Kinetic Inductance Detector based space instruments for the CMB

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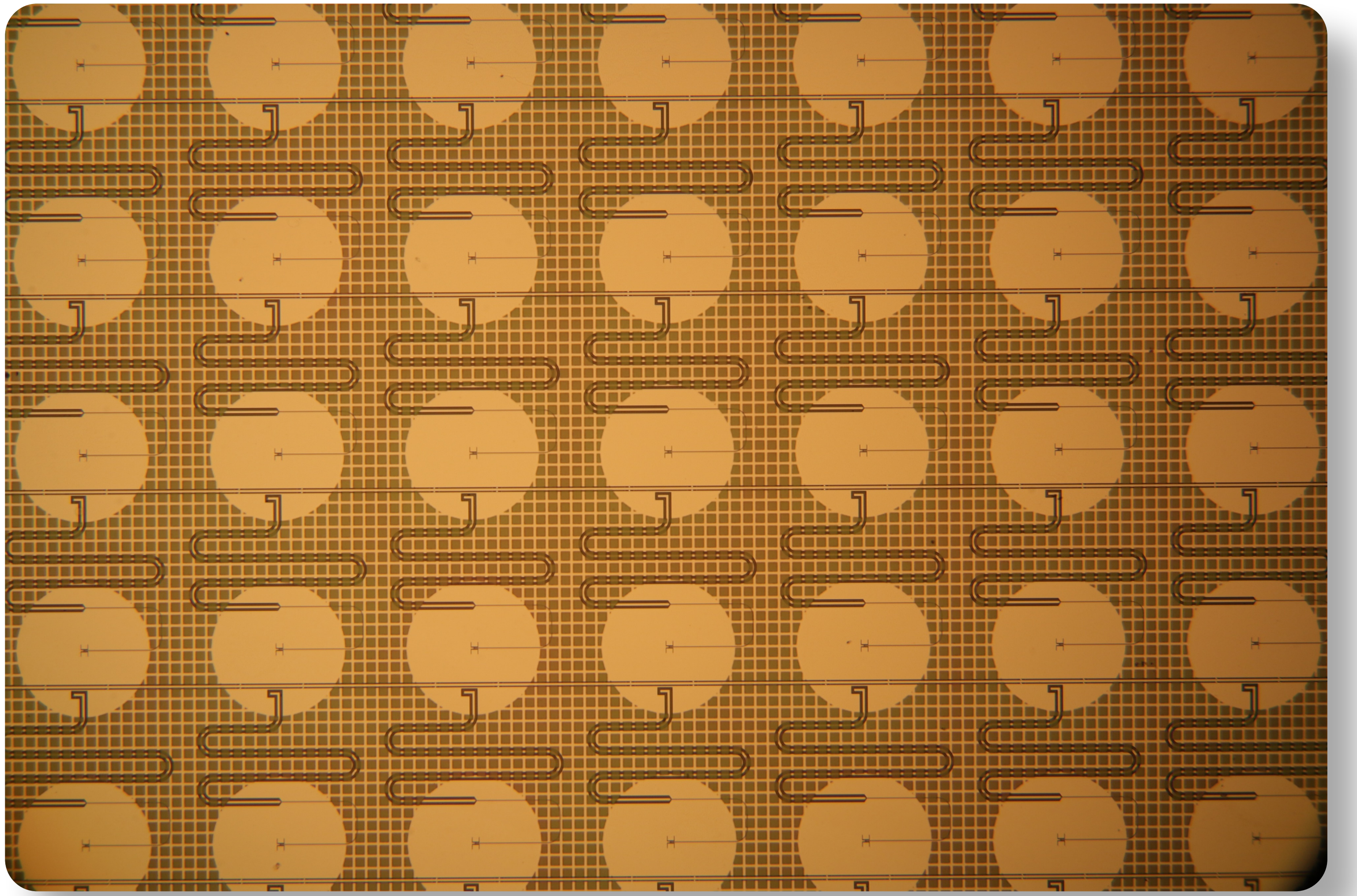


SRON Netherlands Institute for Space Research
spaceKIDS Kinetic Inductance Detectors for Space
TS THz Sensing Group
TU Delft

Why MKIDs

Advanced ACTPol (MF)
TES Array ~ 2000 detectors

- 1000's of wire bonds
- hundreds of components
- dozens of cables
- separate mux chips

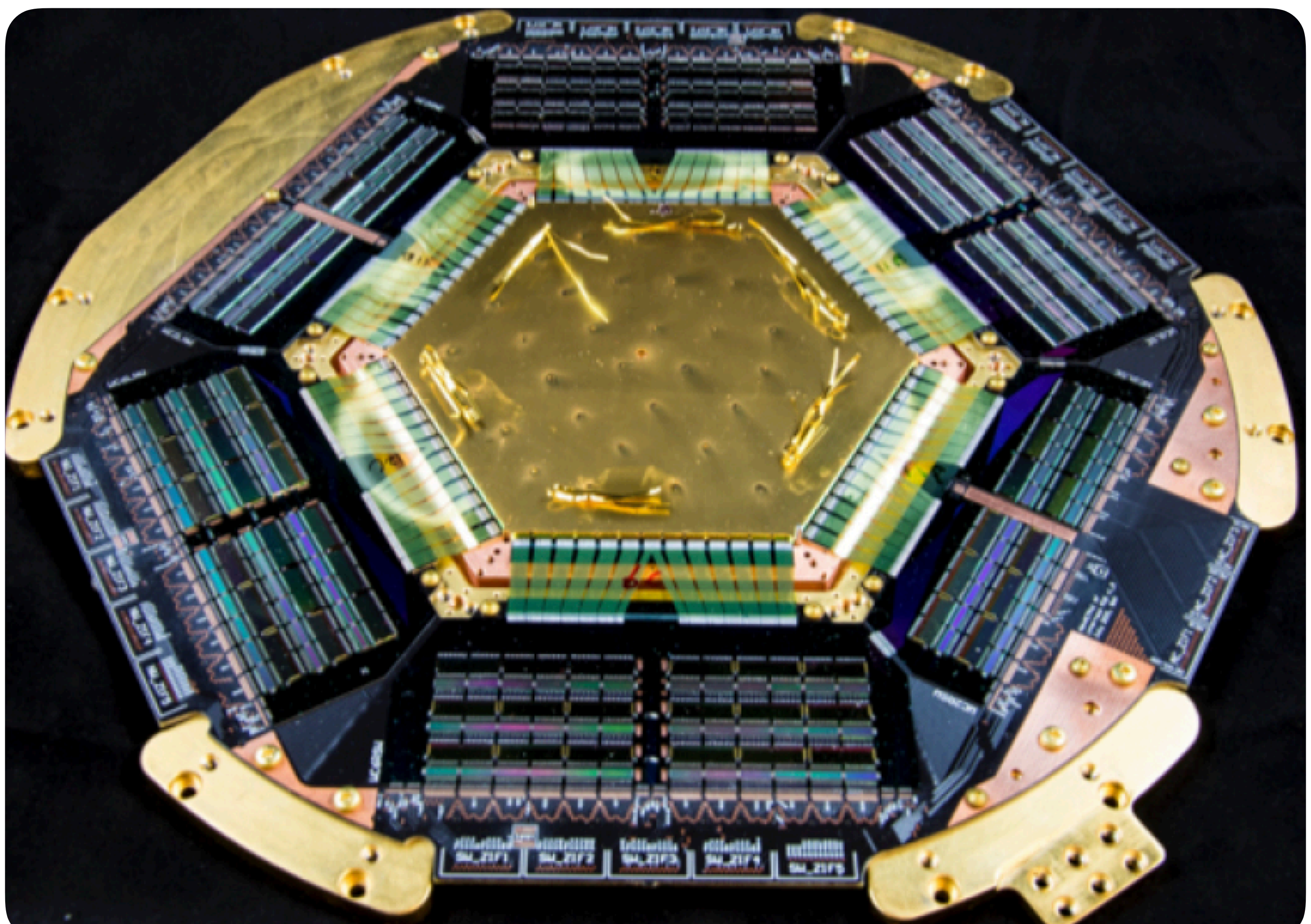
Toltec
MKID Array ~ 4000 detectors

- 14 wire bonds
- 7 coax cable pairs
- 7 LNA's
- no extra chips

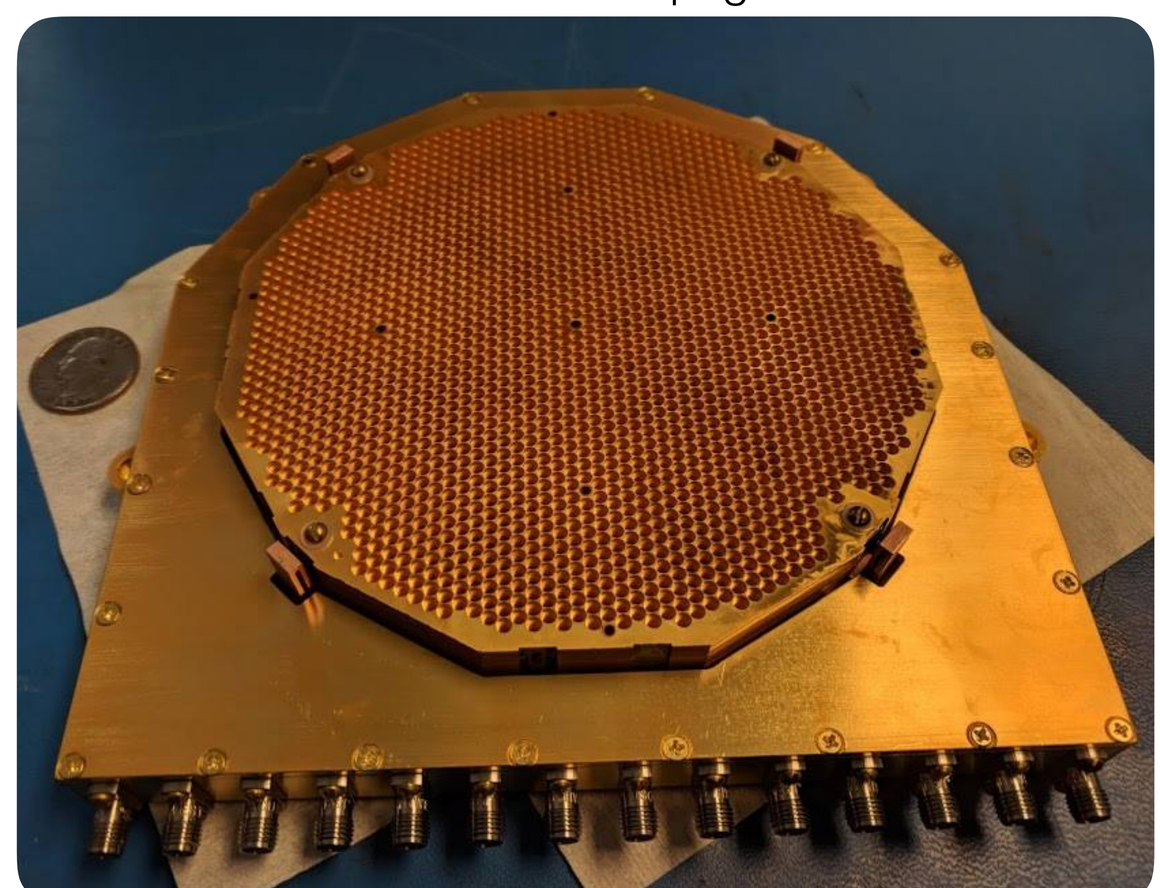
=> could be done with

- 1 LNA, 1 cable pair

Ward et al. Proceedings of the SPIE, Volume 9914, id. 991437 (2016).
DOI: 10.1117/12.2233746



