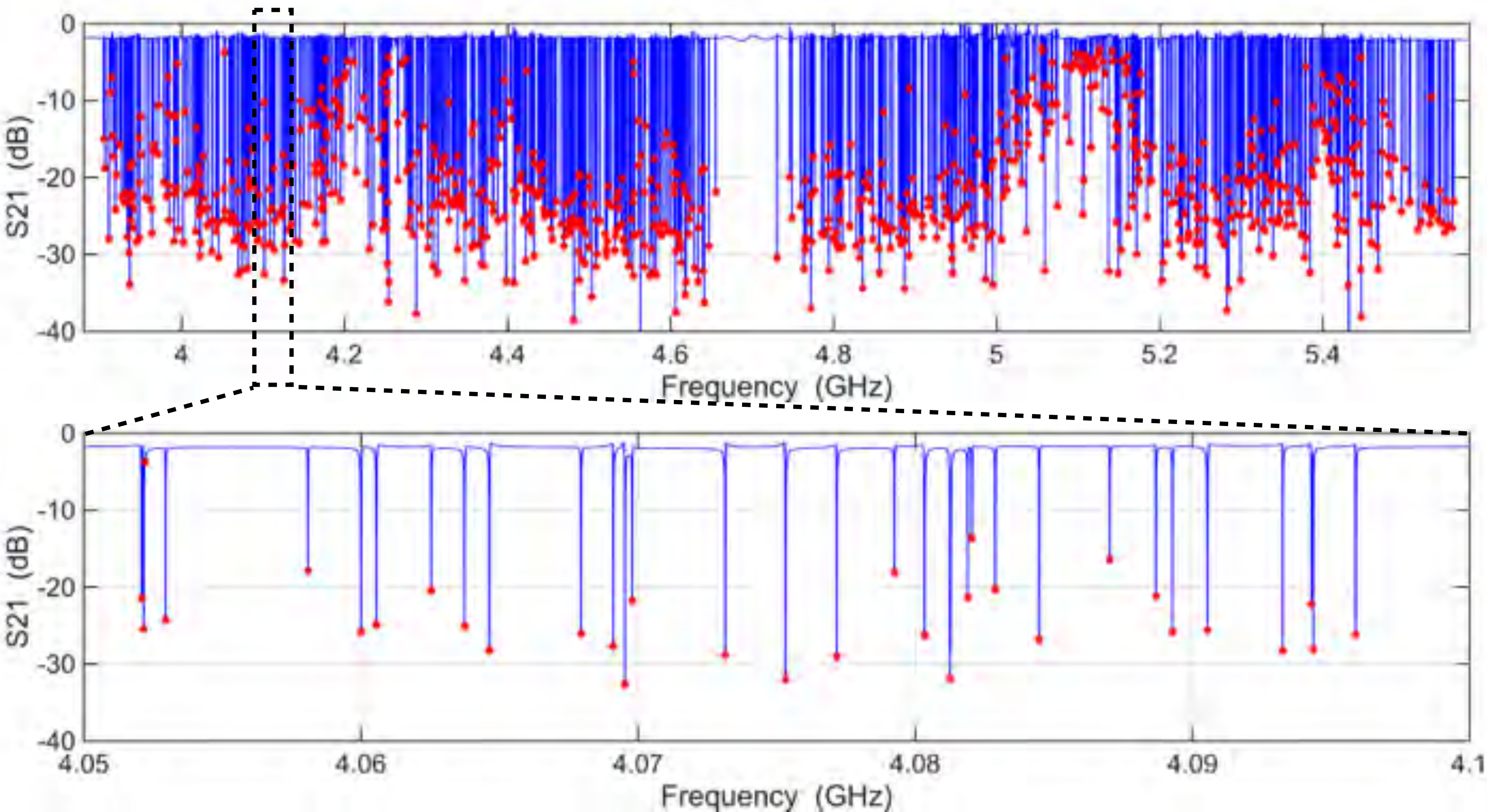






Array Analysis

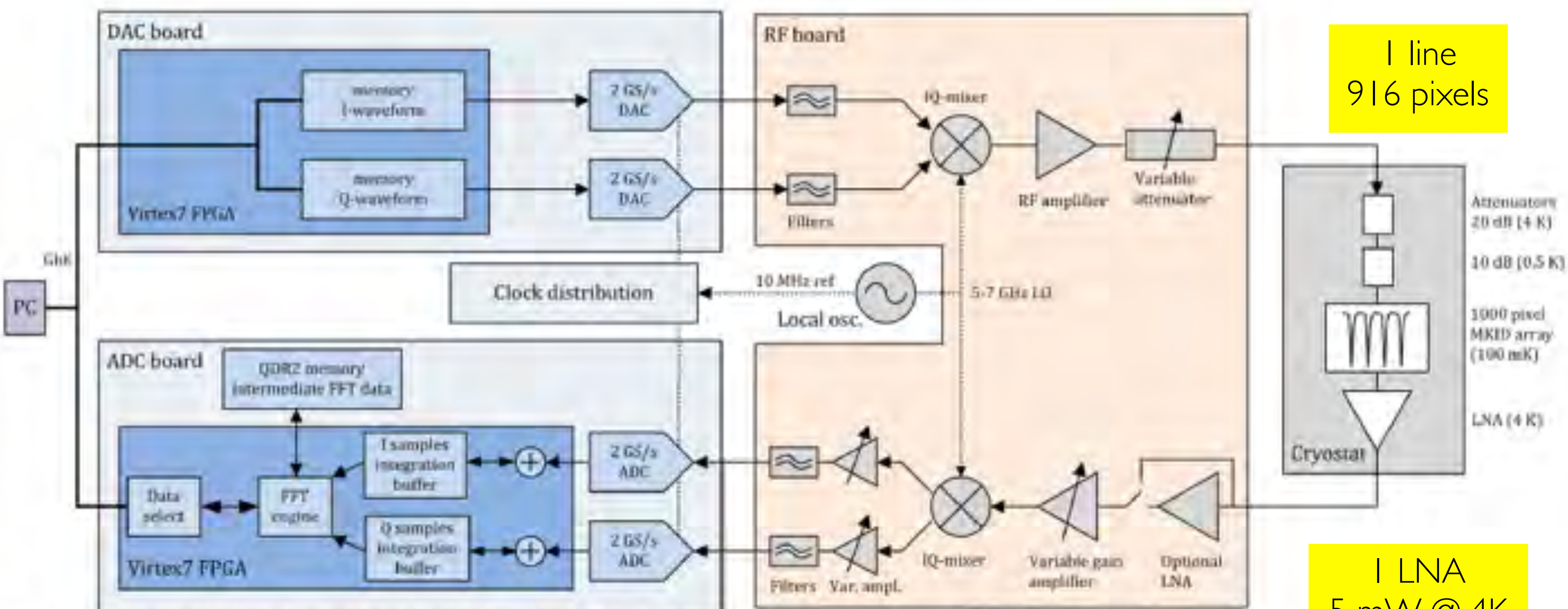
- Frequency range 3.67 – 5.3 GHz
- Resonances 926 (96%) out of 961
- used: 896 (93%)
- <Q> 103.000



