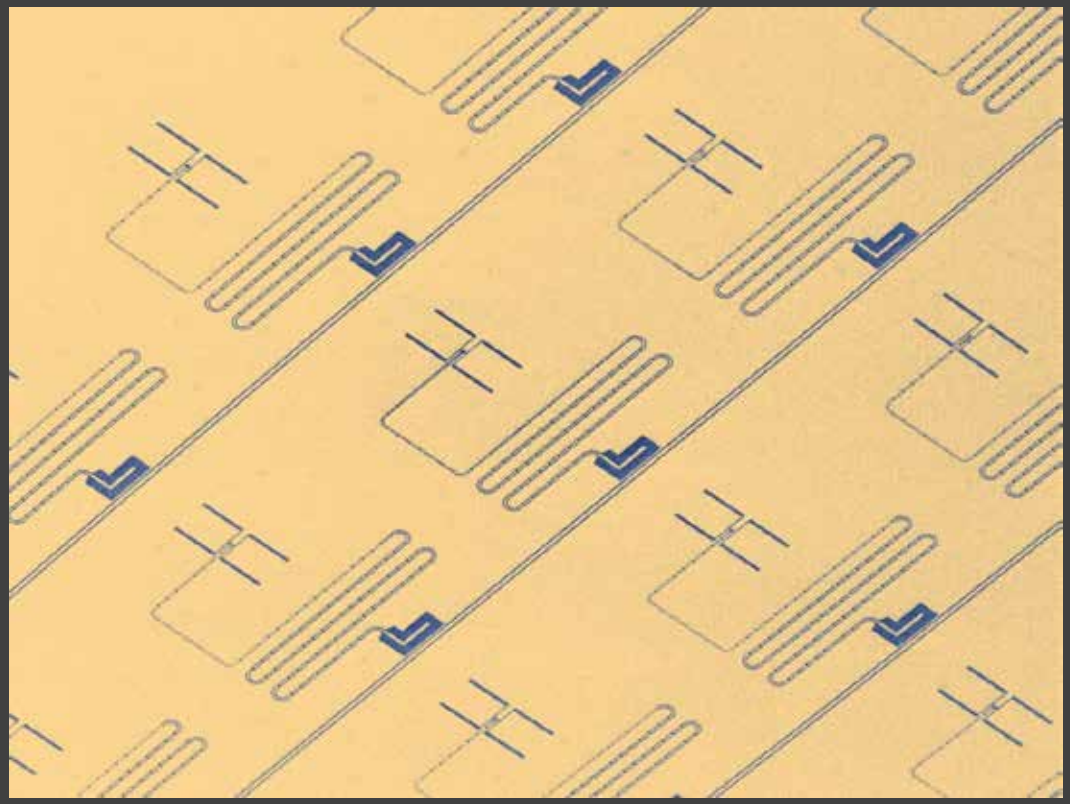
background limited antenna coupled MKID arrays for ground based imaging

Jochem Baselmans, Andrey Baryshev, Stephen Yates, Akira Endo, Lorenza Ferrari, Pascale Diener, Jan-Joost Lankwarden, Pieter de Visser, Reinier Janssen, Henk Hoevers, Teun Klapwijk



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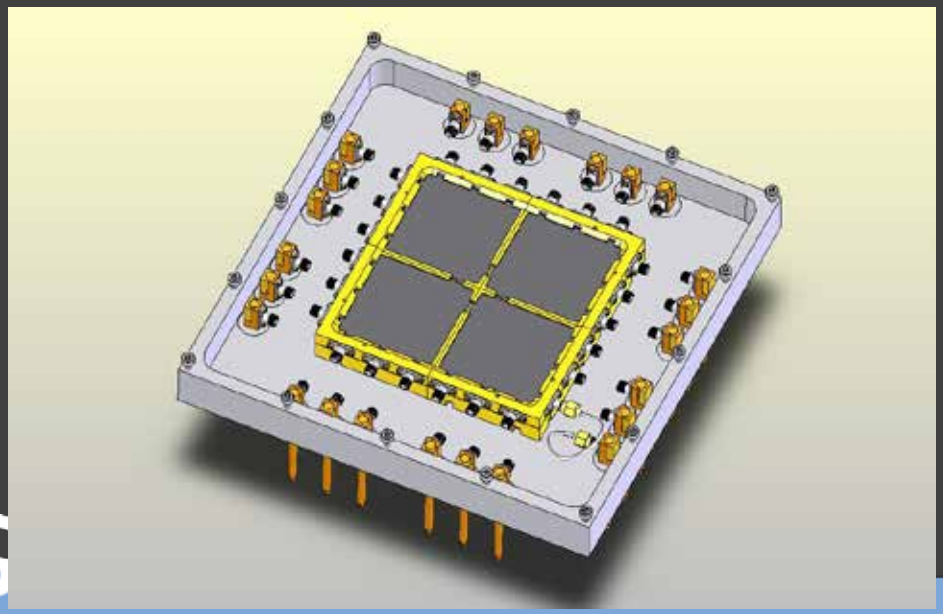
Outline

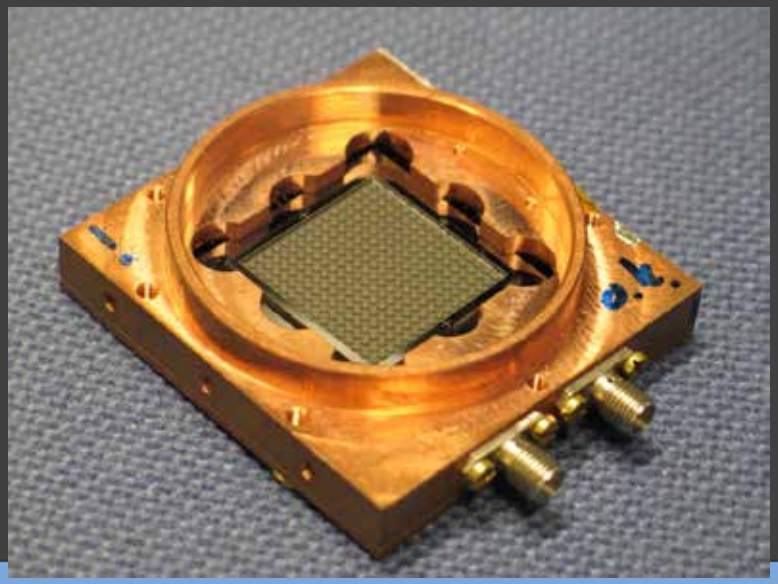
- A-MKID
- Photon noise limited peformance
- Hybrid antenna coupled MKID
- Test chip noise performance – effect of Al and interfaces
- A-MKID system tests