Toltec facebook page



Slide idea from Austerman, Beal, Bryan et al., SPIE 2016

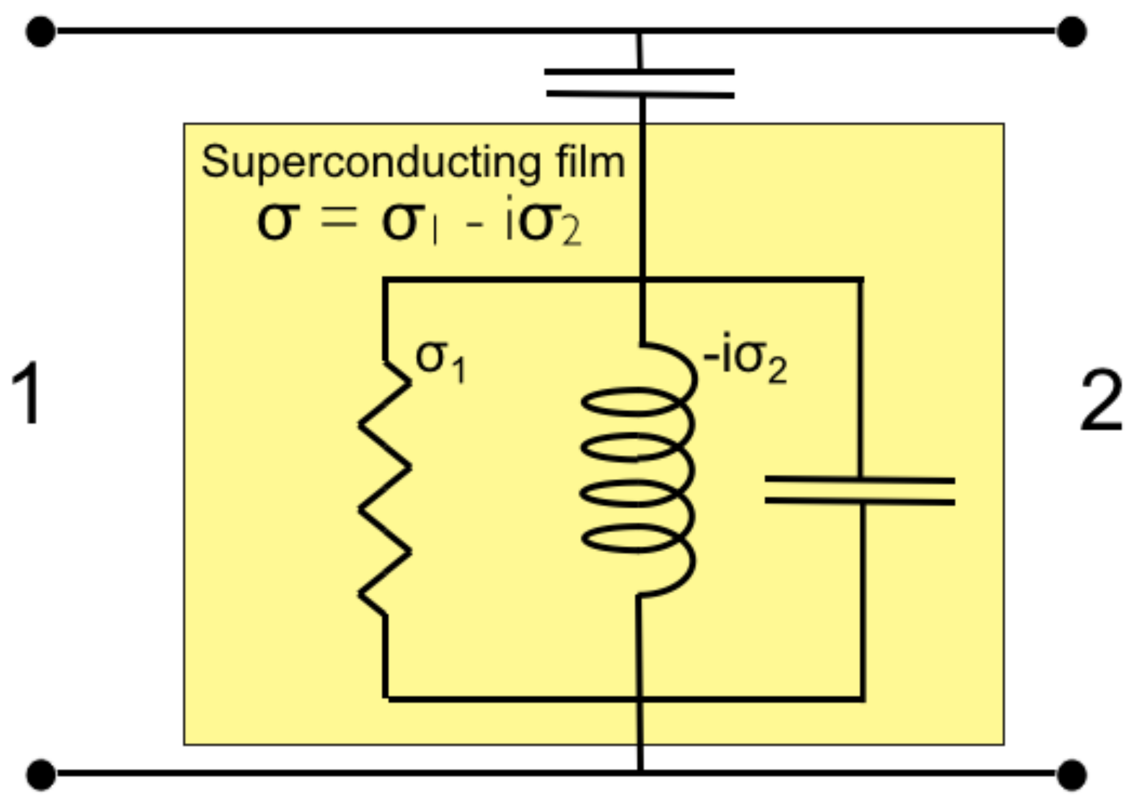
MKID principle of operation

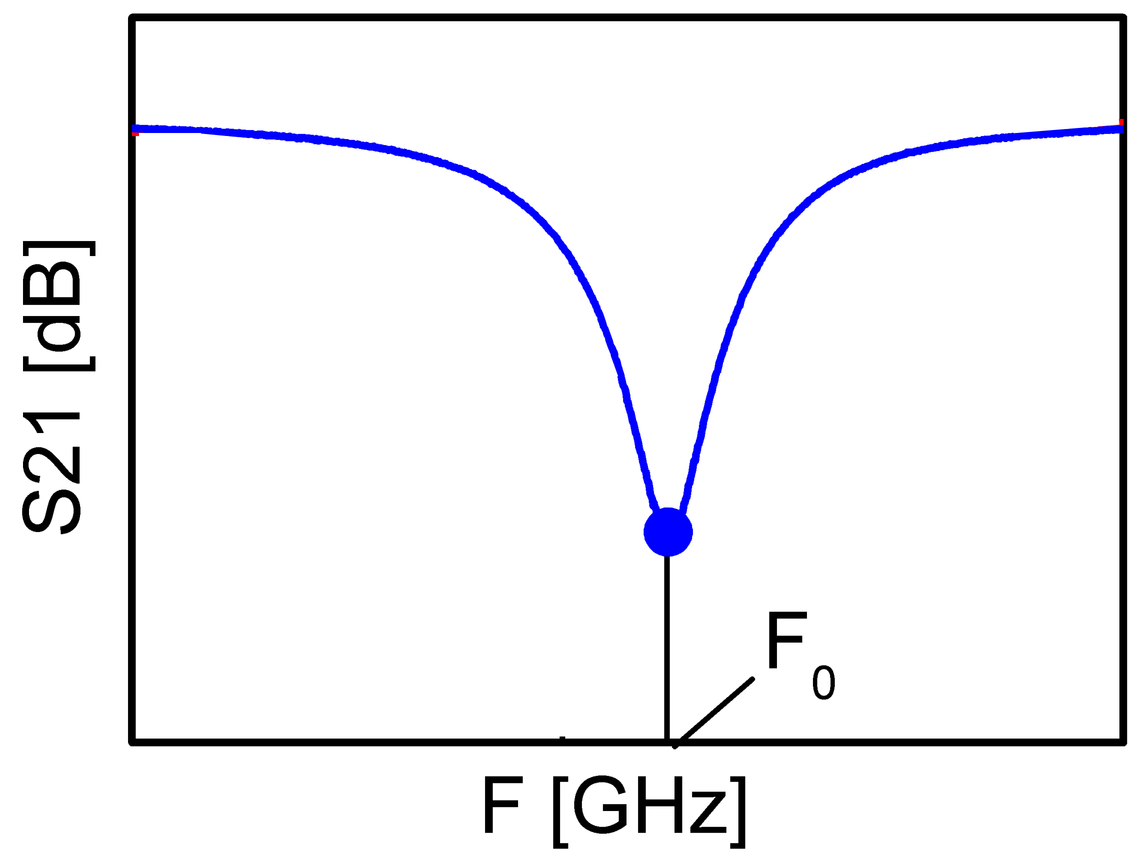
Superconducting film

Inside a microwave resonance circuit

Capable of coupling to radiation

- $Q \sim 10^4 - 10^6$
- $F \sim 1\text{-}10$ GHz



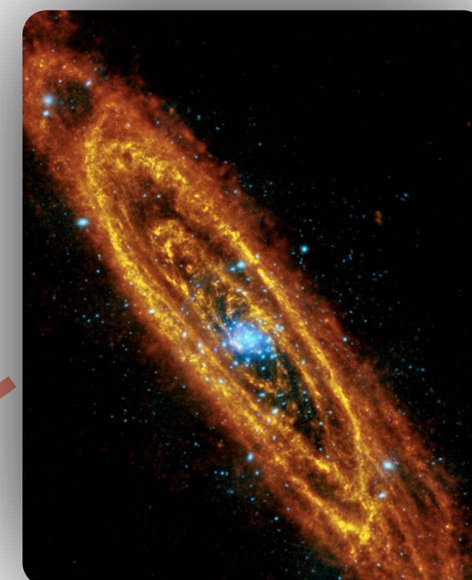


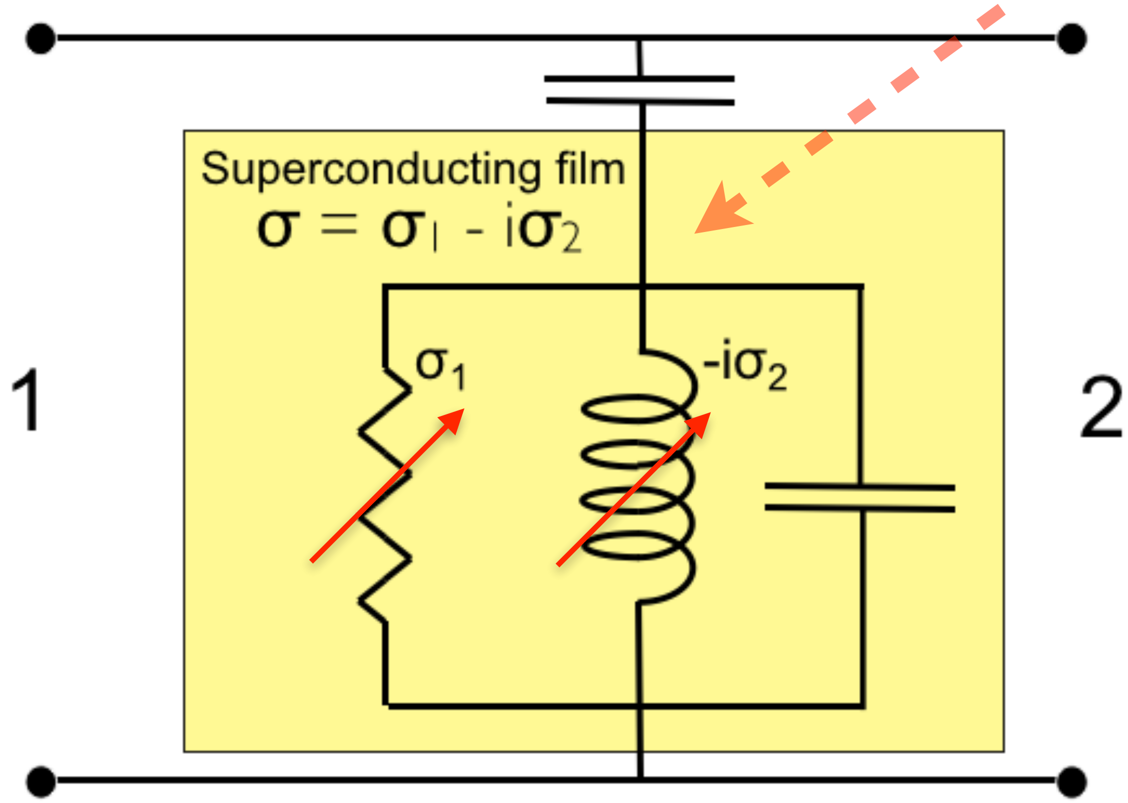
MKID principle of operation

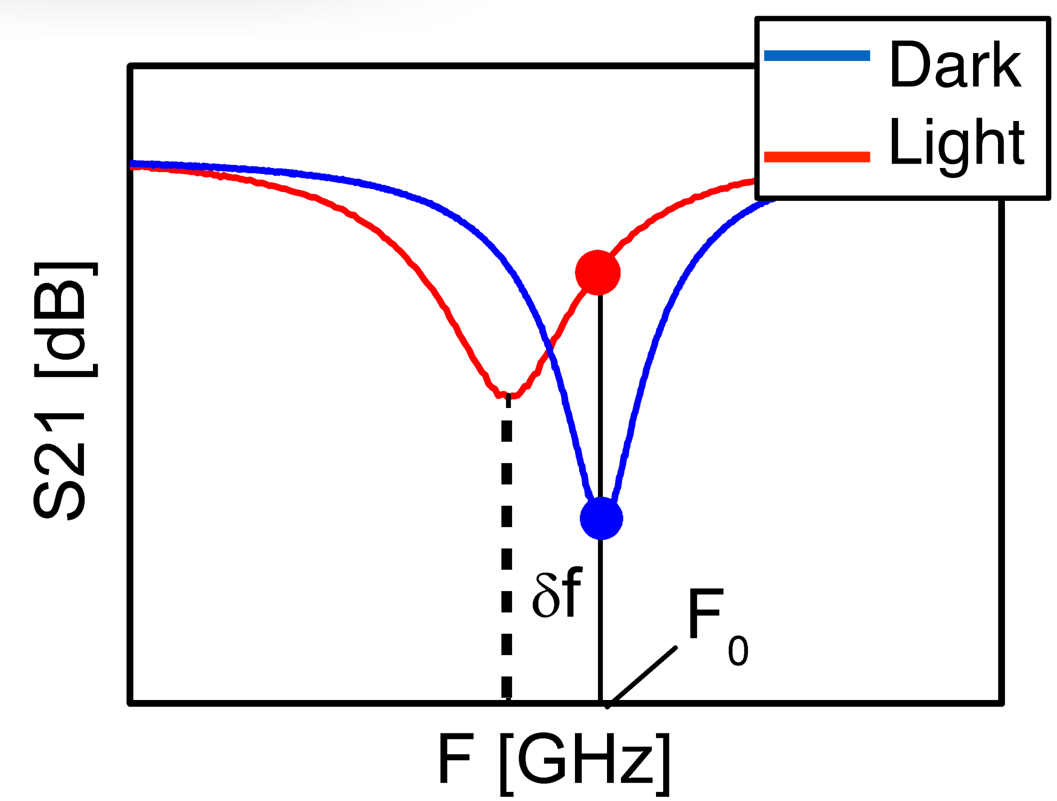
Radiation absorption

- Changes resonance feature

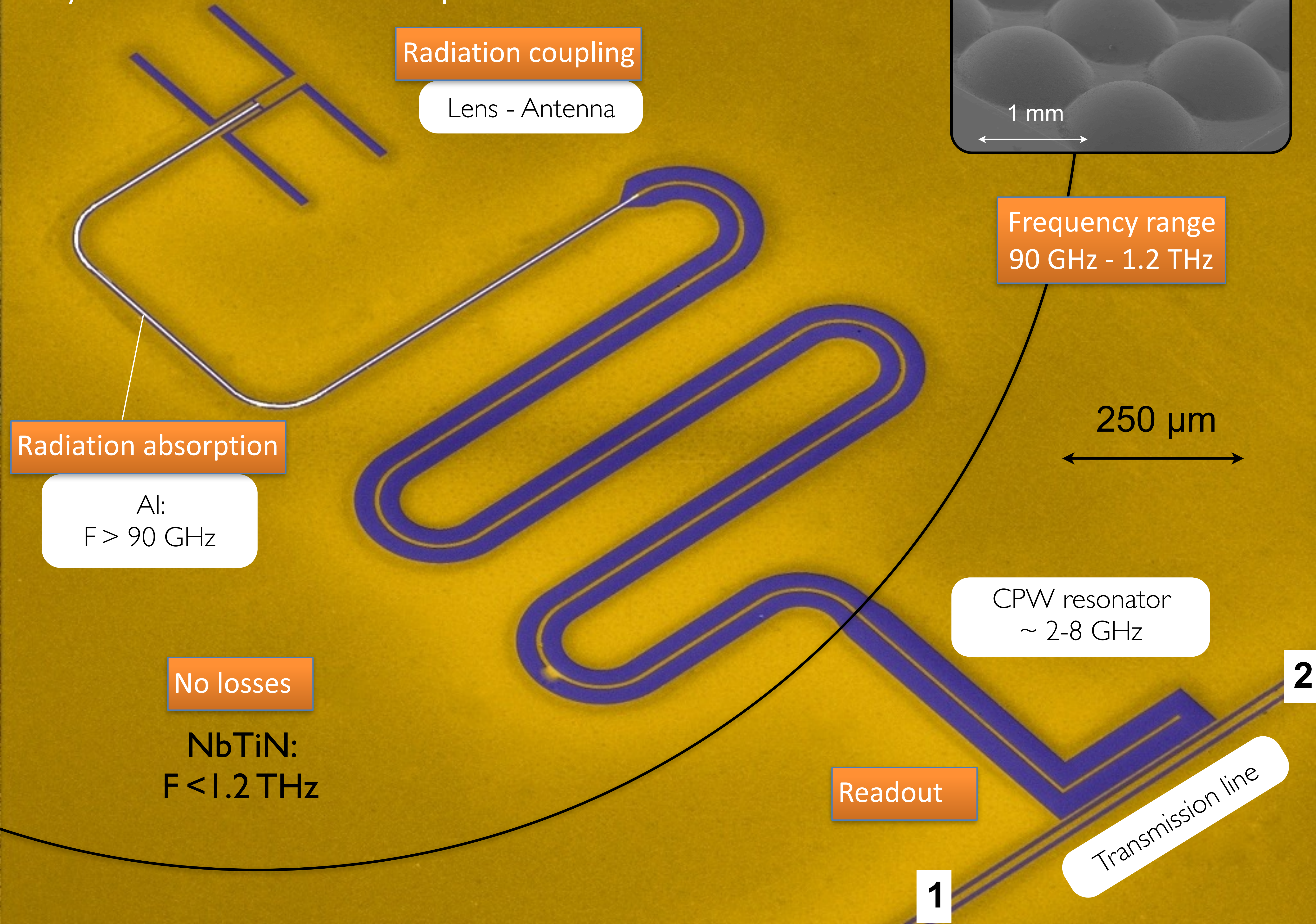