SpaceKIDs Readout System: 2 GHz bandwidth, ≤4000 MKIDs

J. Van Rantwijk, et al. IEEE Trans. Microw. Theory Tech., 2016.

~20 mW/pixel @ 300K

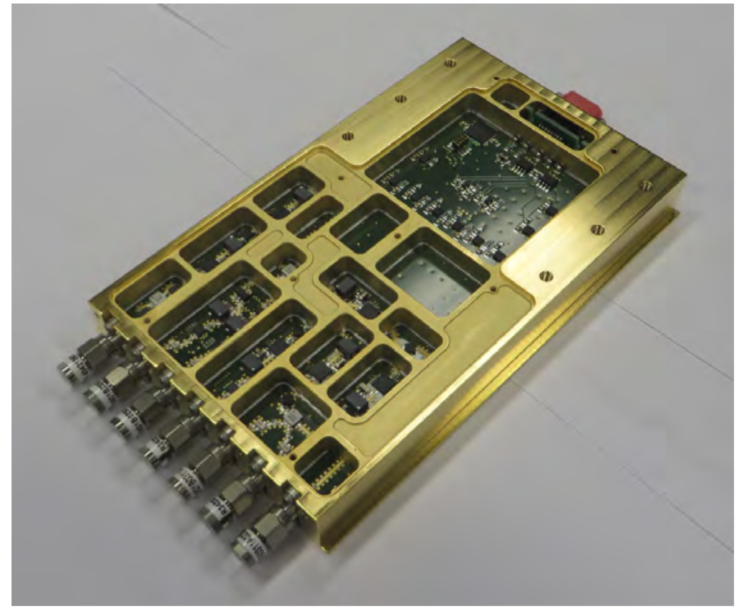


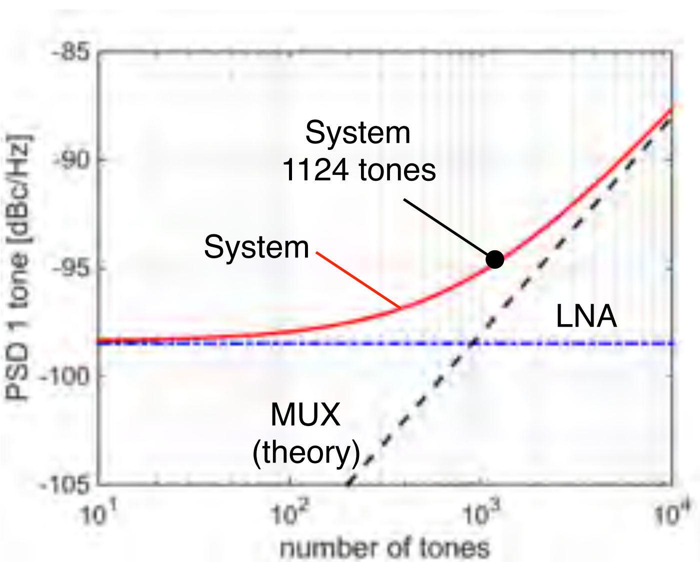
1 line
916 pixels

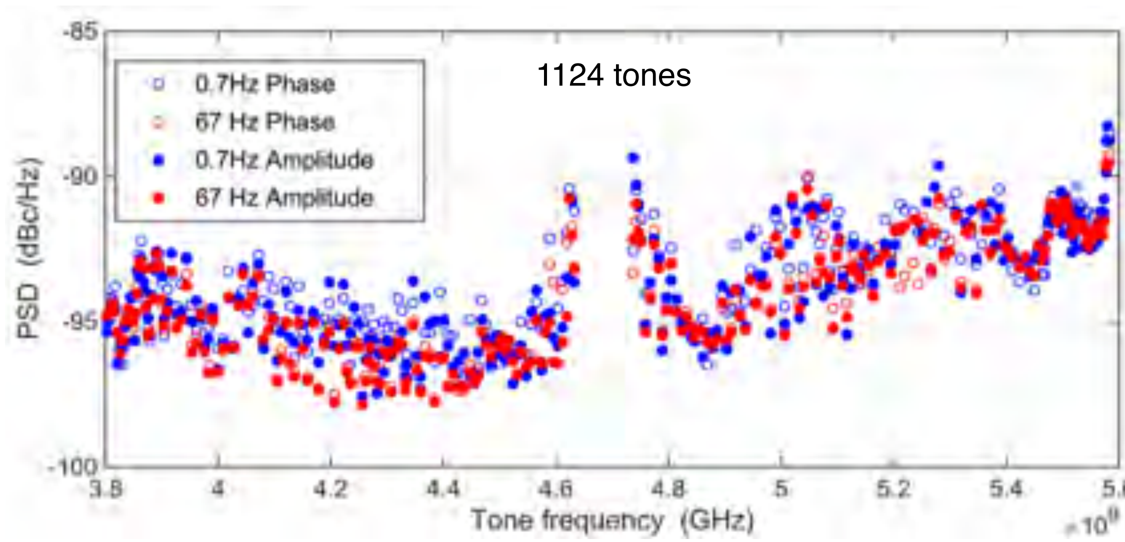
1 LNA
5 mW @ 4K

SpaceKIDs Readout System: 2 GHz bandwidth, ≤4000 MKIDs

J. Van Rantwijk, et al. IEEE Trans. Microw. Theory Tech., 2016.







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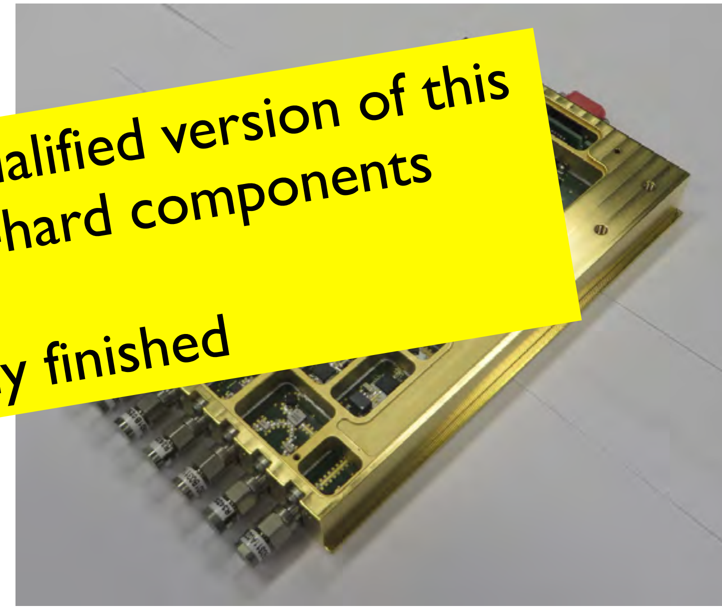
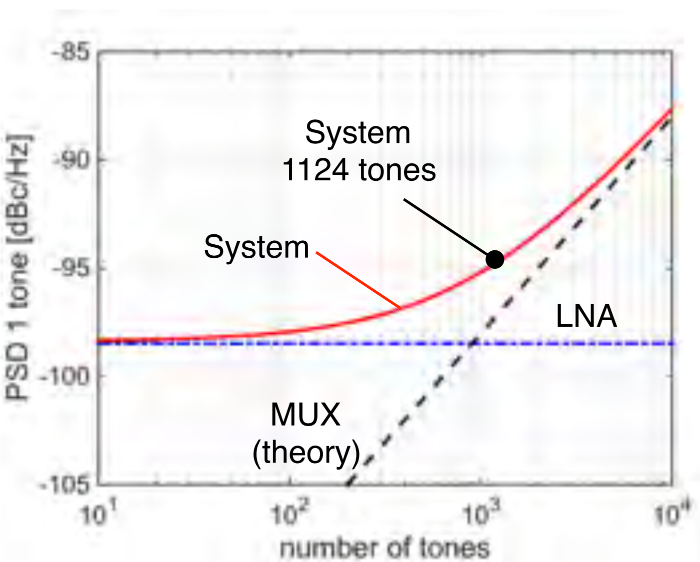
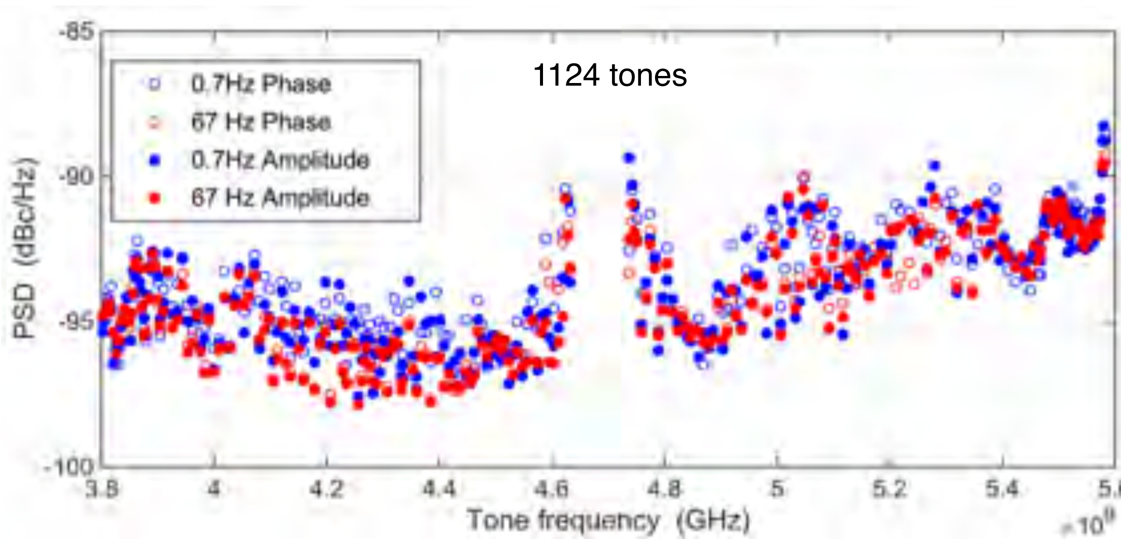


We are building the space qualified version of this hardware using only rad-hard components