A-MKID

- 2 color imaging instrument for APEX, 870 µm and 350 µm
- 15 arcmin FOV, 1 Fl. pixel spacing
- 2 separate arrays of 4 sub-arrays in the FP, polarizer to select band

band	870 µm	350 µm
# pixels	20.000 pixels	3.200 pixels
goal sensitivities	34 mJy $s^{0.5}$	59 mJy $s^{0.5}$
goal pixel NEP	2.7e-15 W/$Hz^{0.5}$	1.4e-14 W/$Hz^{0.5}$

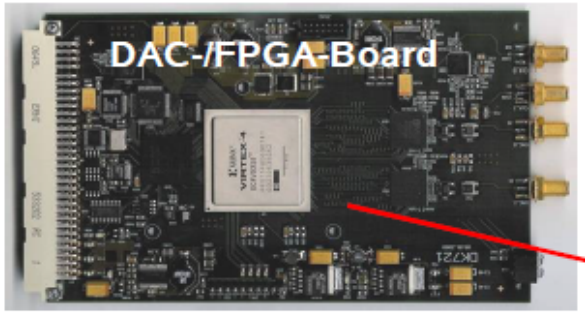


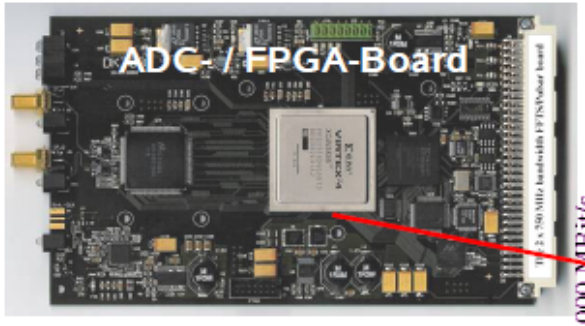


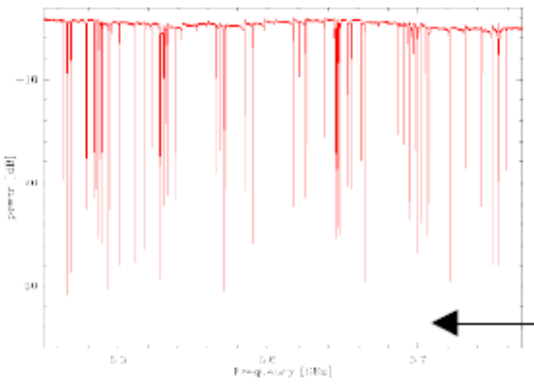
A-MKID :: *Read-Out Concept*

Max-Planck-Institut
für Radioastronomie

DIGITALLABOR







reference frequency
(e.g. 10 MHz)

IF–Synthesizer

DAC–/FPGA–Board
(programmable tone generator)

Baseband

SSB upconverter

synchonisation

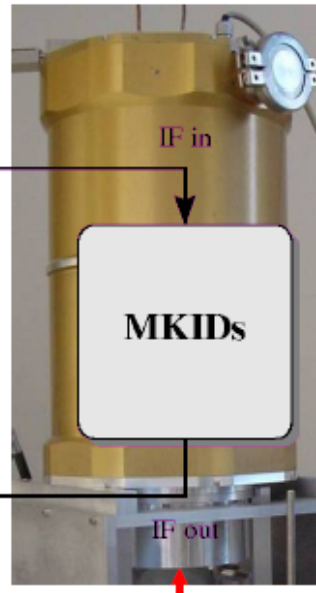
ADC–/FPGA–Board
(synchron time integration)

SSB downconverter

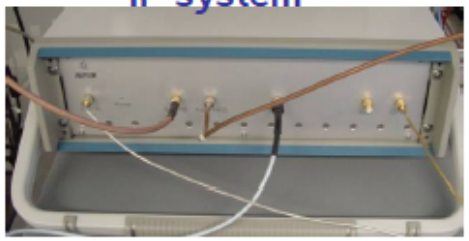
Ethernet 100/1000 MBit/s

Linux–PC
- *KIDs readout control*
- *complex FFT*
- *data processing & recording*

Cryostat



IF-system



Signal

A-MKID - readout

- Phase readout due to low Q of the devices (20.000) due to loading
- MPIfR developped readout (full IQ)
  - Bandwidth 2.5 GHz
  - 32768 bins (76 kHz resolution)
  - 8 ENOB (expected)
  - based upon E2V 10AQ 190 ADC, 4x1.25 Gsample/sec
  - and analog devices AD9739 DAC

Photon noise limited performance

- Random arrival rate of photons creates a white noise in quasiparticle number rolled of at the lifetime
- On top of this there is recombination noise from the random recombination of excess quasiparticles
- If all quasiparticles are due to photon absorption:

Noise PSD | Quasiparticle recombination | Photon arrival | KID responsivity

$$S = \left(S_{G-R} + S_{photon}\right) \simeq \left(\frac{2N_{qp,p}\tau_{qp}}{1+(\omega\tau_{qp})^2} + \frac{2N_{qp,p}\tau_{qp}\eta h\nu/\Delta}{1+(\omega\tau_{qp})^2} \right) \cdot \left[\frac{\delta(A,\theta)}{\delta N_{qp}} \right]^2$$