Can be read out using 1 frequency tone



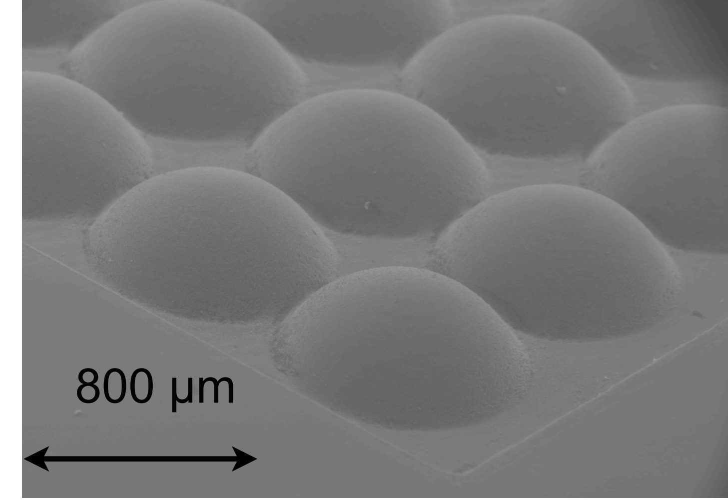


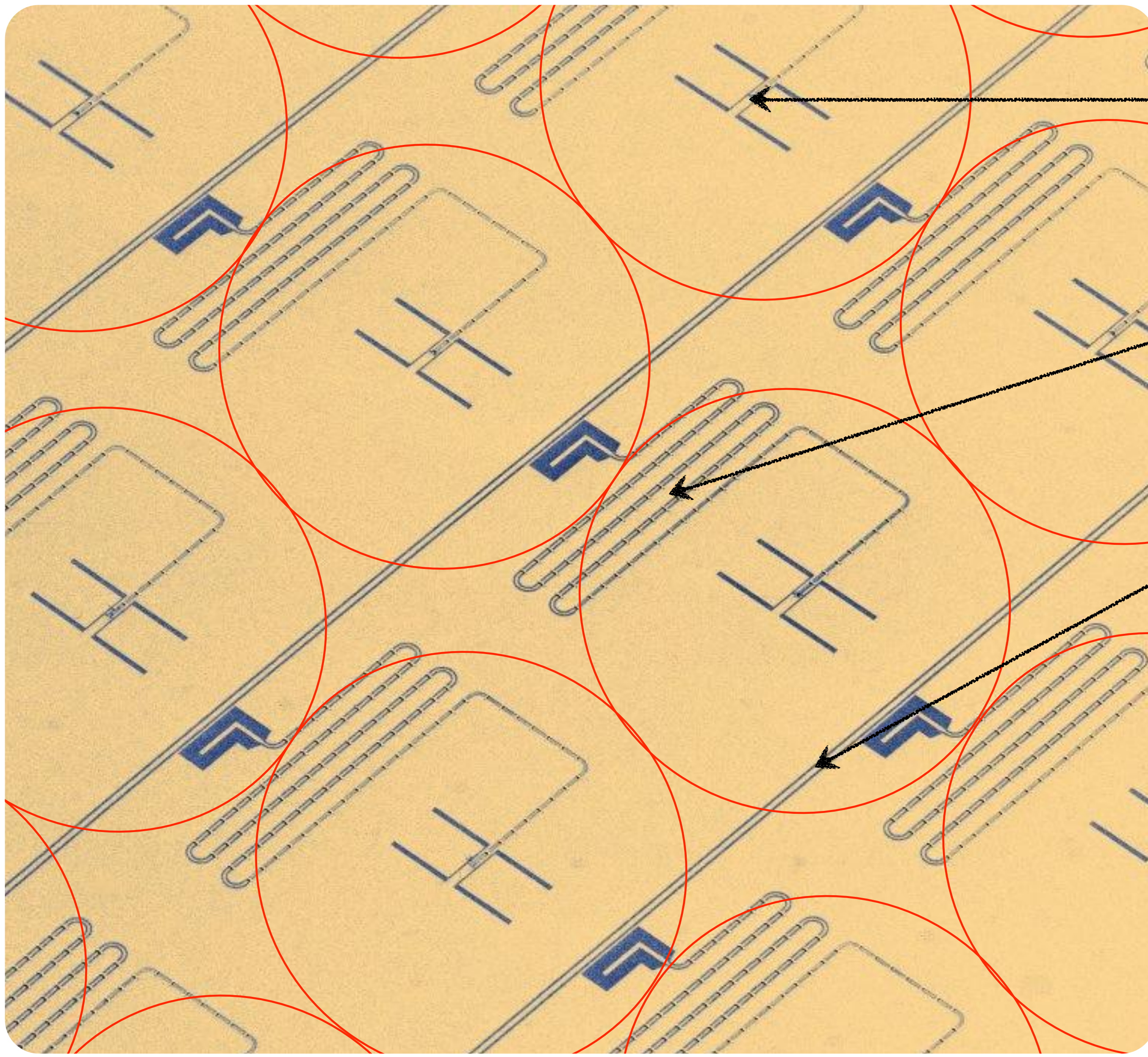


Hybrid antena coupled MKID



KID imaging Array



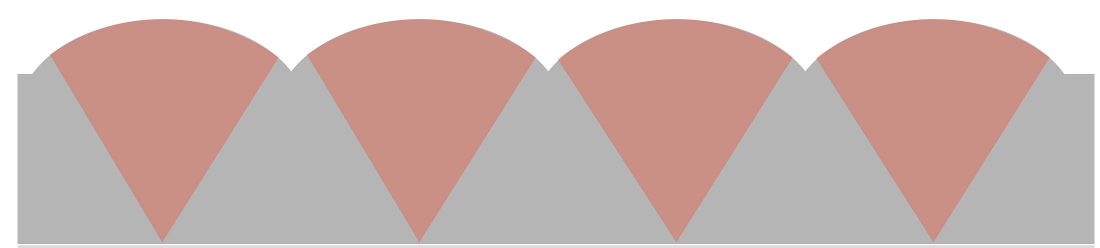


Identical antenna's

Resonators have different length
Different resonance frequencies

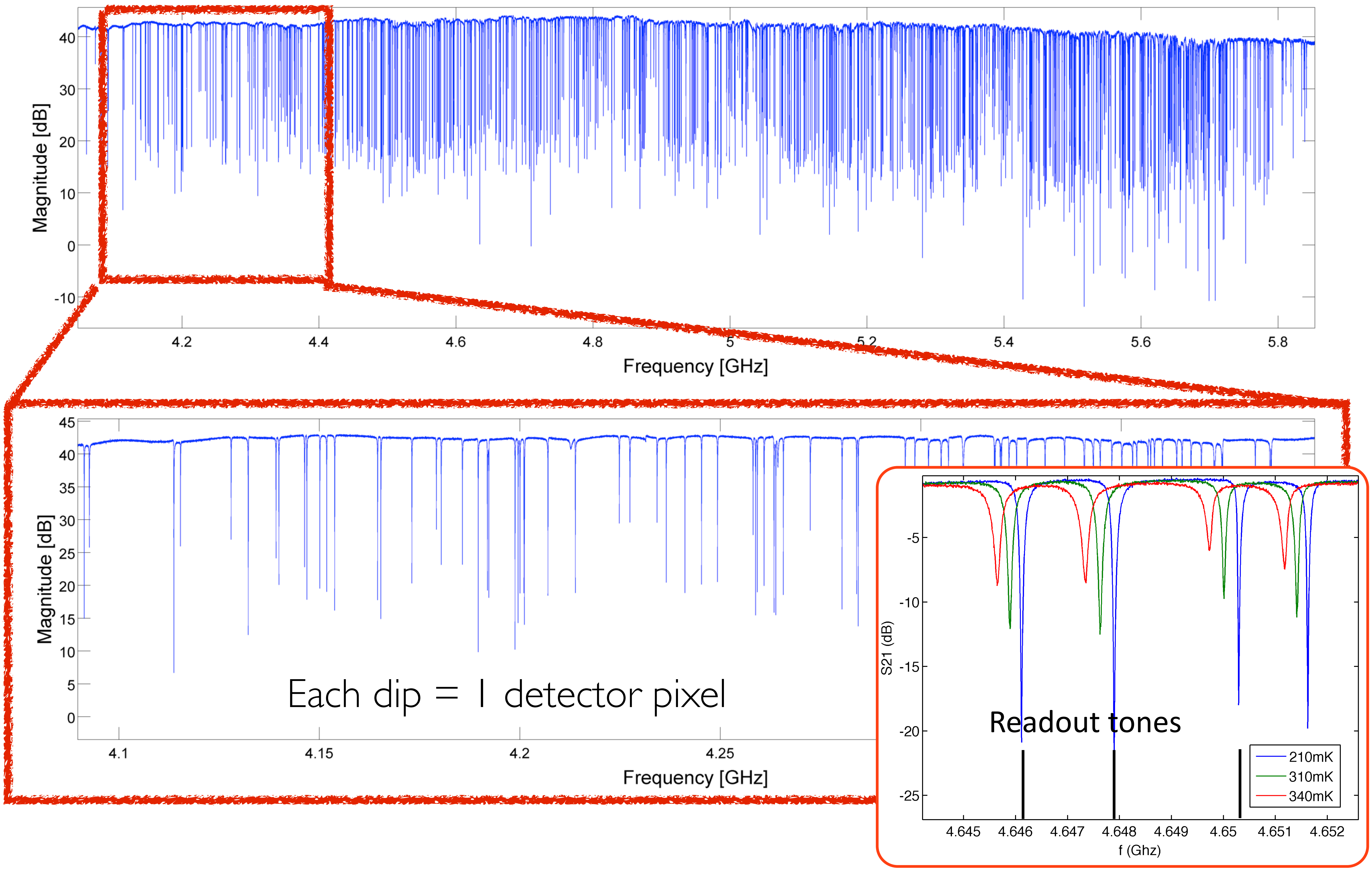
1 readout line connecting all pixels

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



Flies eye lens array, 1 lens/pixel

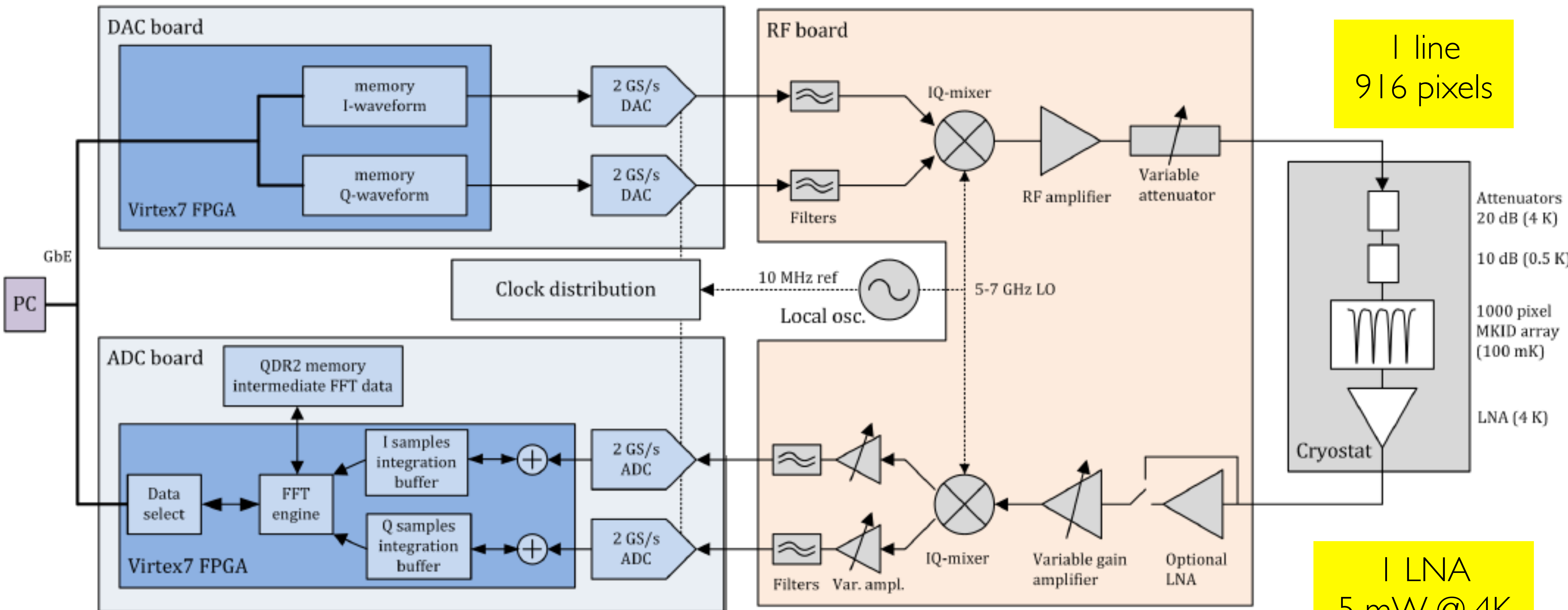
MUX ratio of up to 8,000 detectors/channel