Design is nearly finished





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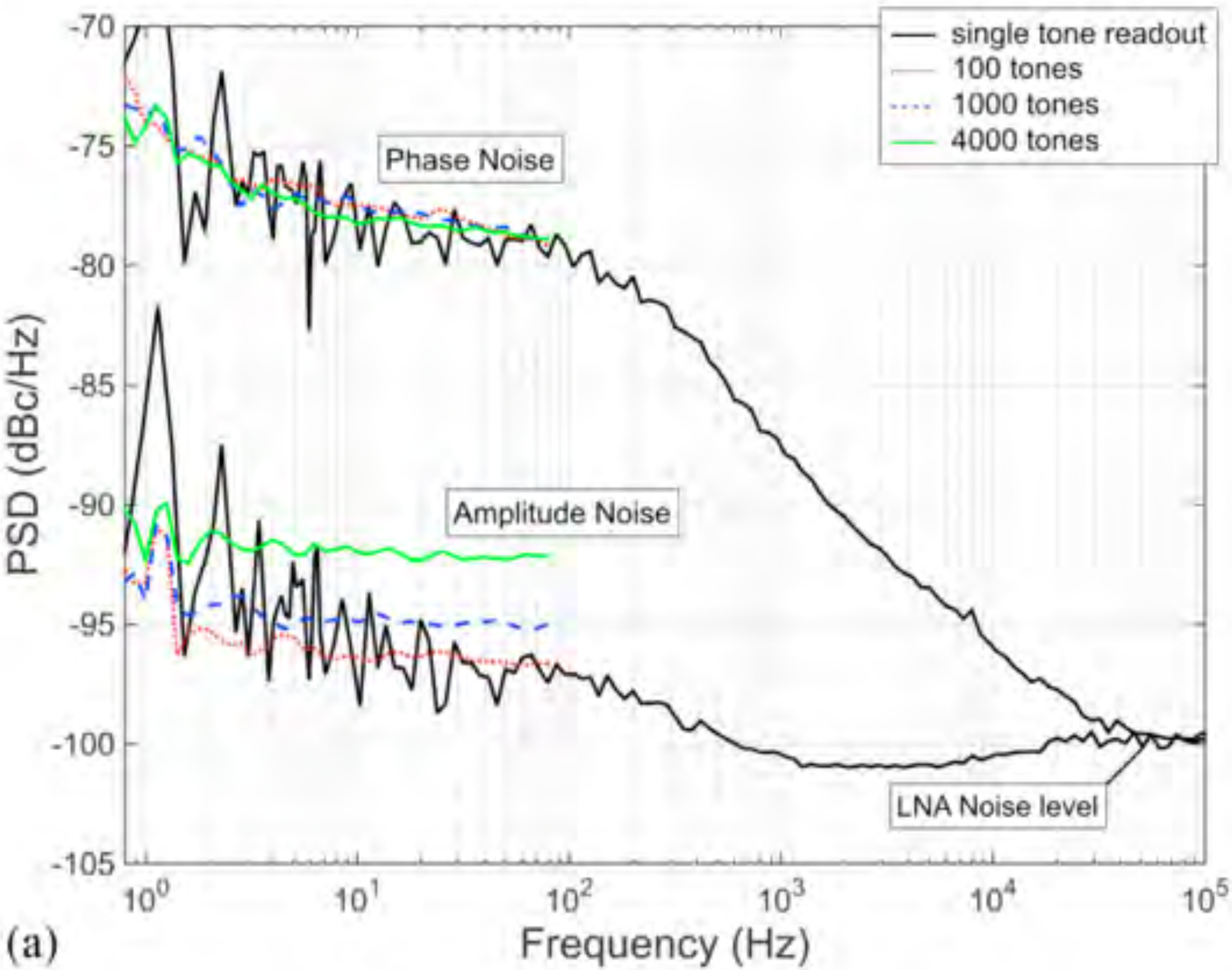
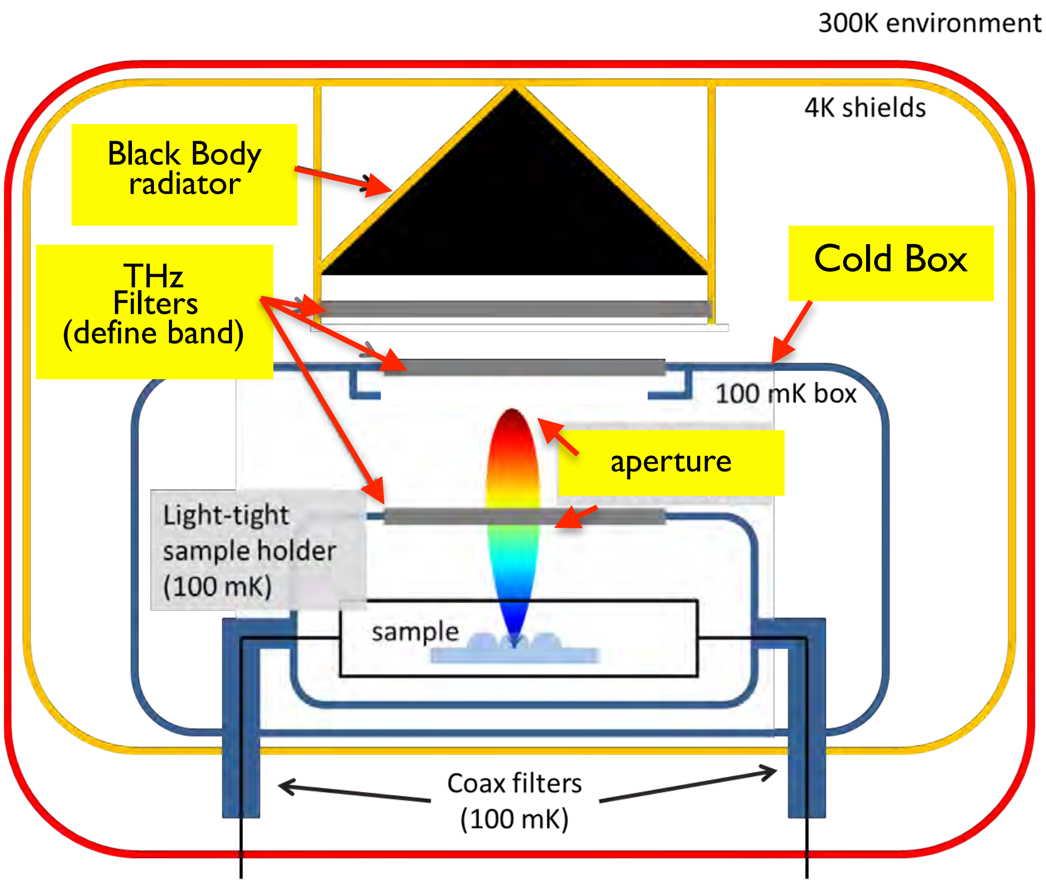


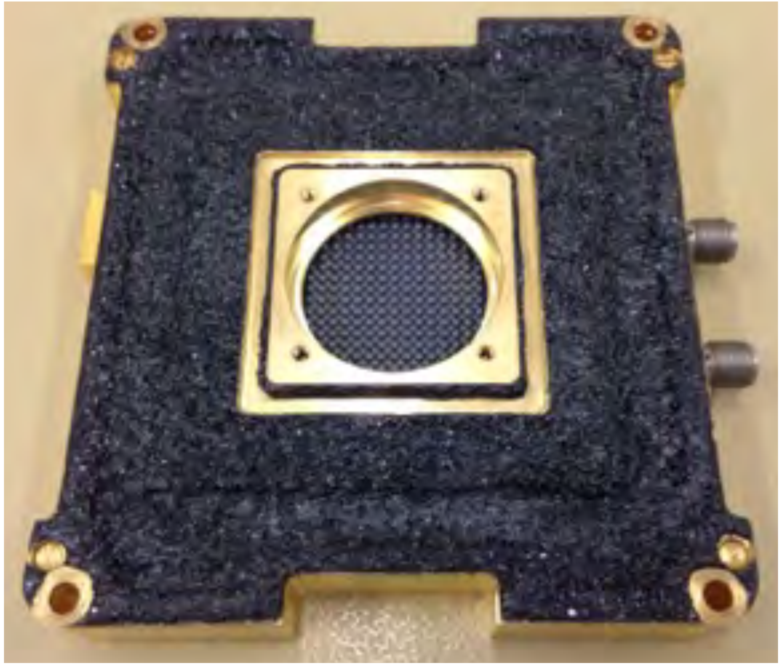
(a)