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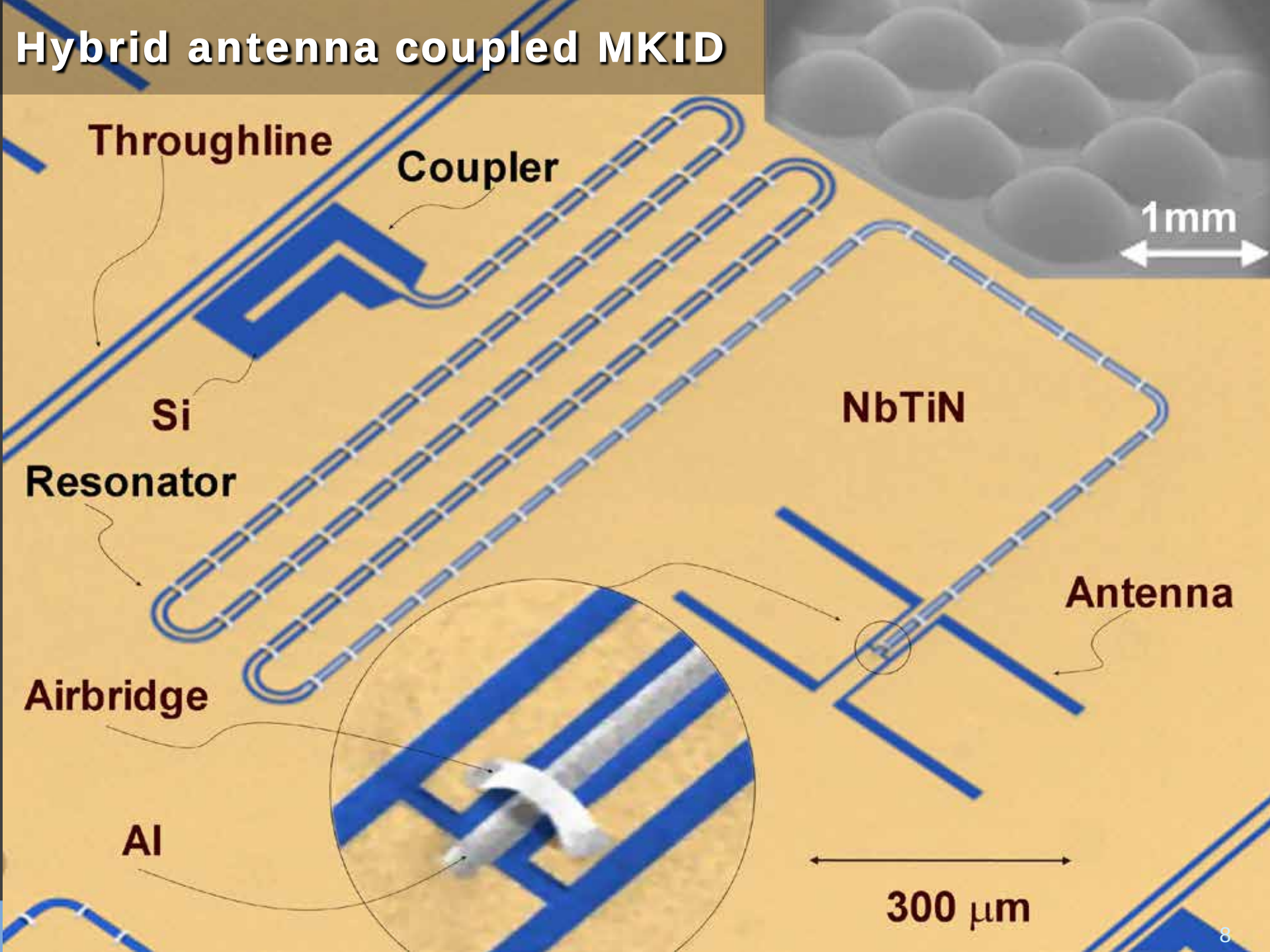
Photon noise limited performance

- Photon noise level $\propto$ n and *independent* of radiation power!
- Photon noise level not much above the G-R noise
  - Not easy to reach
  - Carefull material selection required
- Photon noise limited KIDs have always a contribution due to qp recombination
  - $S_{photon} + S_{G\text{-}R} = S_{photon}$ (1+0.85) at 350 GHz for Al

Noise PSD | Quasiparticle recombination | Photon arrival | KID responsivity

$$S = (S_{G-R} + S_{photon}) \simeq \left(\frac{2N_{qp,p}\tau_{qp}}{1+(\omega\tau_{qp})^2} + \frac{2N_{qp,p}\tau_{qp}\eta h\nu/\Delta}{1+(\omega\tau_{qp})^2} \right) \cdot \left[\frac{\delta(A,\theta)}{\delta N_{qp}} \right]^2$$

Hybrid antenna coupled MKID

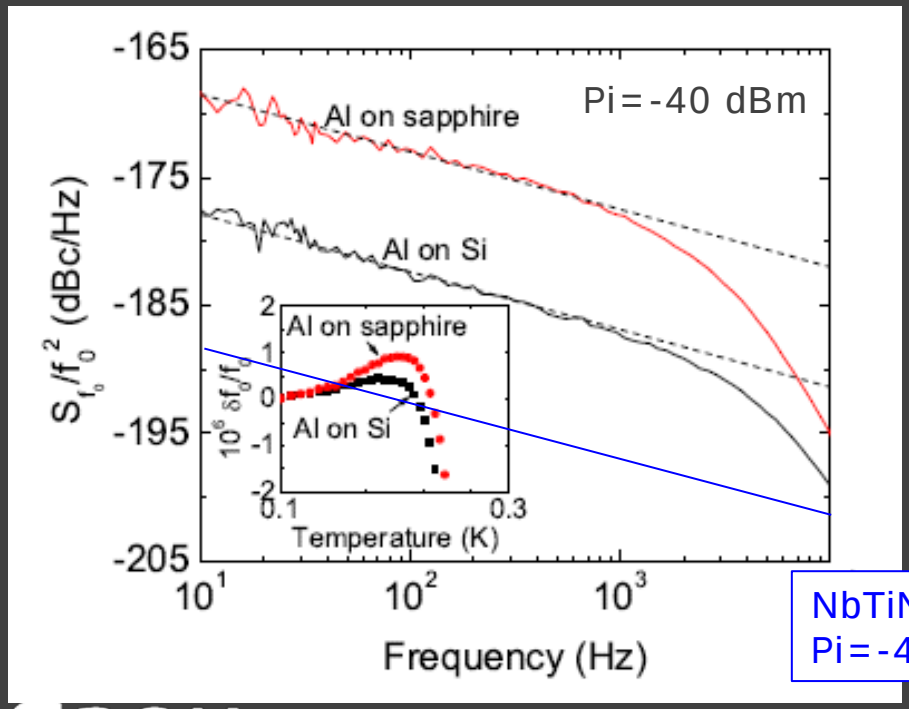


Hybrid antenna coupled MKID

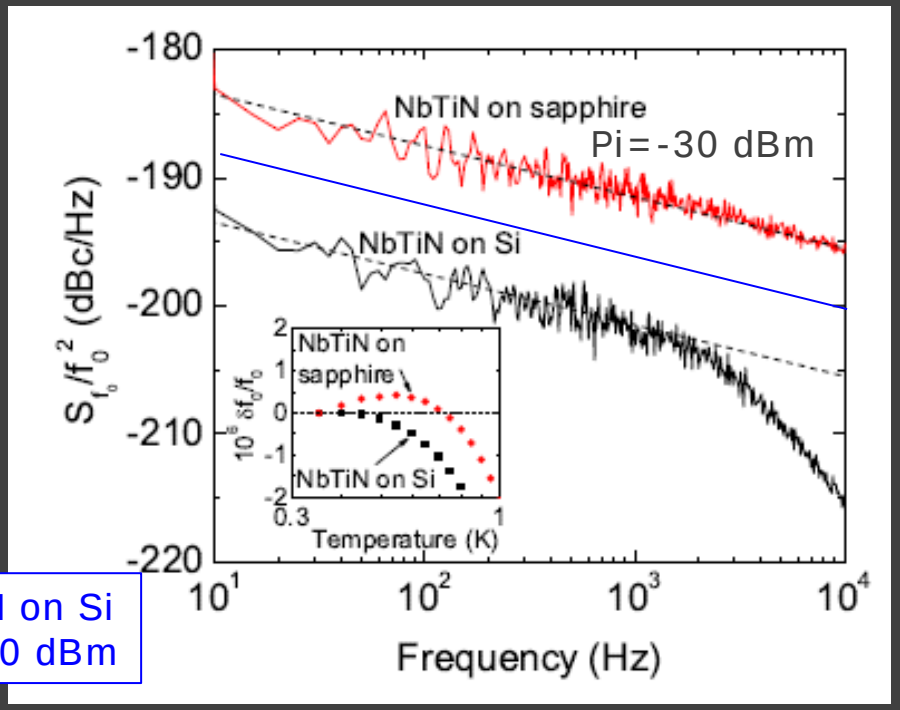
NbTiN as MKID material

- Lower frequencie noise
- 1.2 THz gap frequency
- Very good readout power handling