SpaceKIDs Readout System: 2 GHz bandwidth, ≤8000 MKIDs

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

50 W @ 300K
4 kg



1 line
916 pixels

1 LNA
5 mW @ 4K

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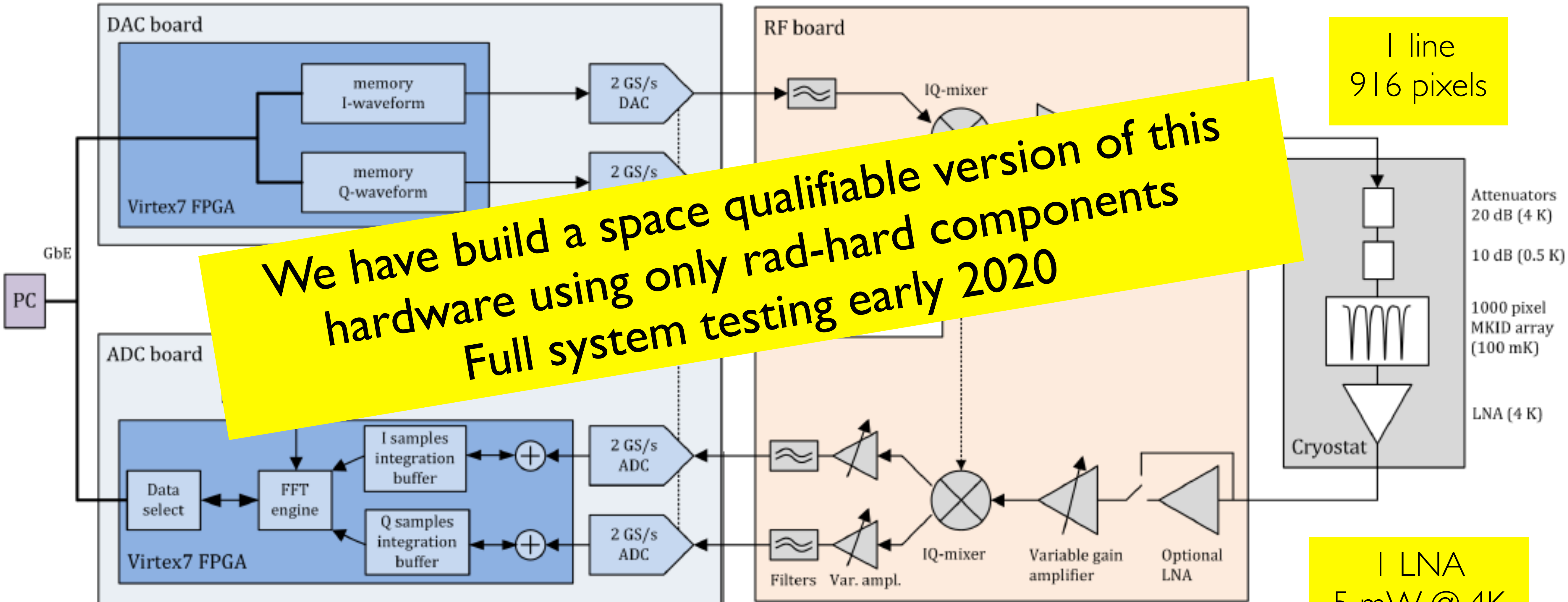


1 line
916 pixels

1 LNA
5 mW @ 4K

We have build a space qualifiable version of this hardware using only rad-hard components
Full system testing early 2020

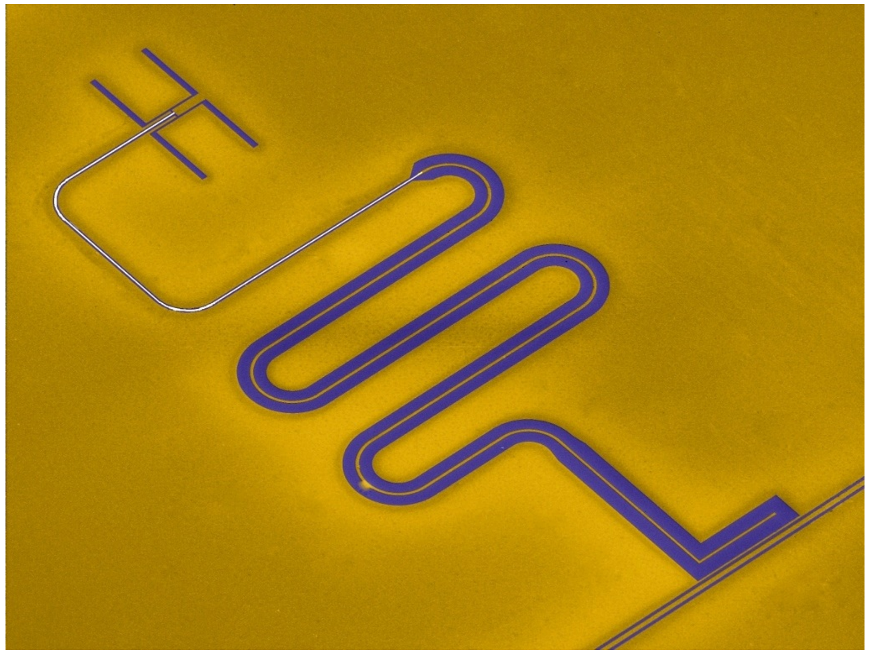
Flexible: Any frequency you want

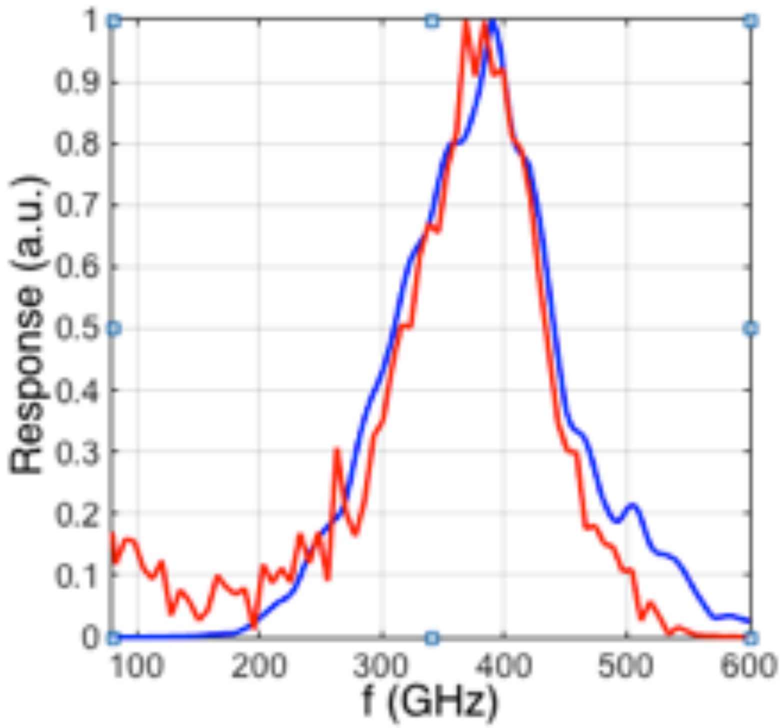
< 90 GHz
new materials

Replace Al with

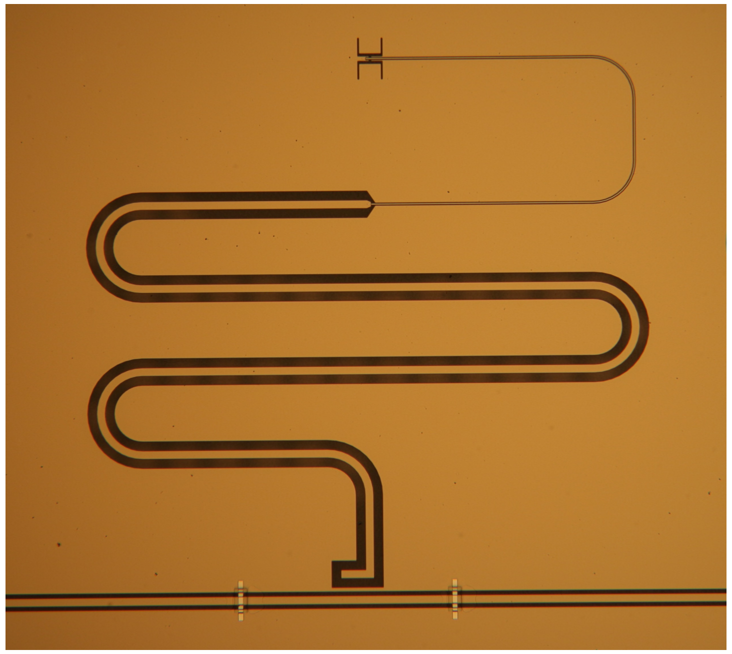
- Hafnium
  - Tc ~ 0.4 K
  - $F_{2\Delta}$ = 30 GHz
- β-Ta
  - Tc ~ 0.6 K
  - $F_{2\Delta}$ = 44 GHz

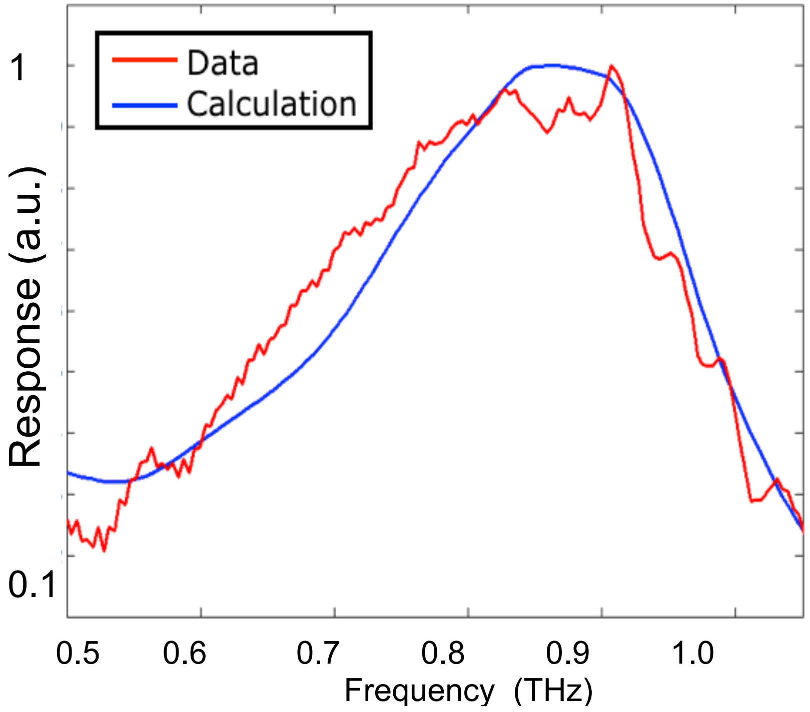
330-400 GHz





800-950 GHz





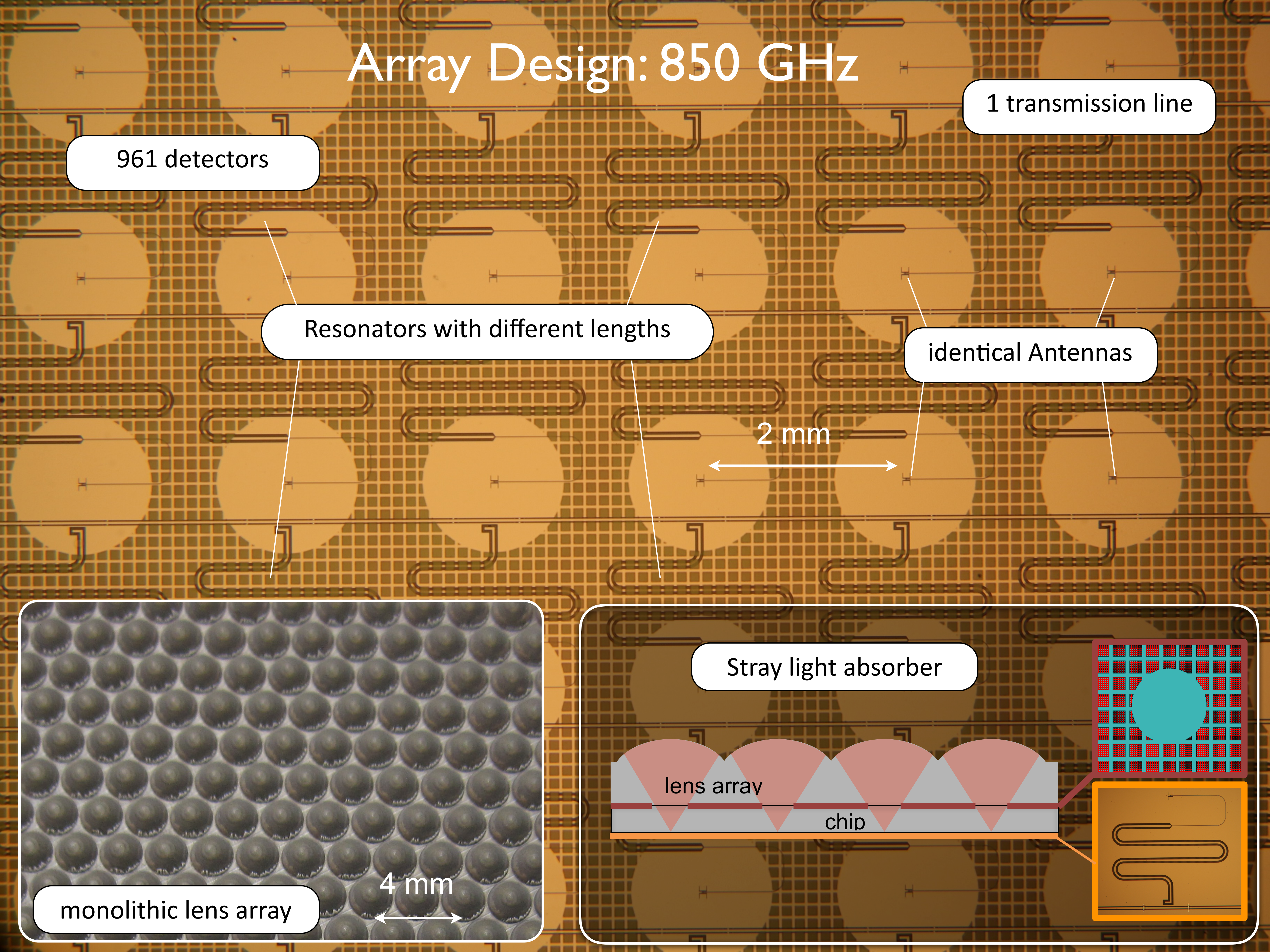
KIDs in space: EU FP7 programme SpaceKIDs