sensitivity measurements

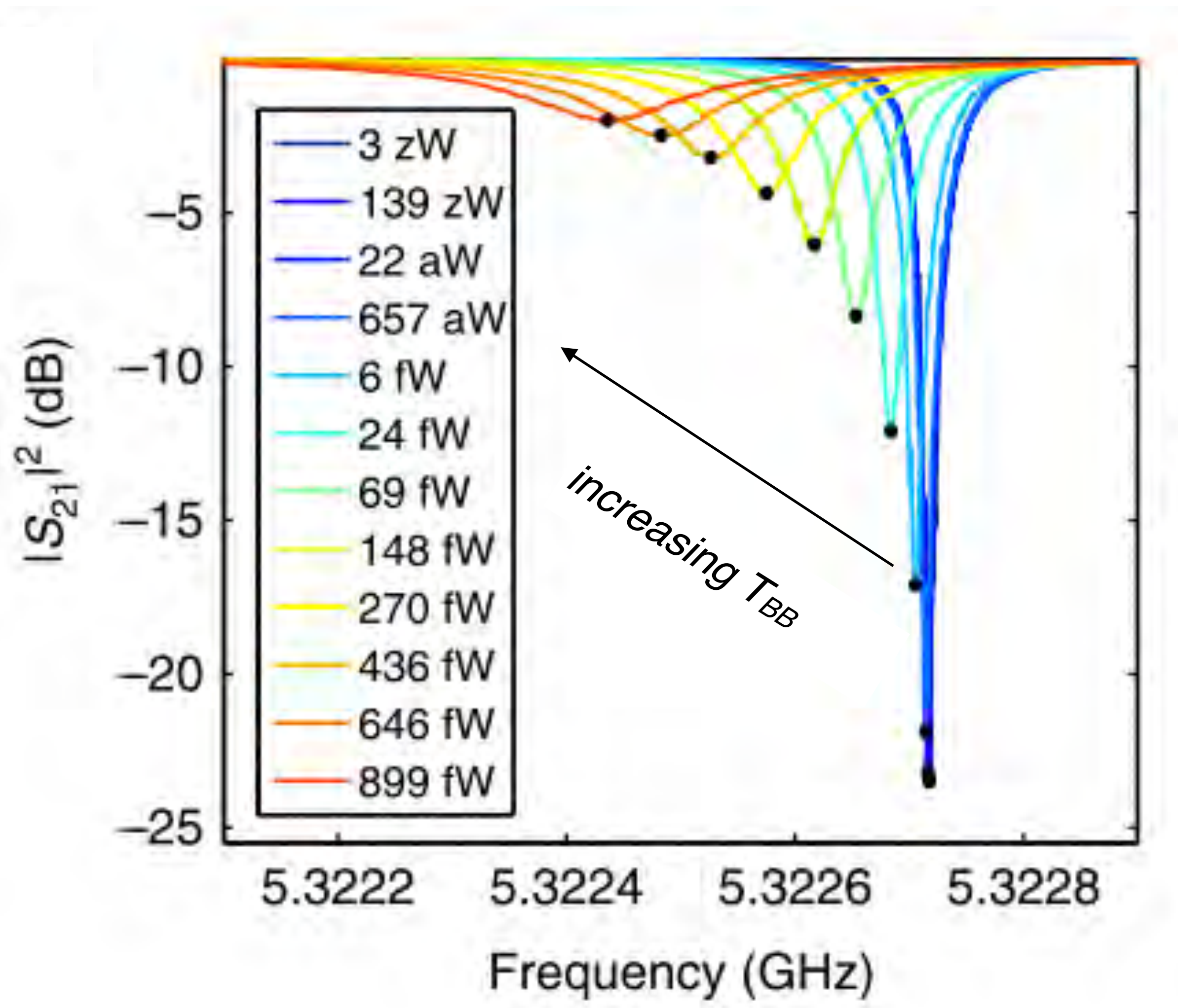
Array in cold box (100 mK)

aperture in BB radiator assembly to illuminate part of the array



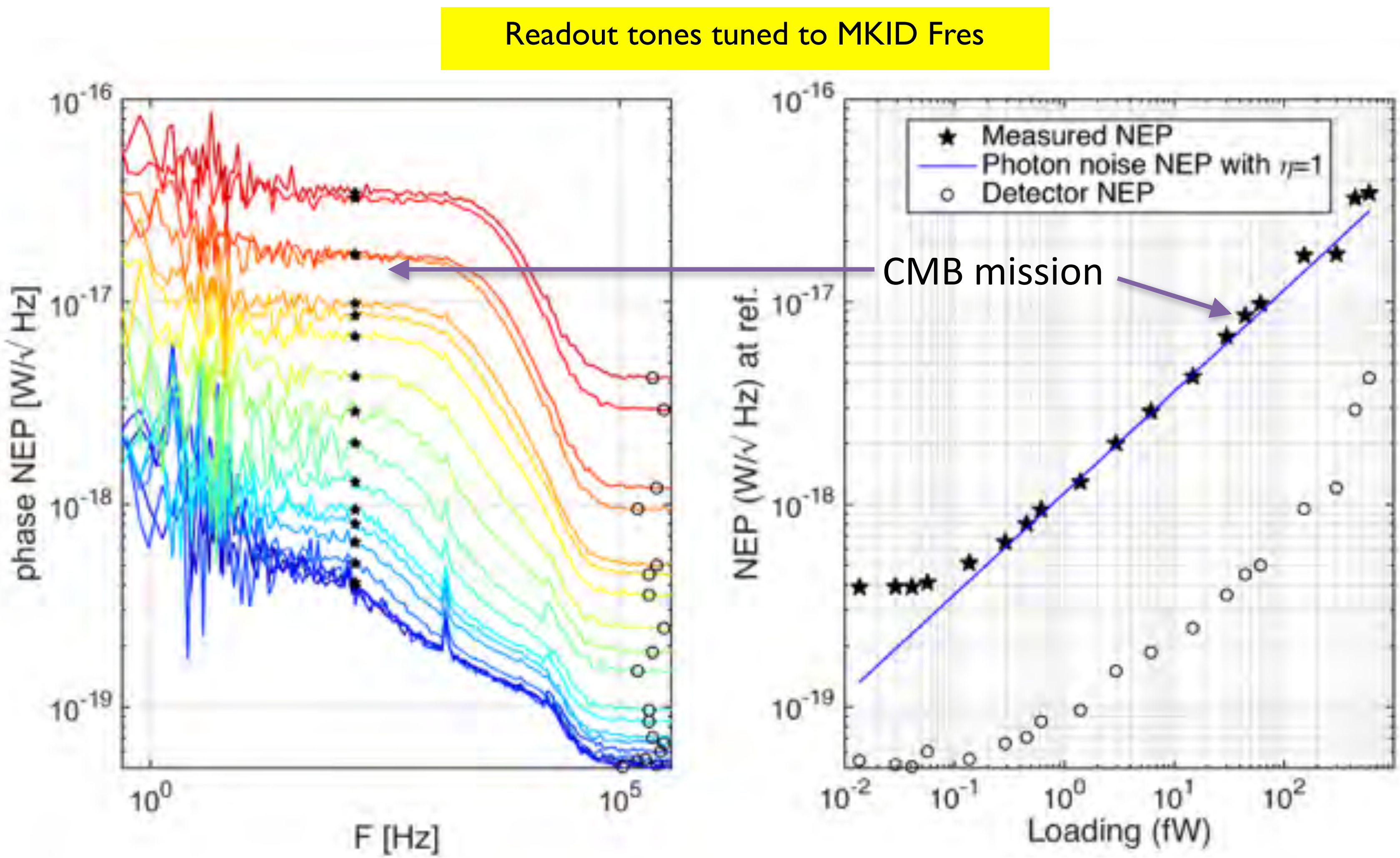


KID vs FIR illumination



Sensitivity vs. FIR illumination

Background limited performance @ relevant sky load



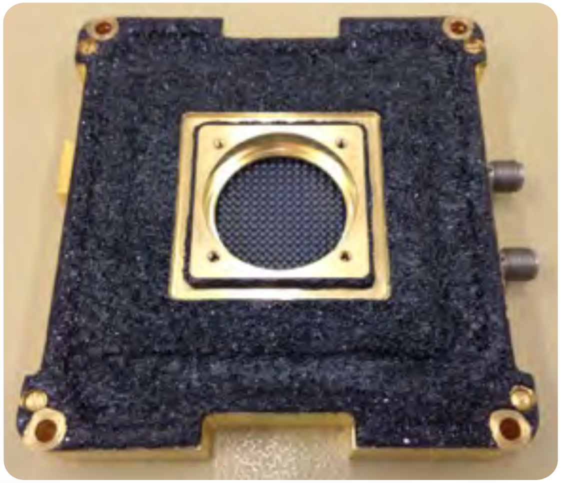
P. J. de Visser et al., *Nature Communications*, vol. 5, pp. 1–8, Feb. 2014.