Rami Barends, Ph.D. Thesis (Deft University) 2009



NbTiN on Si
Pi=-40 dBm

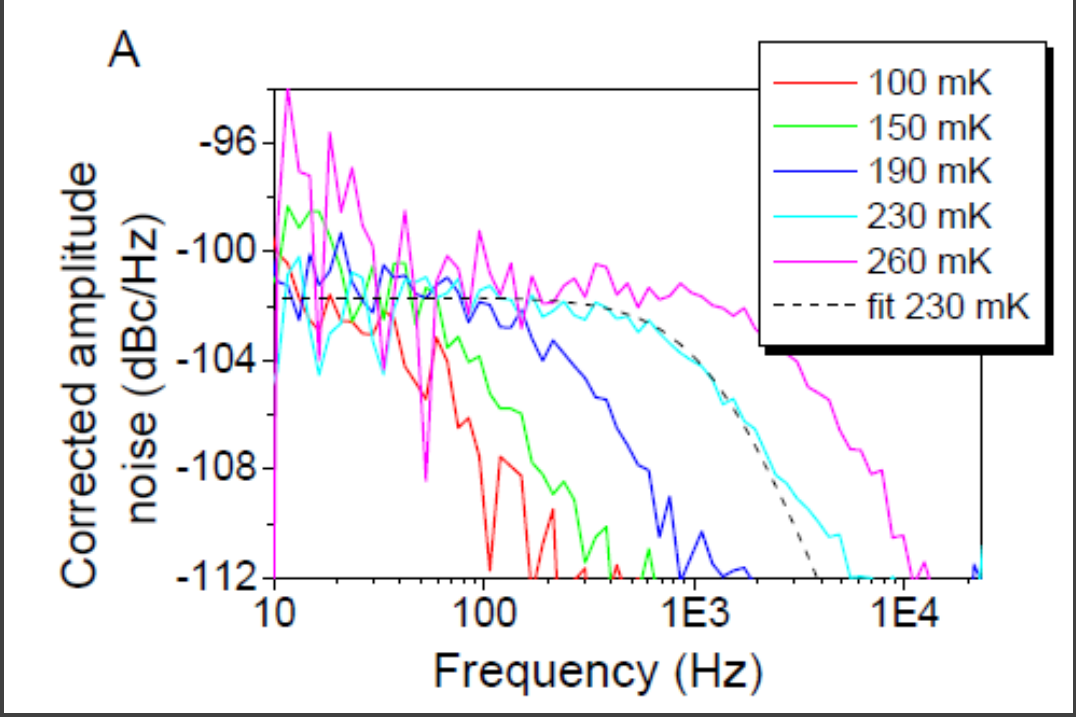


Hybrid antenna coupled MKID

Al to detect quasiparticles

- Al on saphire (see P. de Visser) has shown generation-recombination noise
- Using Al to absorb the radiation should allow us to reach the photon noise limit

See Visser et al., Phys. Rev. Lett. 106, 167004 (2011)



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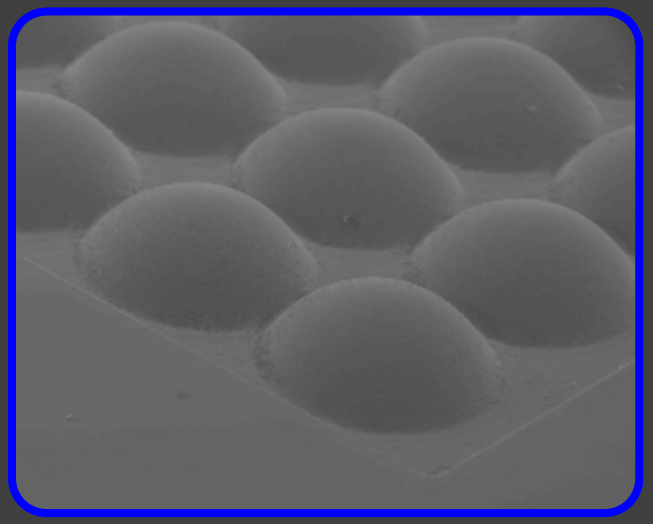
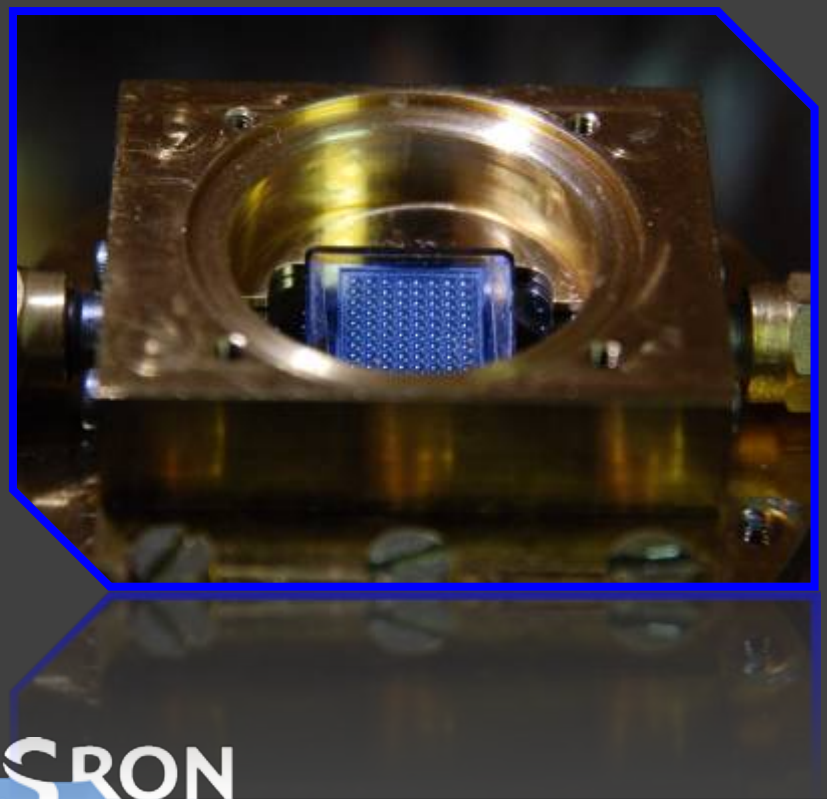
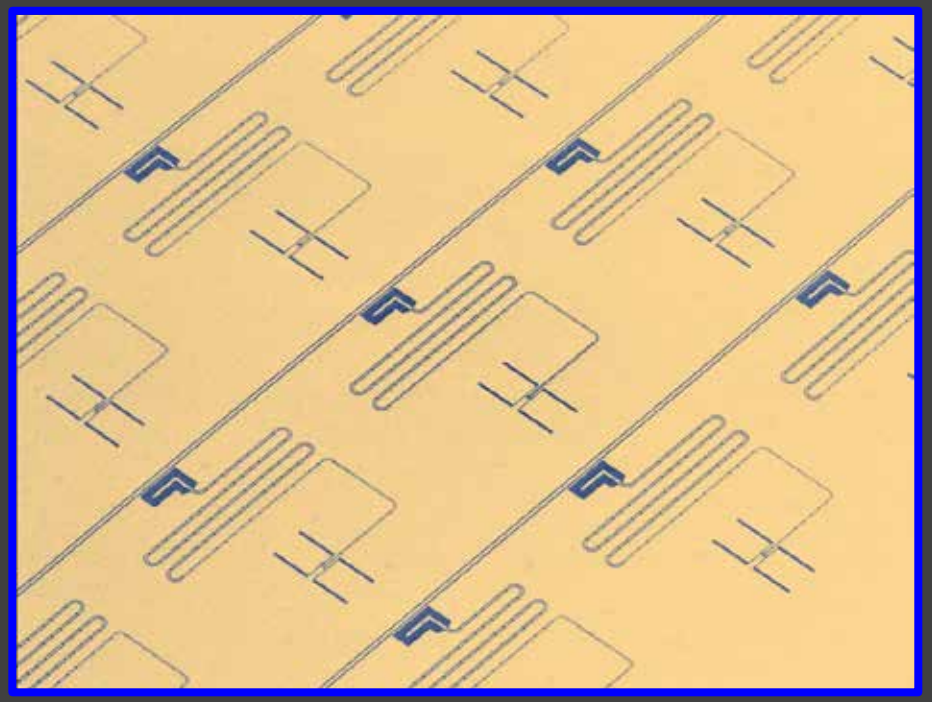
Hybrid antenna coupled MKID