2012-2015

Develop *MKID* technology towards Space applications

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

Array Design: 850 GHz

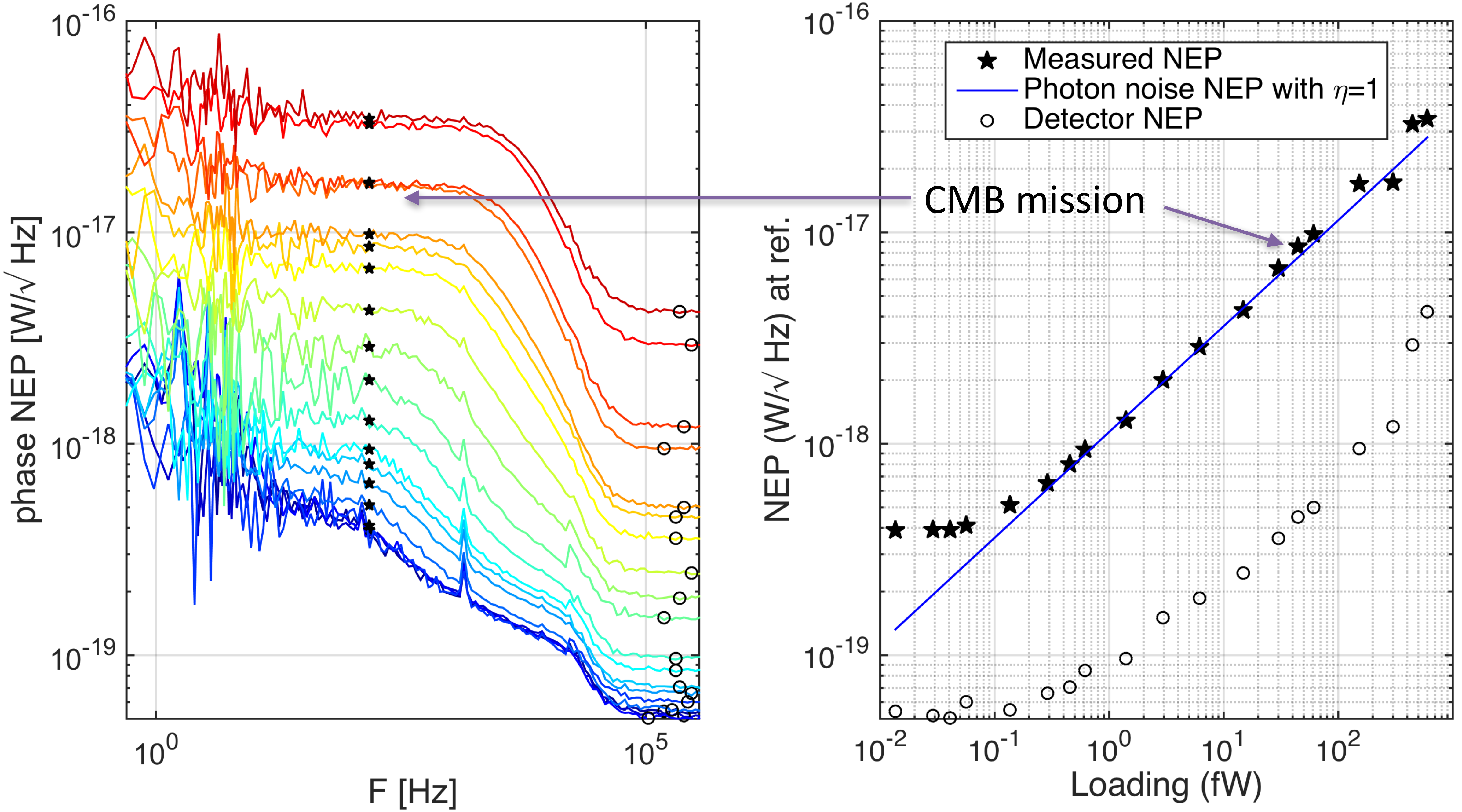


Sensitivity vs. FIR illumination

Background limited performance @ relevant sky load

1 pixel out of 961

Readout tones tuned to MKID Fres

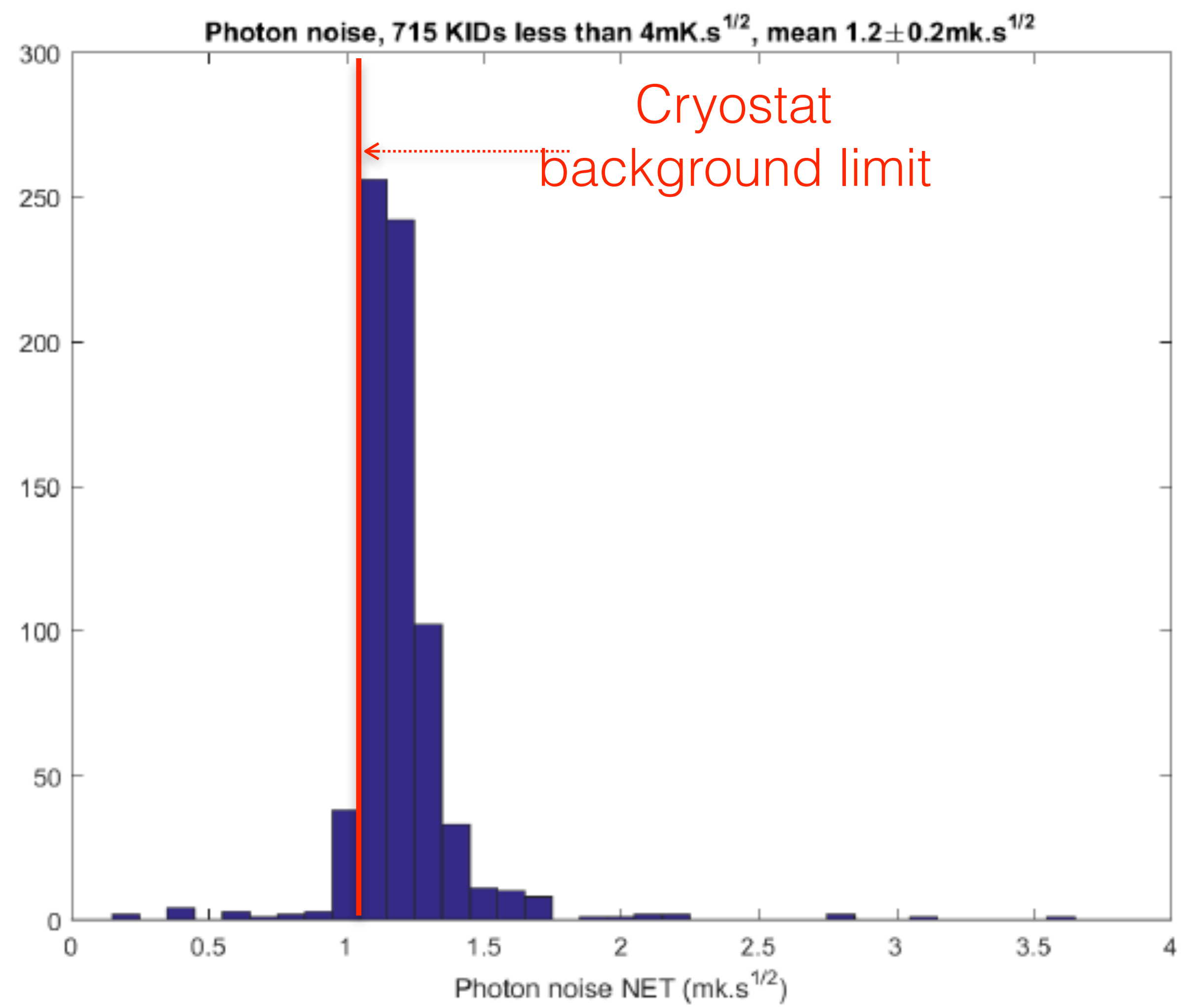


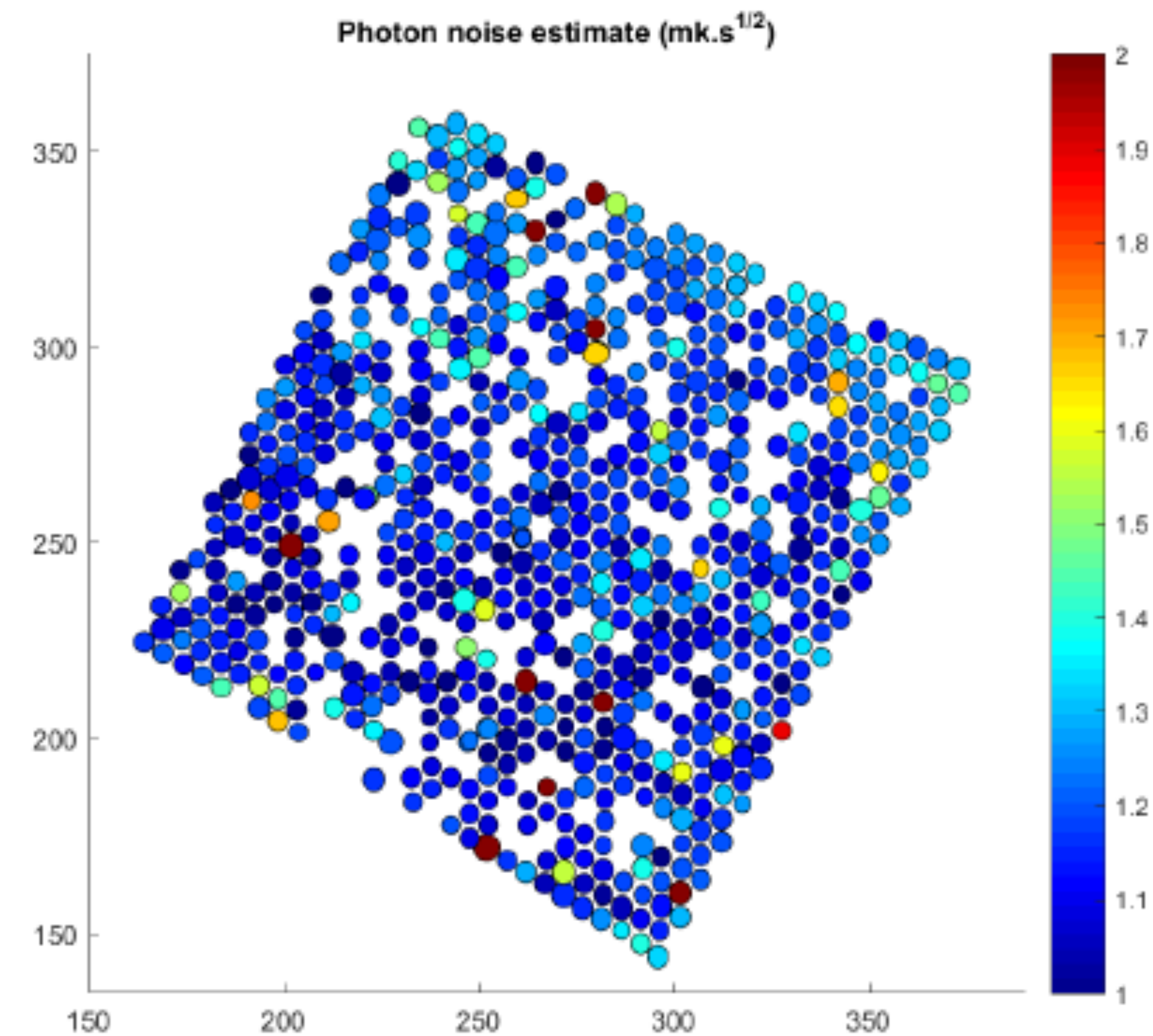
P. J. de Visser et al., *Nature Communications*, vol. 5, pp. 1–8, Feb. 2014.

Statistics: Under ~ 10 pW load

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

⇒ Yield: 83%





Baselmans, J. J. A. et al. A kilo-pixel imaging system for future space based far-infrared observatories using microwave kinetic inductance detectors. Astron. Astrophys. 601, A89 (2017).