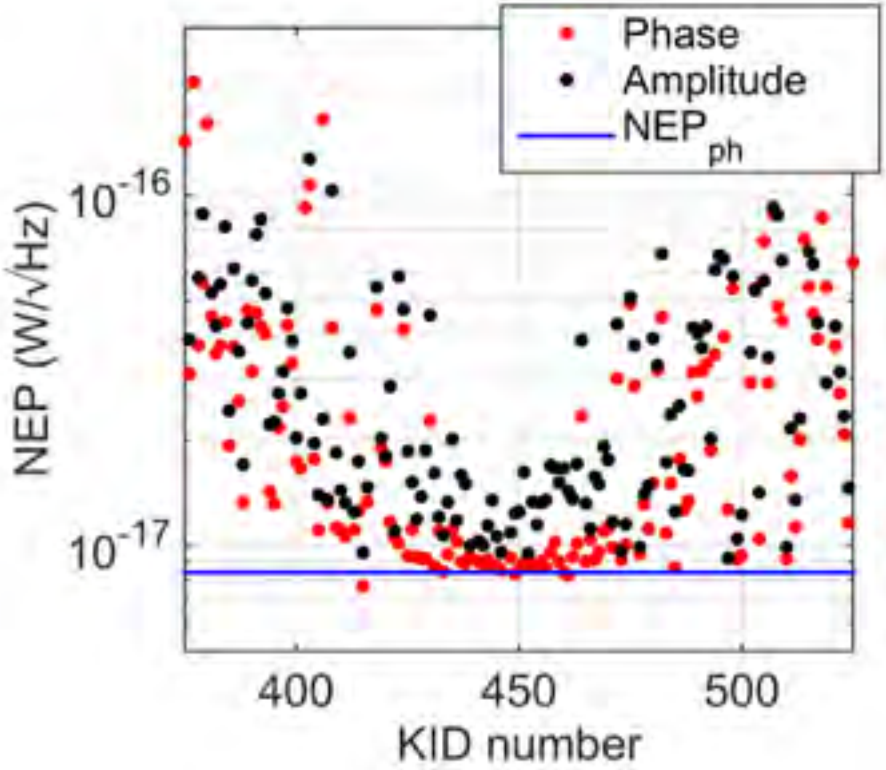
Optical efficiency - central pixels

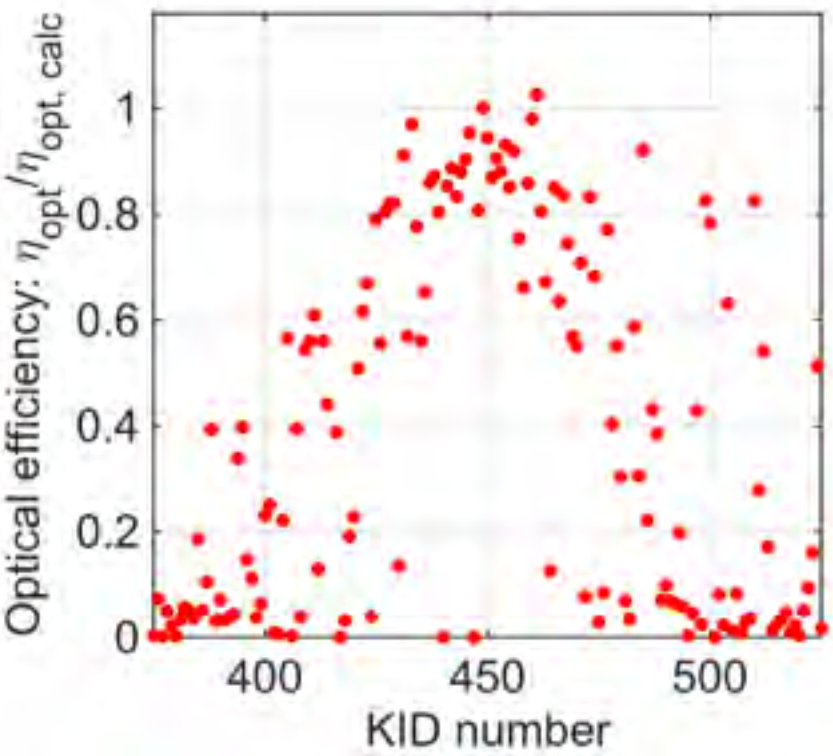
@ 50 fW we evaluate the optical efficiency

0.9 ± 0.1 compared to the calculated value

- Due to assembly method (solved)
- 68% of theoretical limit
  - Sapphire substrate







Cosmic Rays (K. Karatsu)

55x55x0.35 mm chip of Si

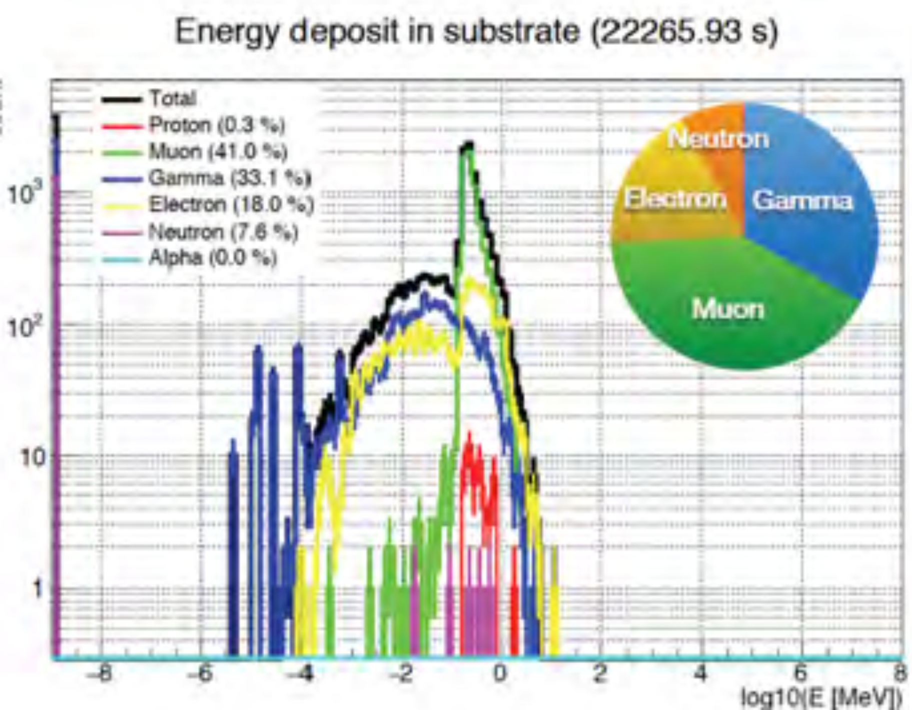
Ground: CRY (http://nuclear.llnl.gov/simulation/)

L2: http://www.sciencedirect.com/science/article/pii/S0168900212005554

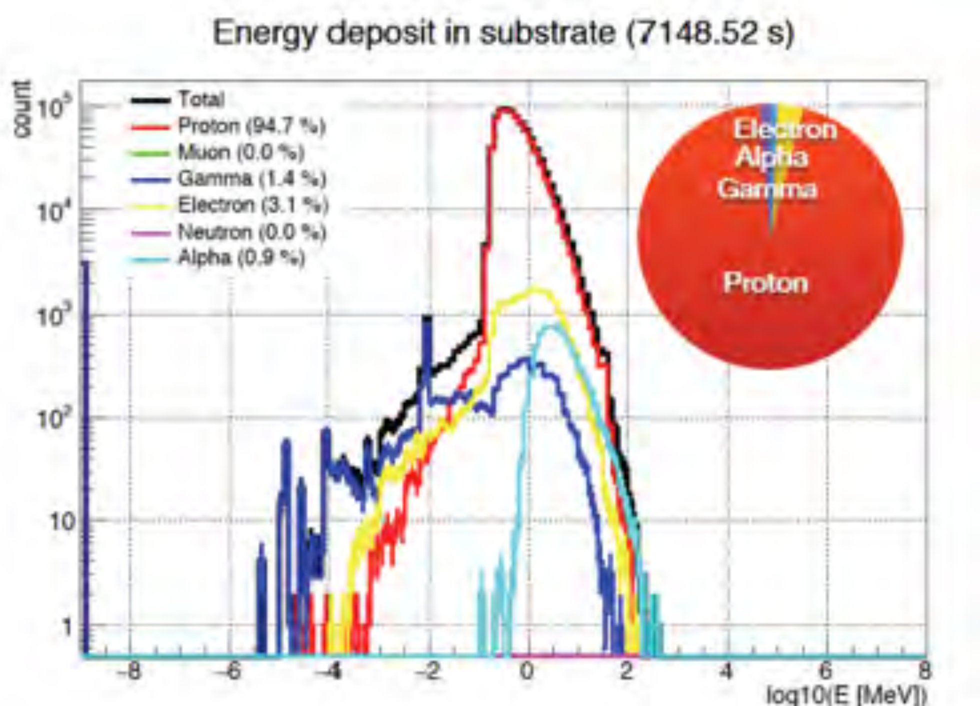
Energy deposition simulation (incl. cryostats/shields etc): GEANT4