Antenna – lens to absorb radiation

- Lens array
  - creates space for KIDs
  - High filling fraction
  - Focussing of radiation to antenna
- Si lens array + Parylene-C l /4 AR coating







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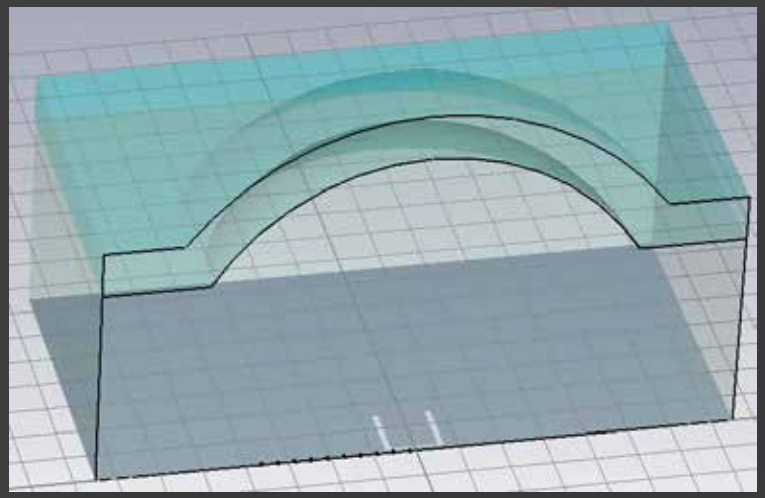
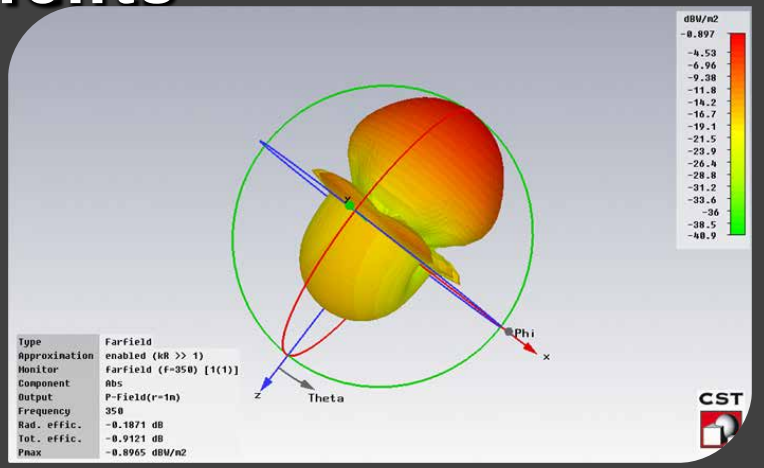
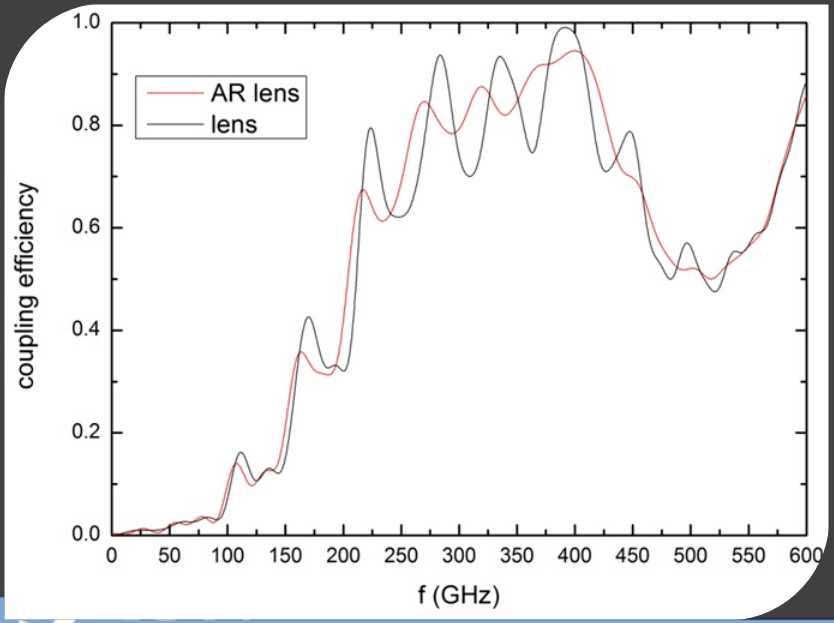
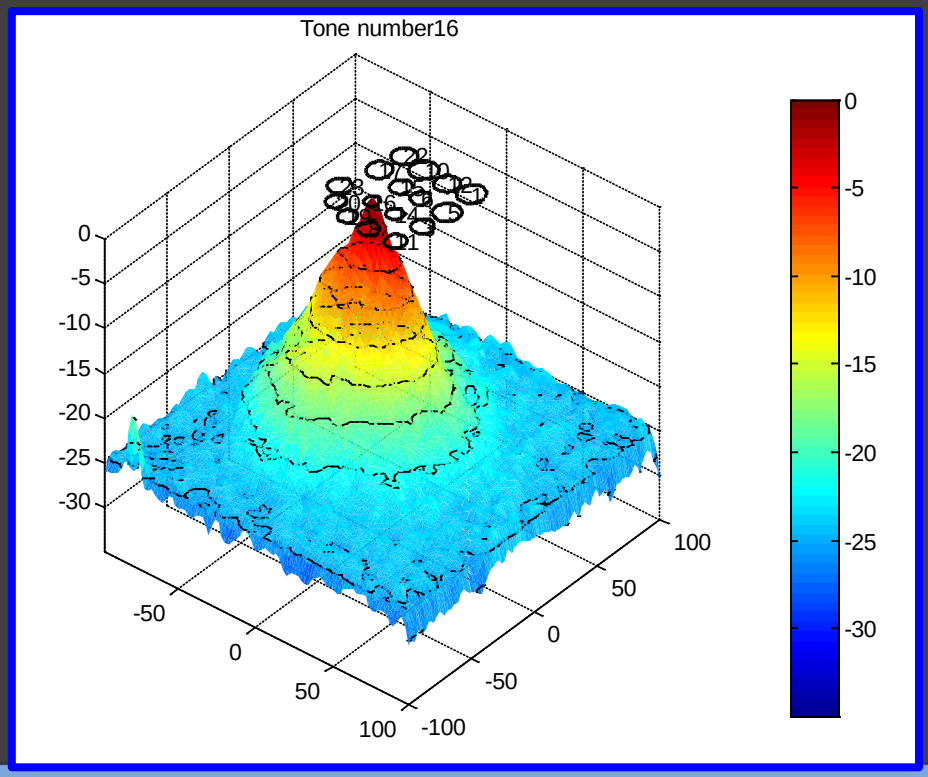
CST modelling + measurements