Cosmic Rays - lab tests

Single glitches with time constant ~ 1 msec

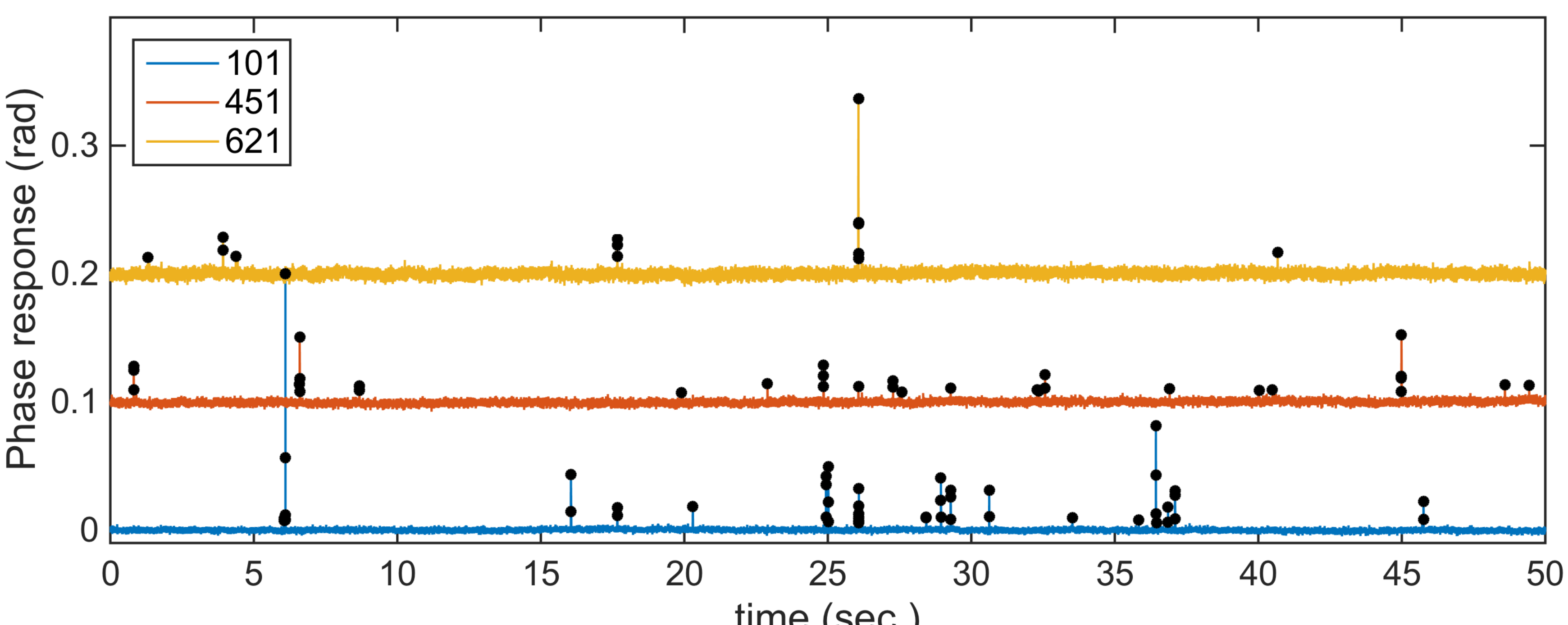
- fractional dead time (>5**σ**): 3.2 · 10^{-4}

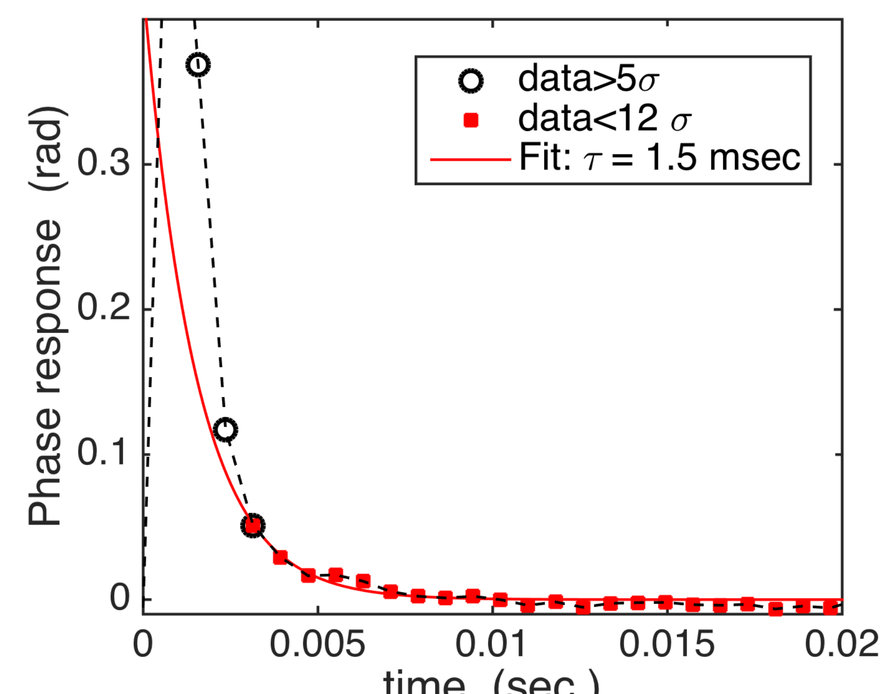
At 'CMB' loading - 100 fW

- L2 estimation dead time: 1%
- negligible effects on integration: Catalano, A.,et al. 2016b, A&A, 592, A26

Can even be improved: See Poster of K. Karatsu

Karatsu, K. et al. Mitigation of cosmic ray effect on microwave kinetic inductance detector arrays
Appl. Phys. Lett. 032601, (2019).

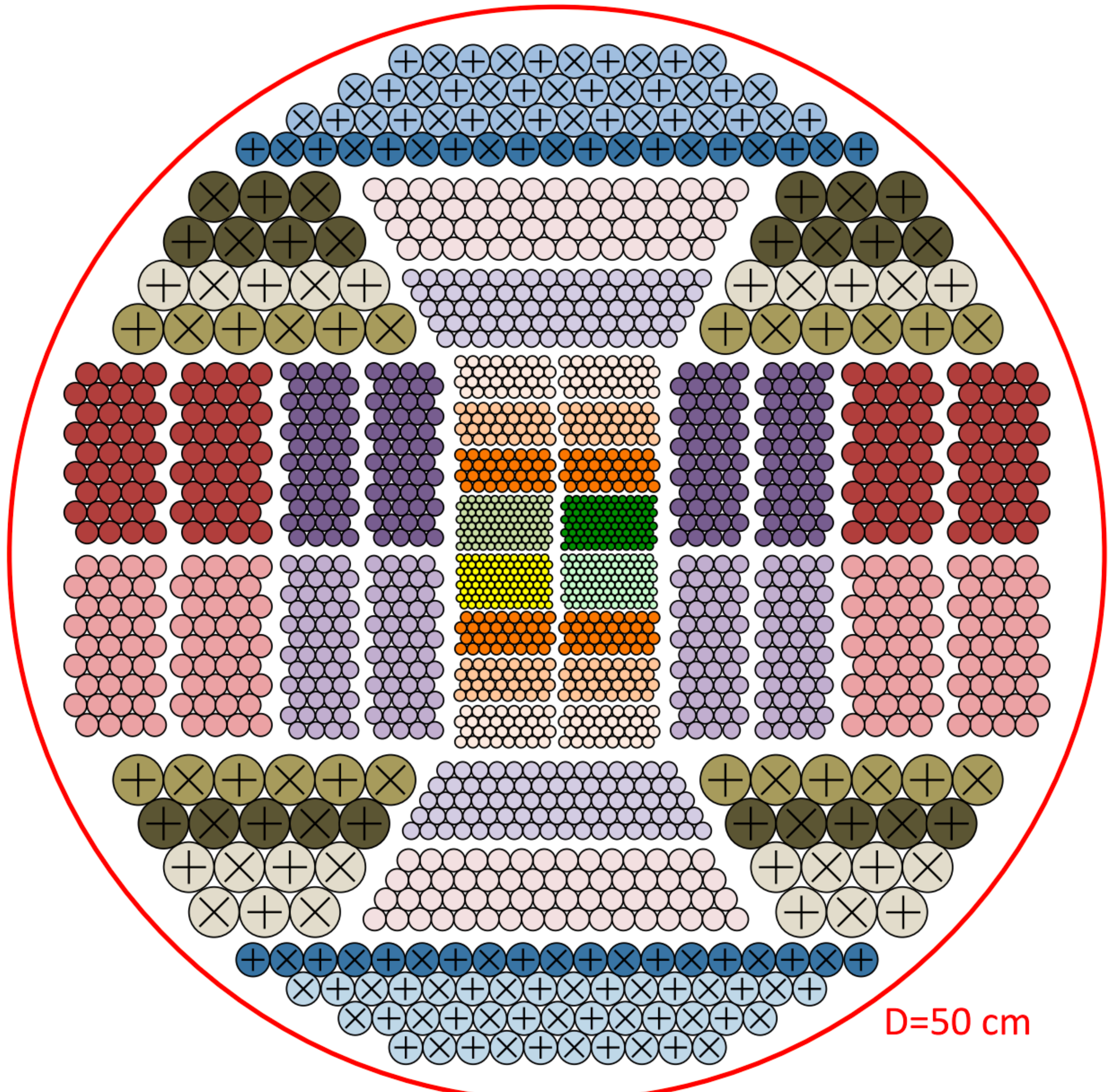




This we can plug 1:1 in the concept of CORE

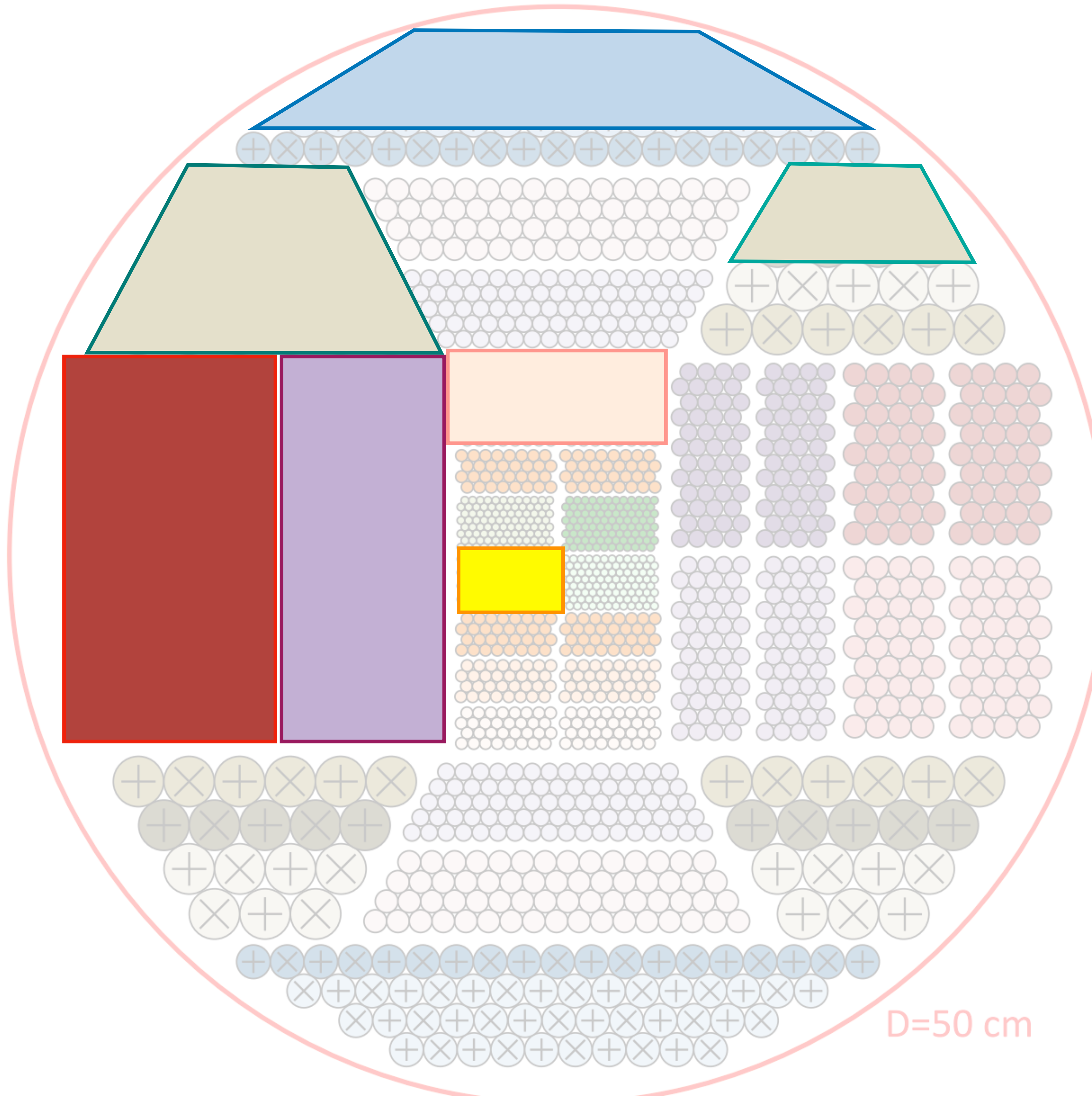
2100 detectors: 1 LNA, 1 cable pair, 1 readout system, ~ 50W, 4 kg

	GHz	N_{det}
Work needed	60	24×2
	70	24×2
	80	24×2
Demonstrated	90	39×2
	100	39×2
	115	38×2
	130	124
	145	144
	160	144
	175	160
	195	192
	220	192
	255	128
	295	128
	340	128
	390	96
	450	96
	520	96
	600	96
	TOTAL	2100