- https://geant4.web.cern.ch/geant4/

Ground
247 counts/m^2/sec



L2
$3.8 \cdot 10^4$ counts/m^2/sec



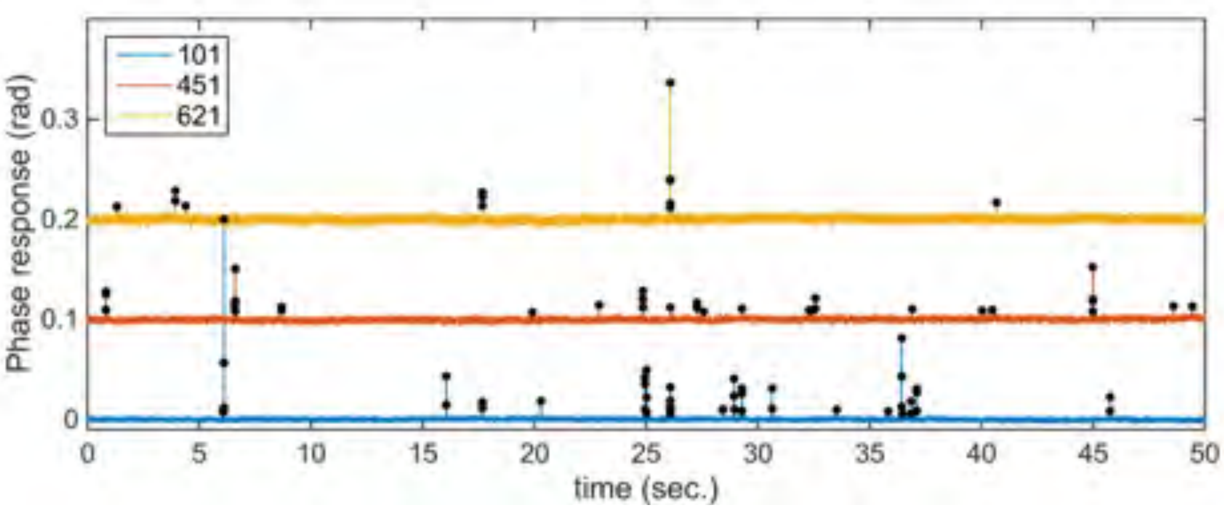
Cosmic Rays - lab tests

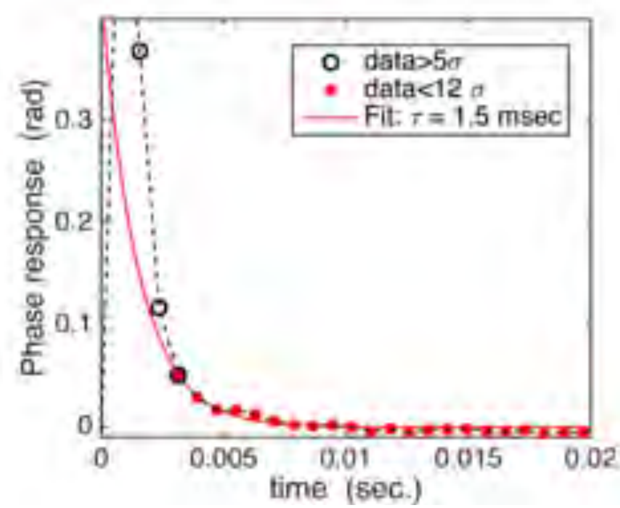
At negligible absorbed power

- Single glitches with time constant ~ 1 msec
- fractional dead time (>5σ): $3.2 \cdot 10^{-4}$
  - negligible effects on integration: Catalano, A.,et al. 2016b, A&A, 592, A26
- L2 estimation (ignoring energy effects): 4%

At 100 fW loading

- fractional dead time (>5σ): $9 \cdot 10^{-5}$
- L2 estimation (ignoring energy effects): 1%

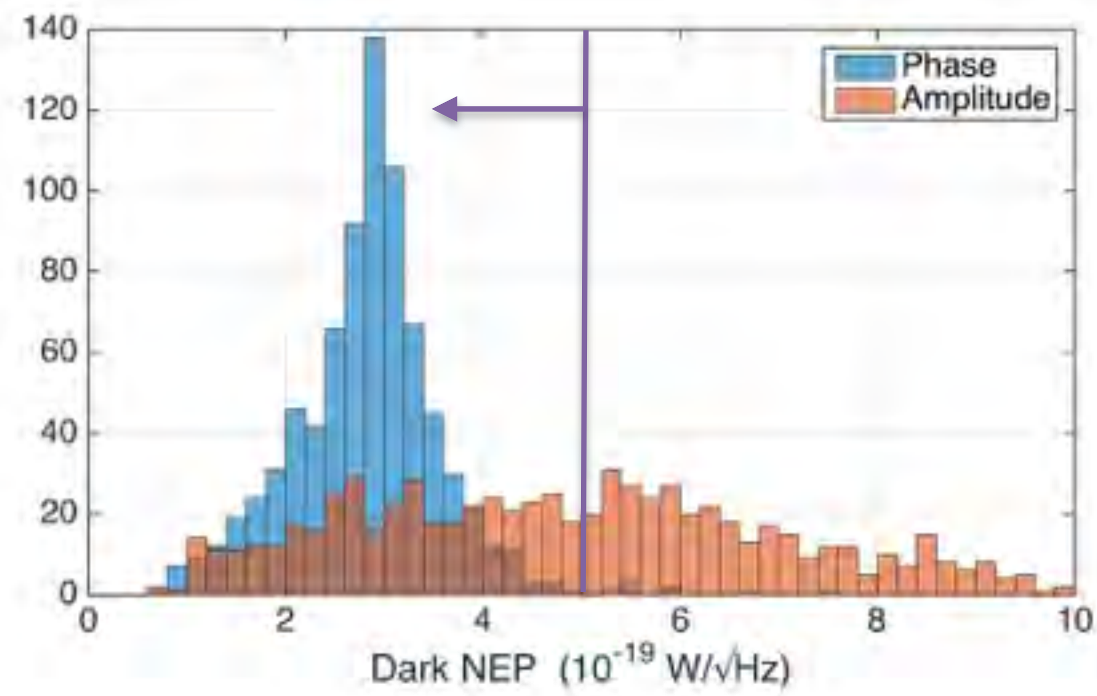


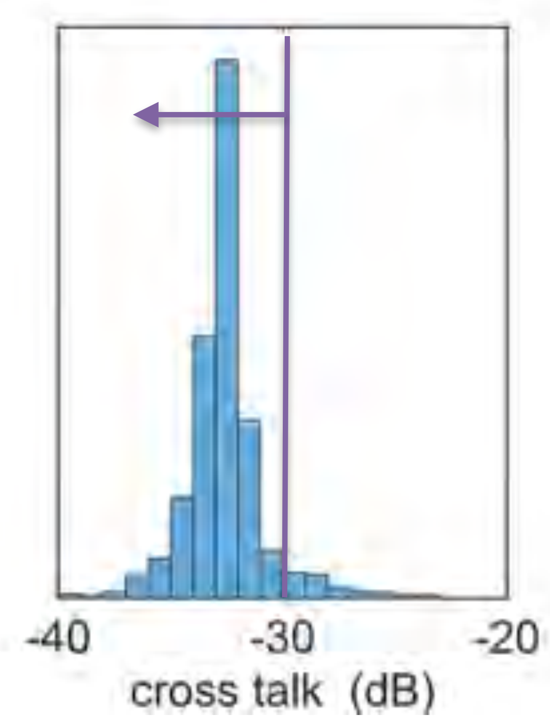


System yield

NEP < 5 $\cdot 10^{-19}$ W/√Hz
cross talk < -30 dB
Cosmic ray dataloss <10%

$\Rightarrow$ 83%





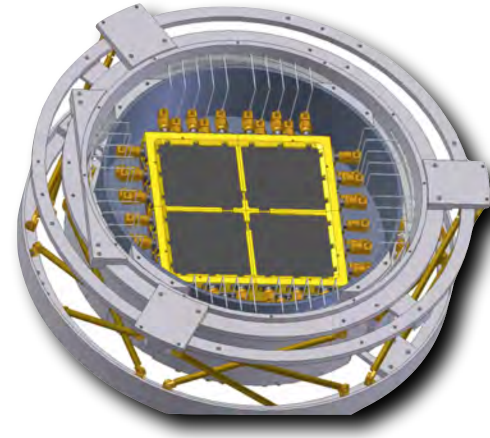
Max-Planck-Institut für Radioastronomie

SRON

TUDelft

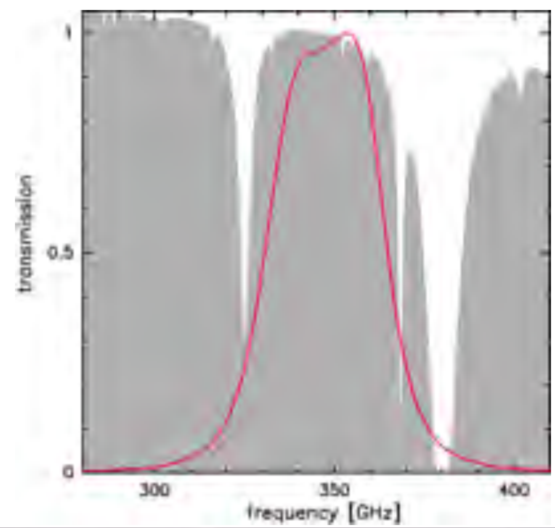
A-MKID arrays

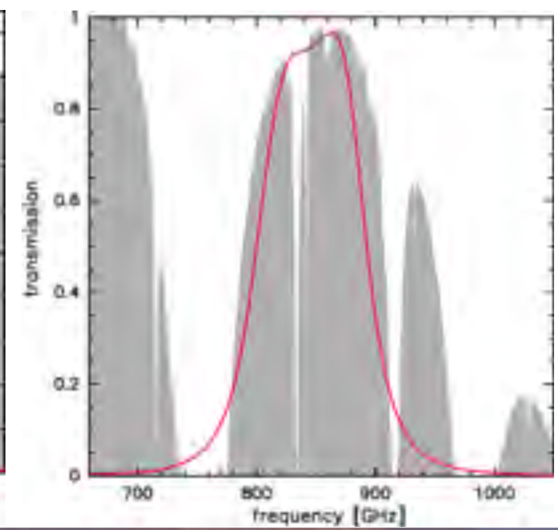
**World's largest submm camera,
with ultimate sensitivity from ground**