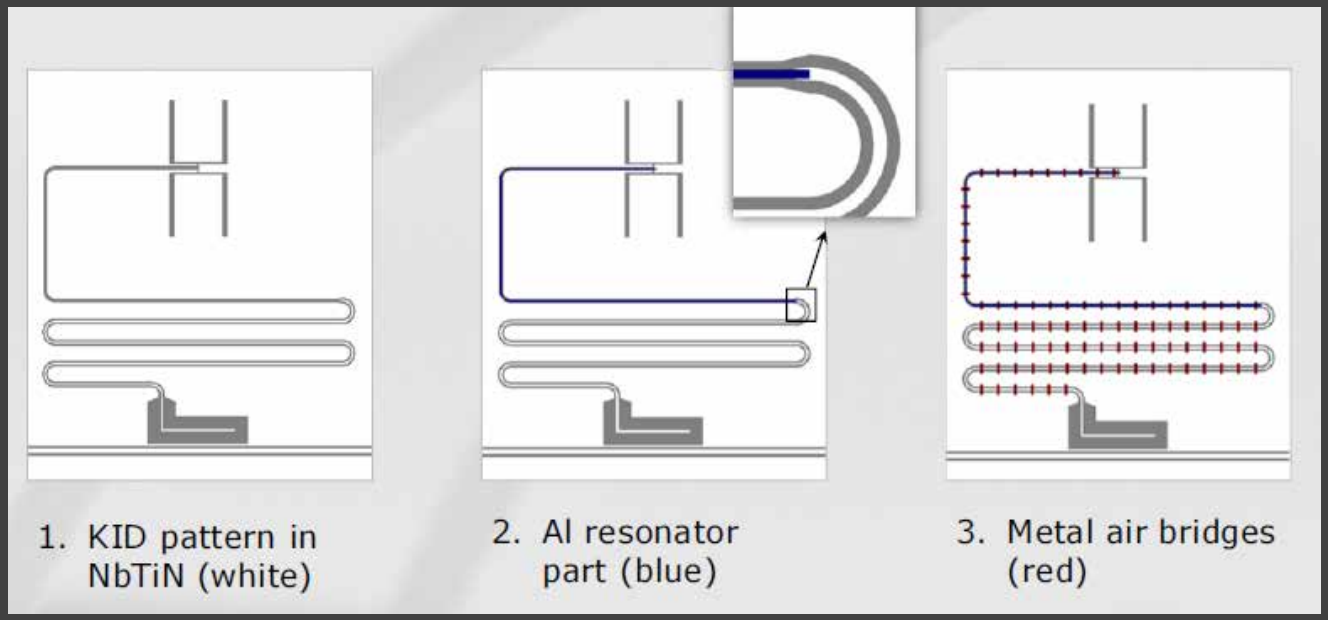








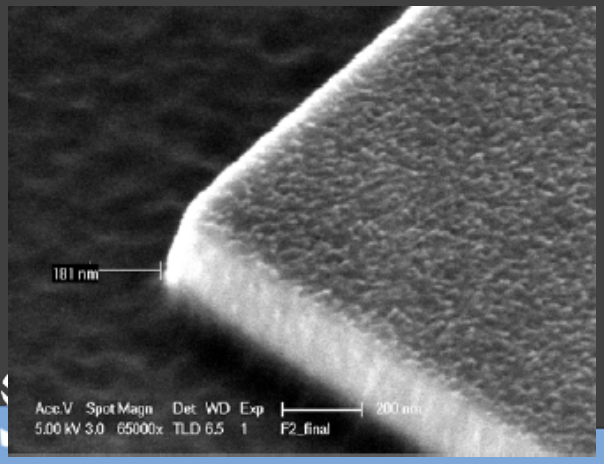
Fabrication – Hybrid KIDs on Si

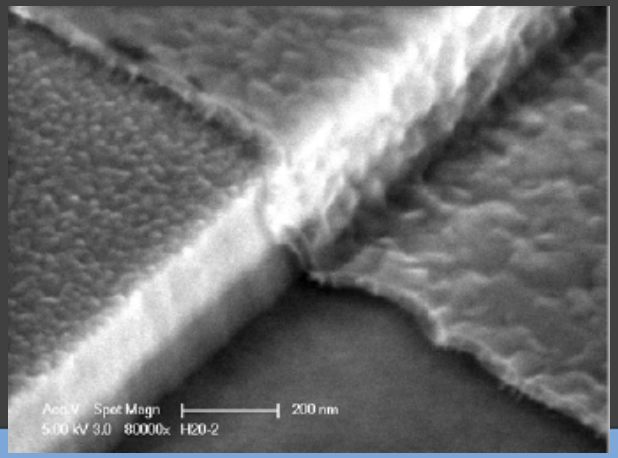


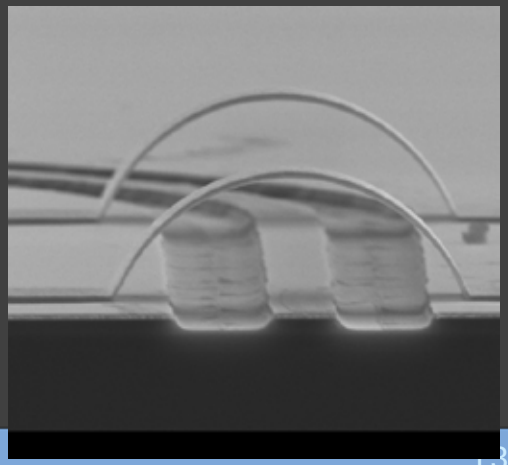
Dry etch 300 nm NbTiN
13.5 sccm SF_6
20 sccm O_2
65 ° slopes