Advanced options: broad band antenna's + filters

- **24 x 60 - 80 GHz, 3 colors**
- **32 x 90 - 115 GHz, 3 colors**
- **144 x 130 - 145 GHz, 3 colors**
- **192 x 175 - 220 GHz, 3 colors**
- **128 x 255 - 340 GHz, 3 colors**
- **96 x 390 - 600 GHz, 3 colors**



- ~ Half the FP area
- ~ same sky sampling
- same # detectors
- Needs @ most 1: 1.55 BW

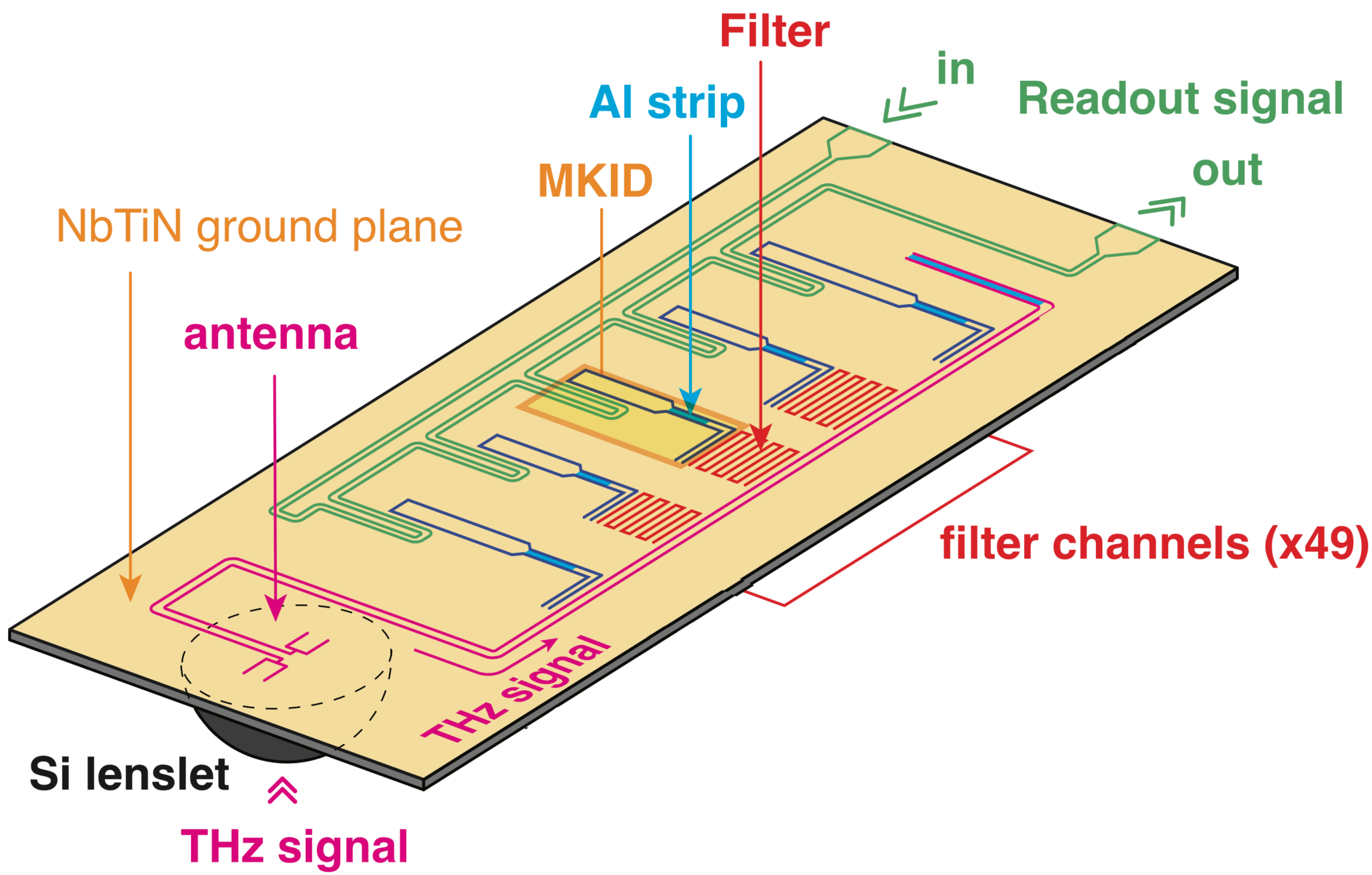
Advanced options: on-chip spectrometers

R = 350 filters

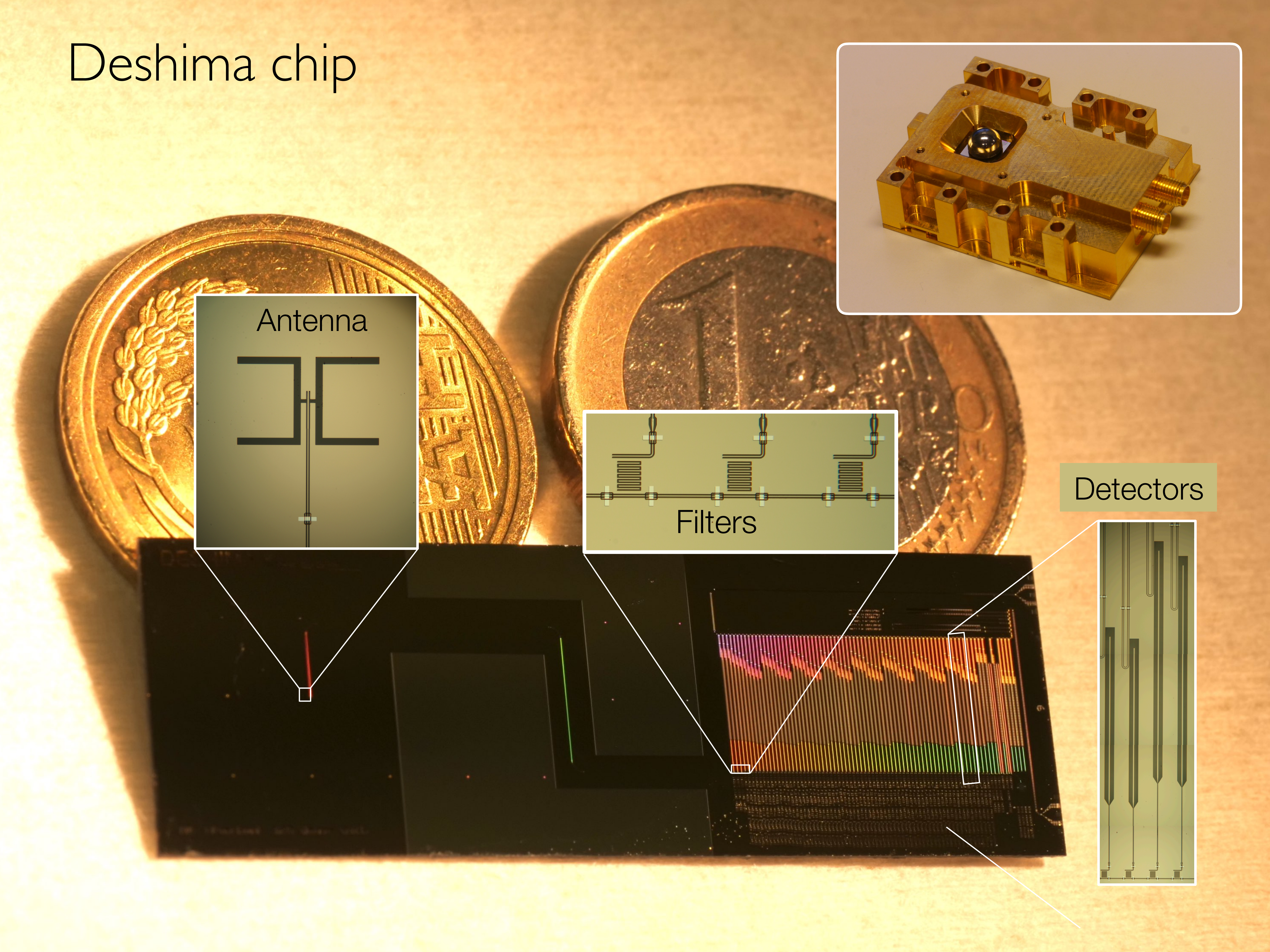
330-375 GHz prototype

possible for 50 GHz - 1.1 THz

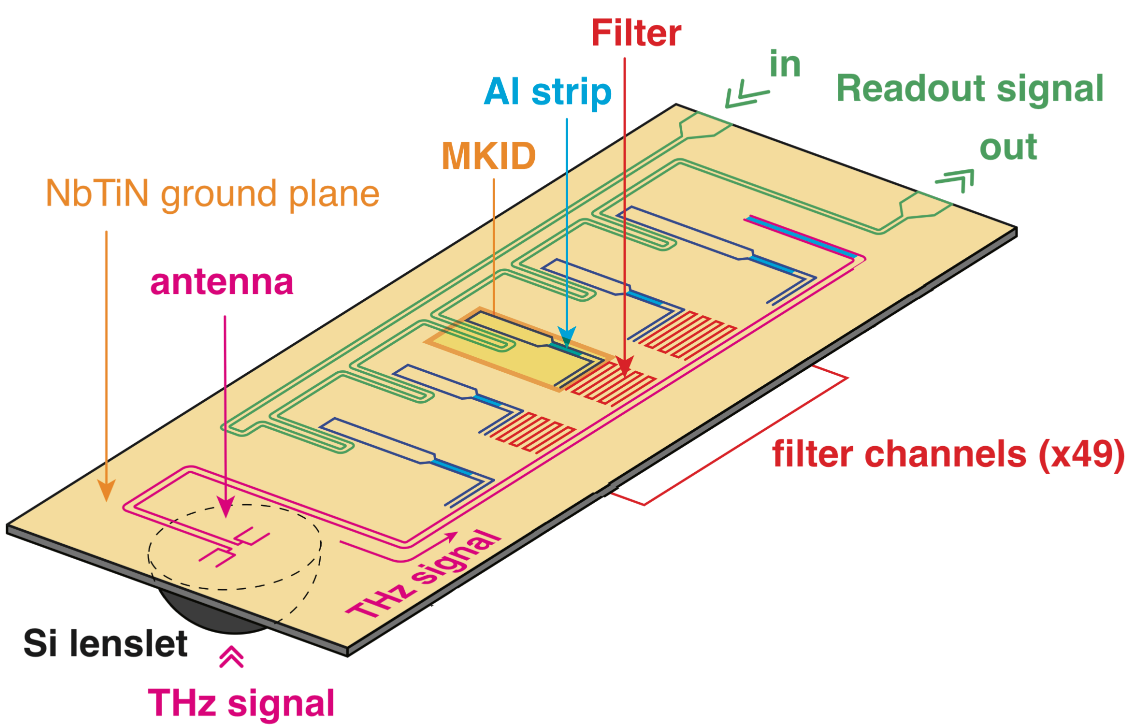
DESHIMA

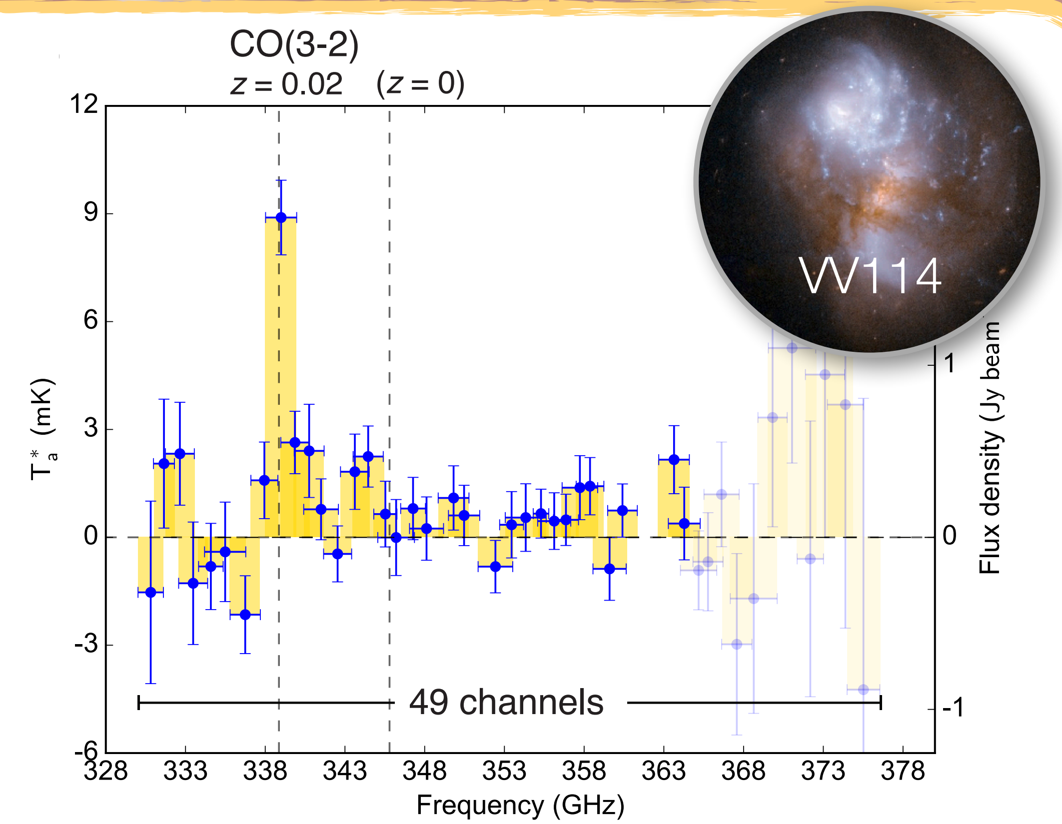


Endo, A. et al. Wideband on-chip terahertz spectrometer based on a superconducting filterbank.
J. Astron. Telesc. Instruments, Syst. 5, 035004 (2019).