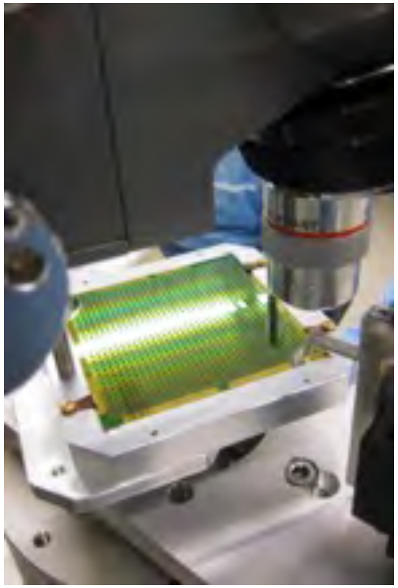
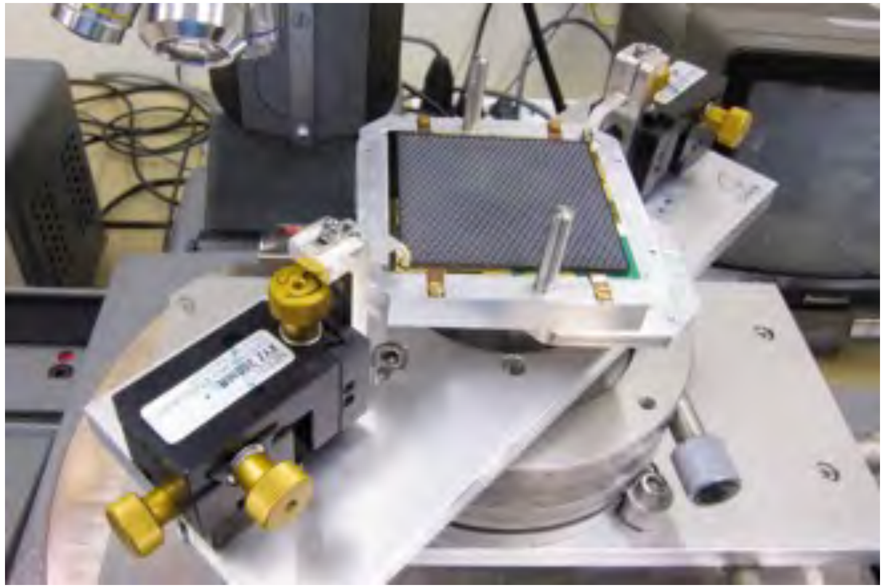
2 FPA's
25120 MKIDs
15 arcmin x 15 arcmin field-of-view

350 GHz	850 GHz
4 x 880 pixels	4 x 5x 1080 pixels
3520 pixels	21600 pixels

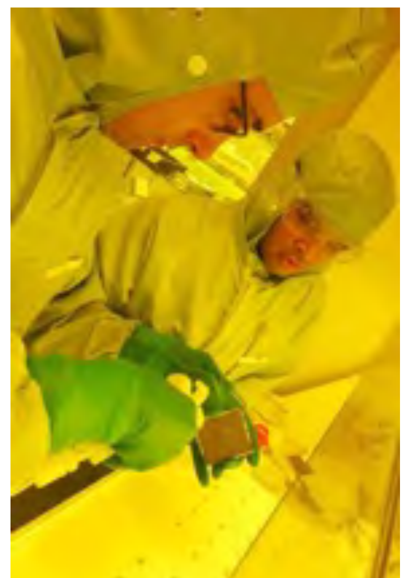




How it looks during assembly (April – May 2016)

Detector chip under alignment microscope (left) and aligned lens array before gluing (right)


Gluing of lens array (left), cleaning protective backside layer (middle) and wire bonding (right)