50 nm Al sputter depo
Wet etch of excess Al
or
Lift-off process

250 nm Al sputter depo
On sacrifical resist layer
Wet etch to define bridges



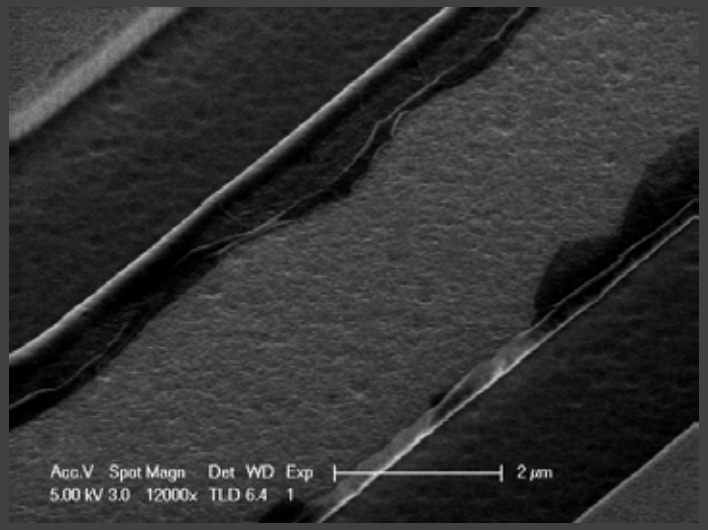


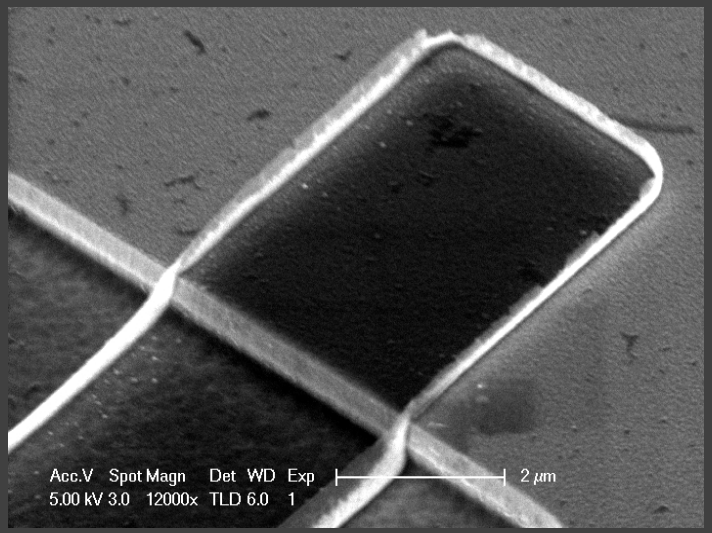


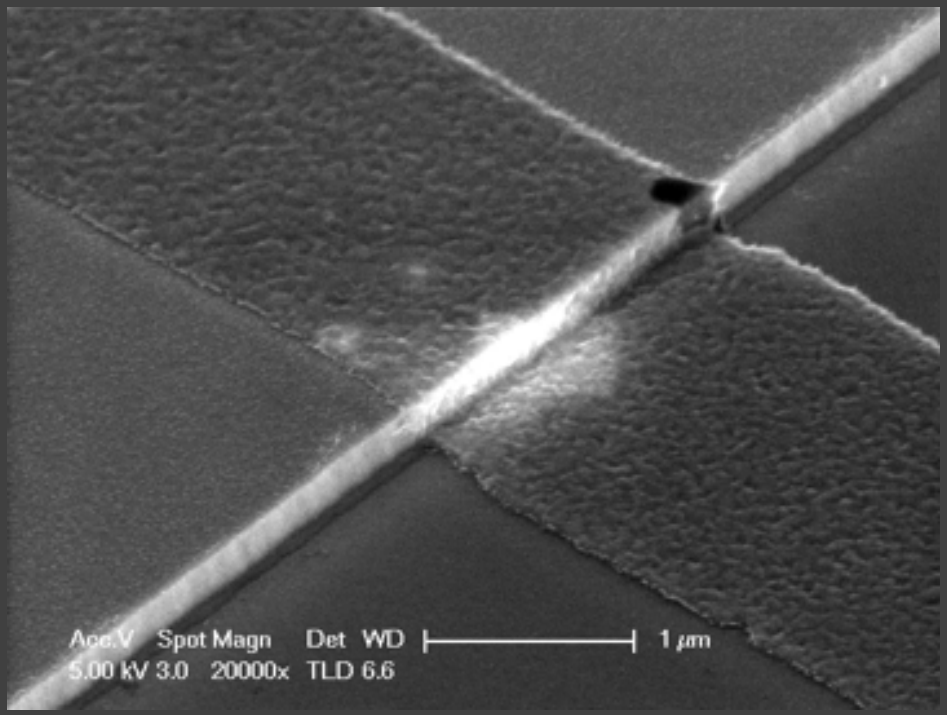
Fabrication: Al lift-off vs wet ecthing

Lift-off process (untill recent)
Hard to reproduce

Wet etch process







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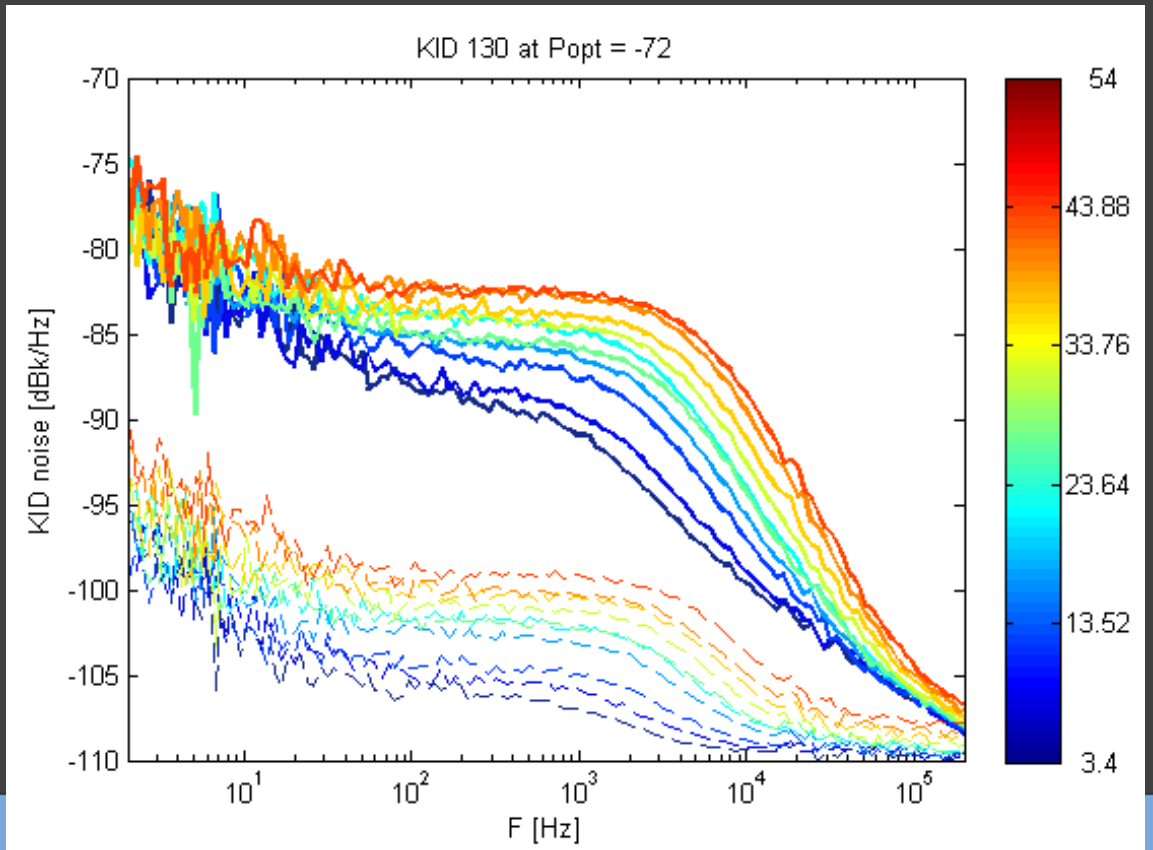
See Yates et al. http://arxiv.org/abs/1107.4330

Result