Deshima chip
Antenna
Filters
Detectors

2017: Deshima @ ASTE



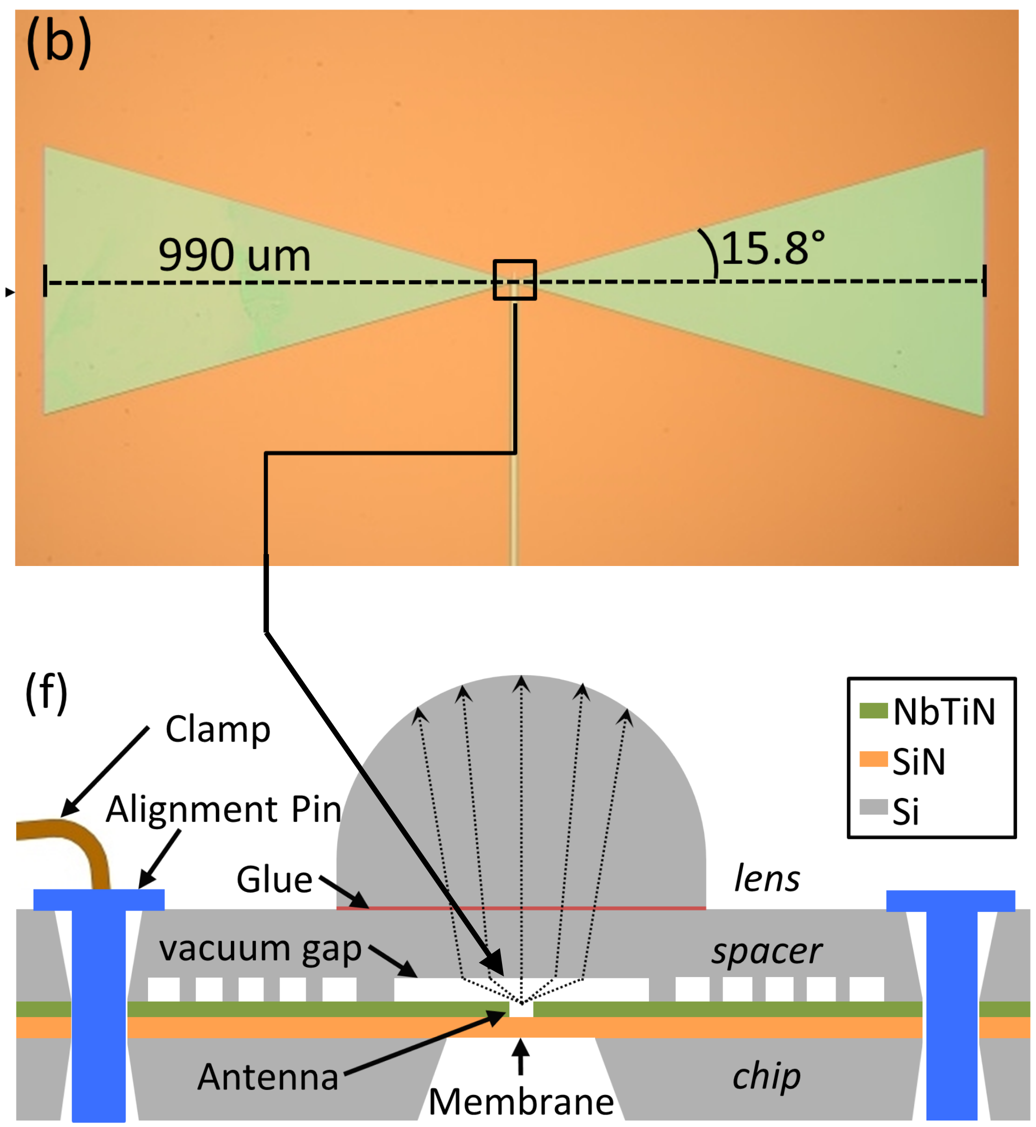


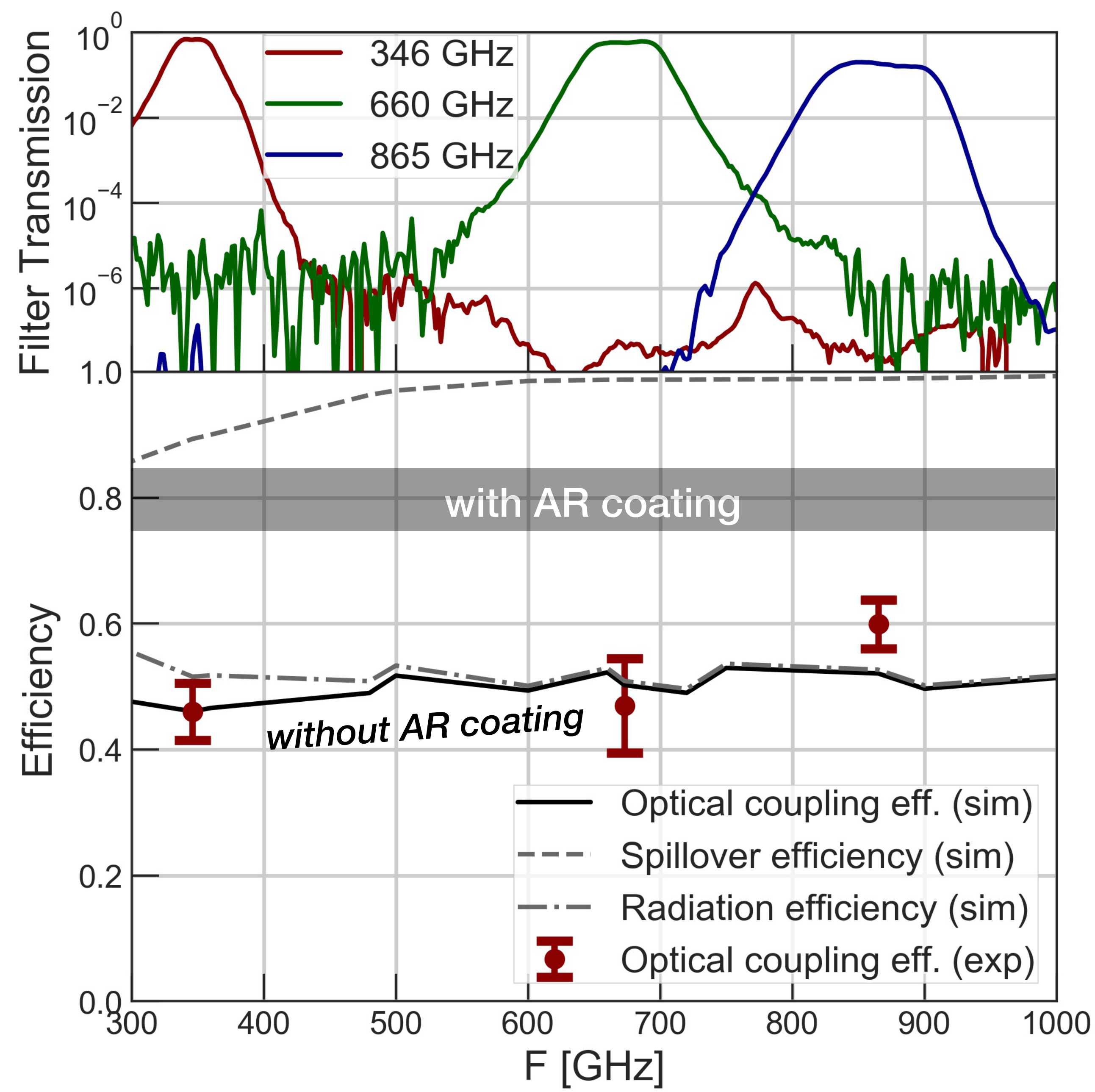
Endo, A. et al. First light demonstration of the integrated superconducting spectrometer.
Nature Astronomy (2019)

Deshima upgrade: Large input band

1:3 bandwidth demonstrated - with constant *Aperture* efficiency

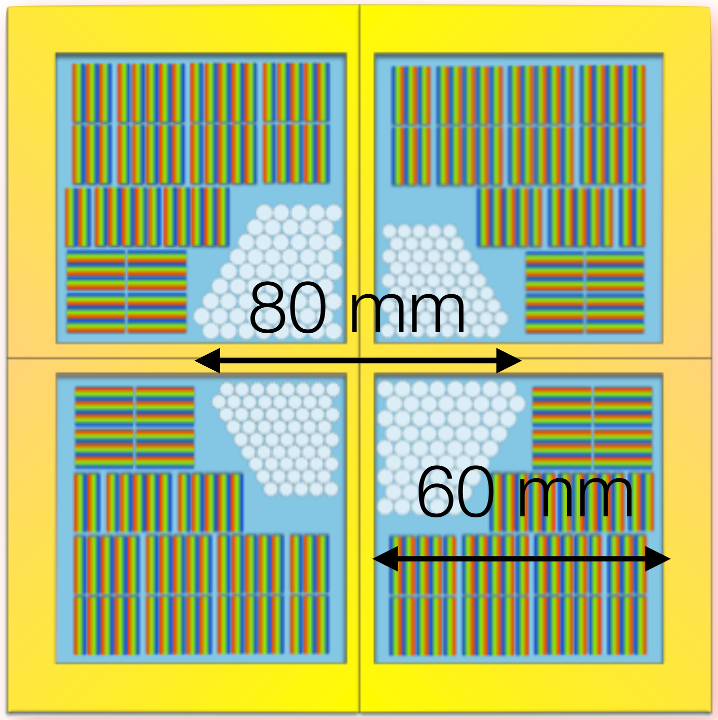
220-440 GHz Deshima-2 user construction





S. Haehnle et al., An Ultra-Wideband Leaky Lens Antenna for Broadband Spectroscopic Imaging Applications
Accepted for IEEE trans. on antennas and Propagation (2019)
arXiv:1912.07428

Concluding Remarks

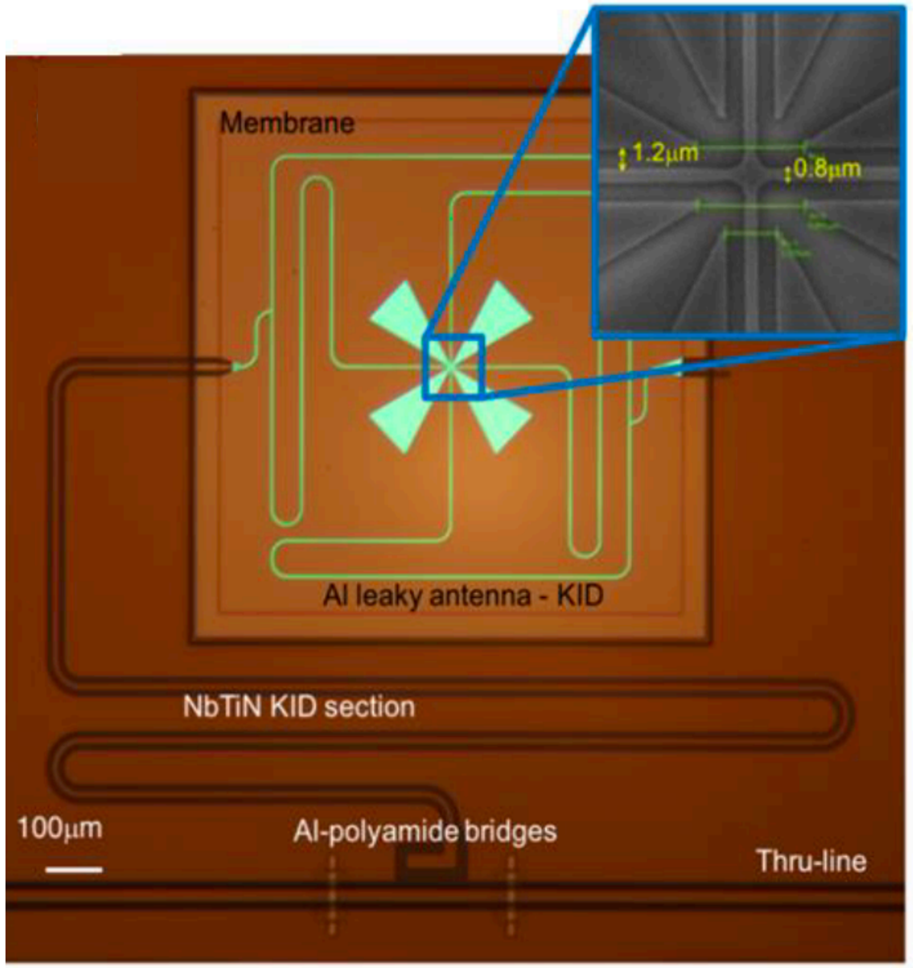


We have demonstrated

- kpixel MKID imaging arrays + readout system
  - ***ready for space***
- background limited + high efficiency + low cosmic ray susceptibility

Future CMB KID-based systems

- *imaging arrays*
- *broad band on-chip imaging spectrometers*
- many Deshima's on 1 chip
  - dual polarisation
  - F down to 60 GHz with β-Ta absorber



Yurduseven, O. et al. Incoherent Detection of Orthogonal Polarizations via an Antenna Coupled MKID: Experimental Validation at 1.55 THz. IEEE Trans. Terahertz Sci. Technol. 1–1 (2018).