A-MKID arrays large area reliability

All Si system

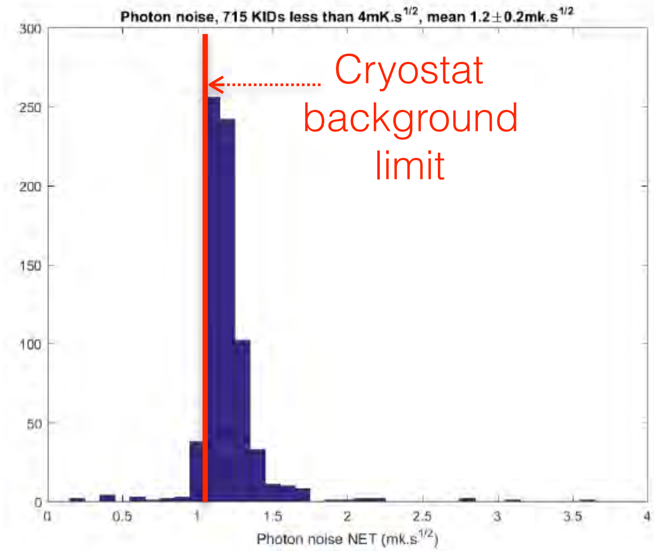
350 GHz band arrays delivered

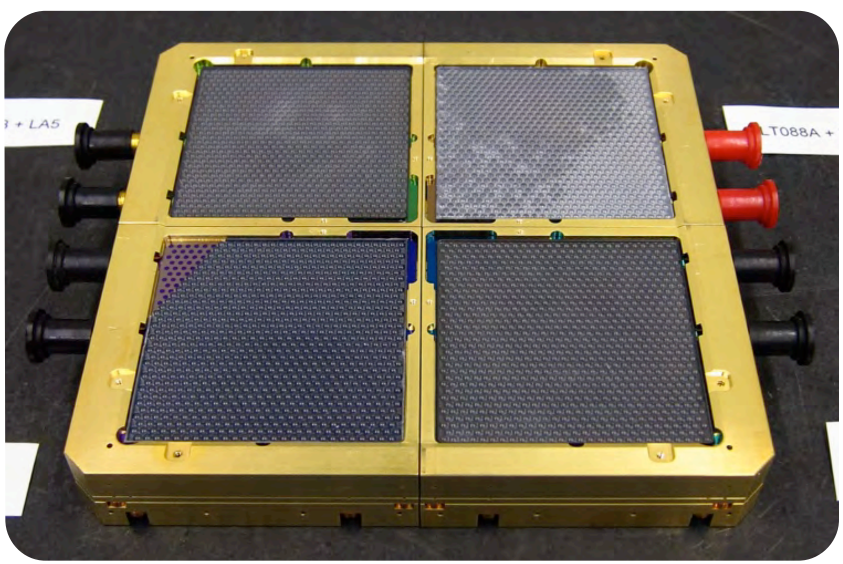
~85% yield

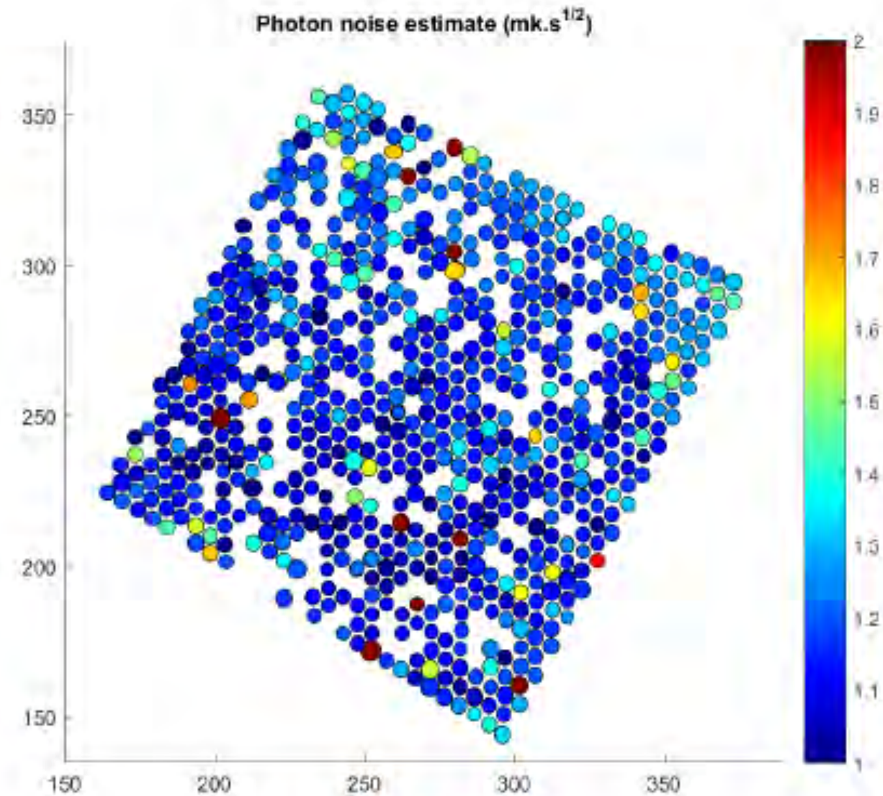
Background limited sensitivity

95% of theoretical efficiency

3520 pixels

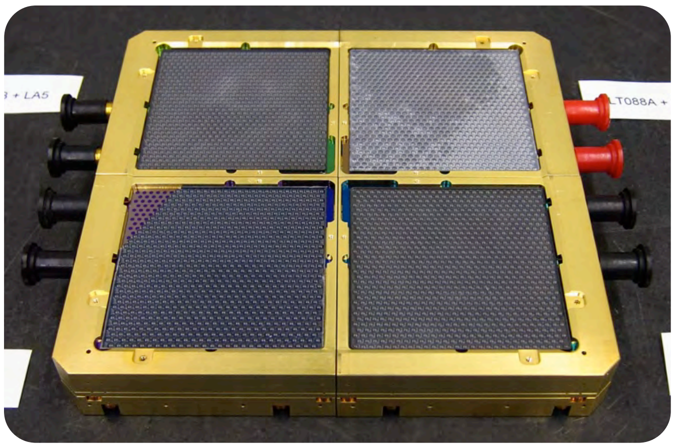


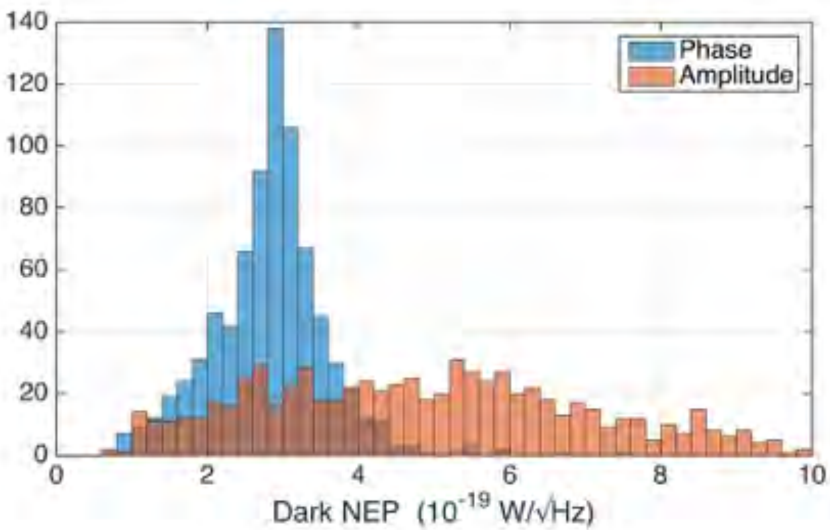




SRON - TU Delft
THz sensing

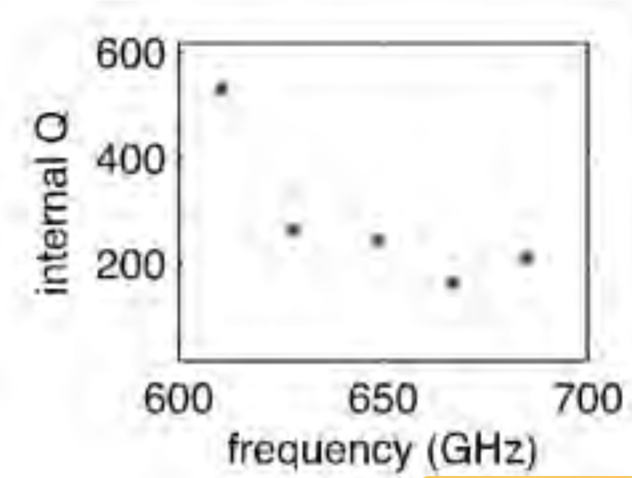
Large, ultra sensitive imaging arrays

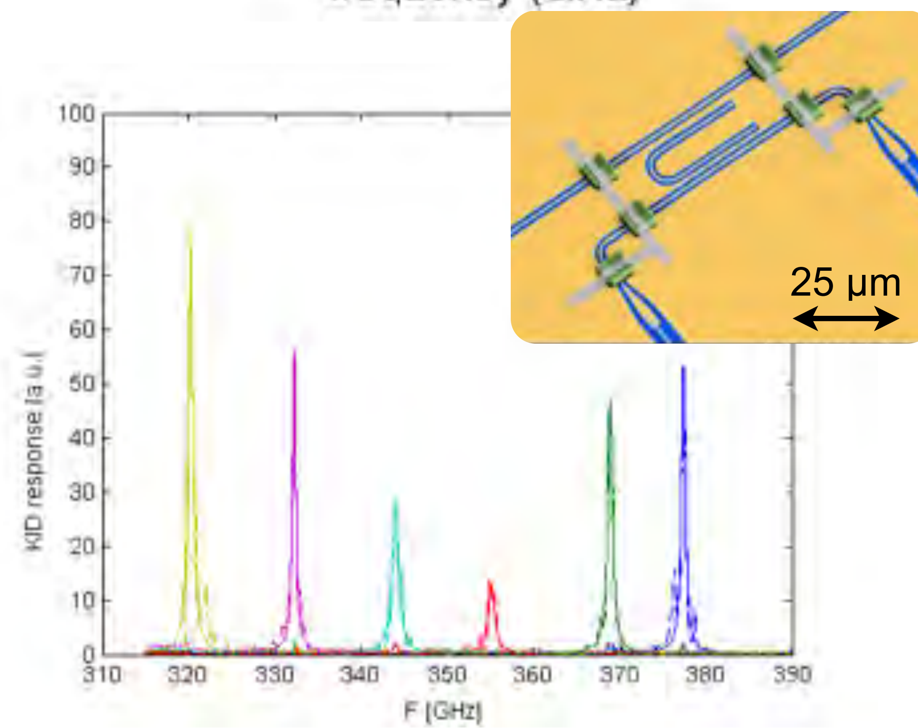




http://arxiv.org/abs/1609.01952

High Q superconducting striplings

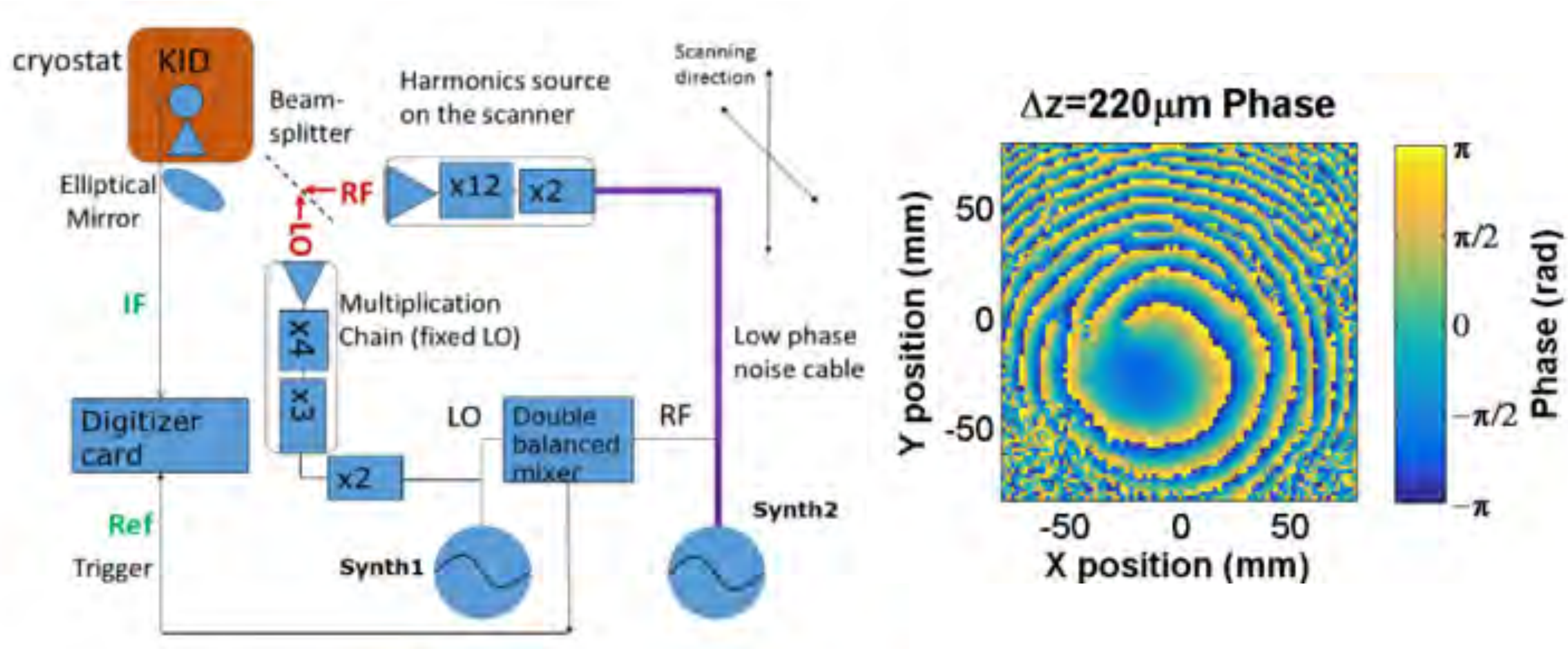




A. Endo et al., 2013. Appl. Phys. Lett. 103 032601

SRON - TU Delft THz sensing

Measurement of amplitude and phase of direct detector beams



K. Davis et al., accepted for IEEE trans of THz theory and Techn.

Concluding Remarks

We have demonstrated

- kpixel arrays of MKIDs + readout system
- background limited performance + high efficiency
- the antenna design determines the radiation coupling
  - very well under control
  - flexible system in terms of radiation coupling and bandwidth
- antenna coupling + (existing) stripline technology allows for multi colour/dual polarisation pixels using planar OMT

http://arxiv.org/abs/1609.01952

Thank you