Hybrid KIDs with lift-off process

- Photon noise limited performance
- High optical efficiency
- But…. 1/f noise
  - Use amplitude readout -> too stringent requirements digital electronics
  - Reduce phase noise at low frequencies



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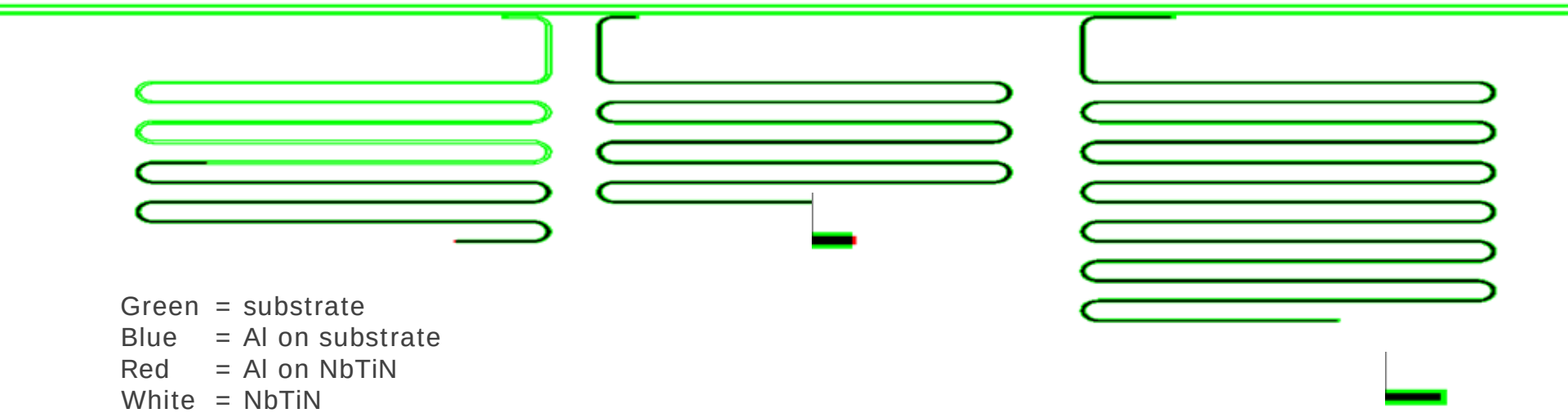
Test chip

- CPW resonators 3-2-3 mu wide
- Change the length of the Al section
- Also HW devices (without interface)



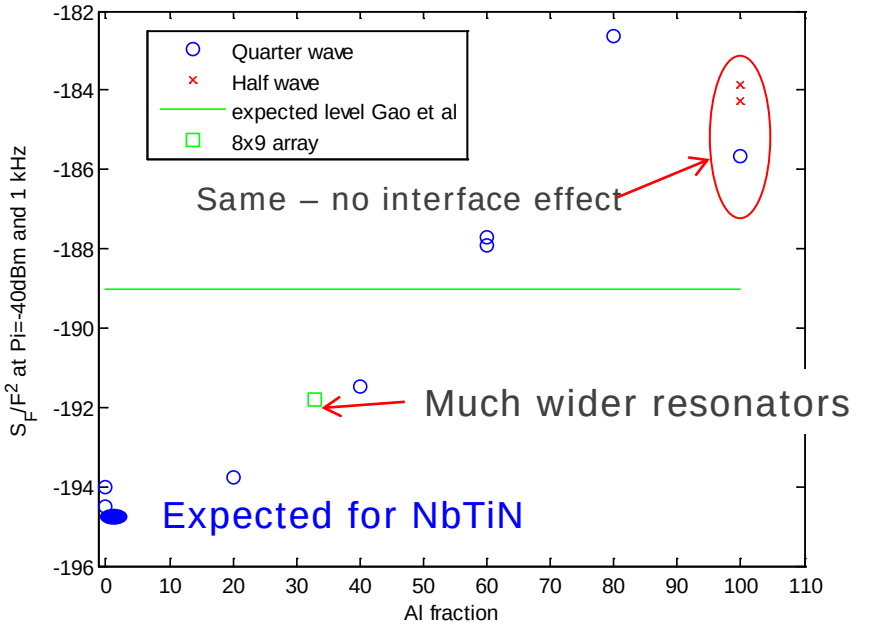
Green = substrate
Blue = Al on substrate
Red = Al on NbTiN
White = NbTiN

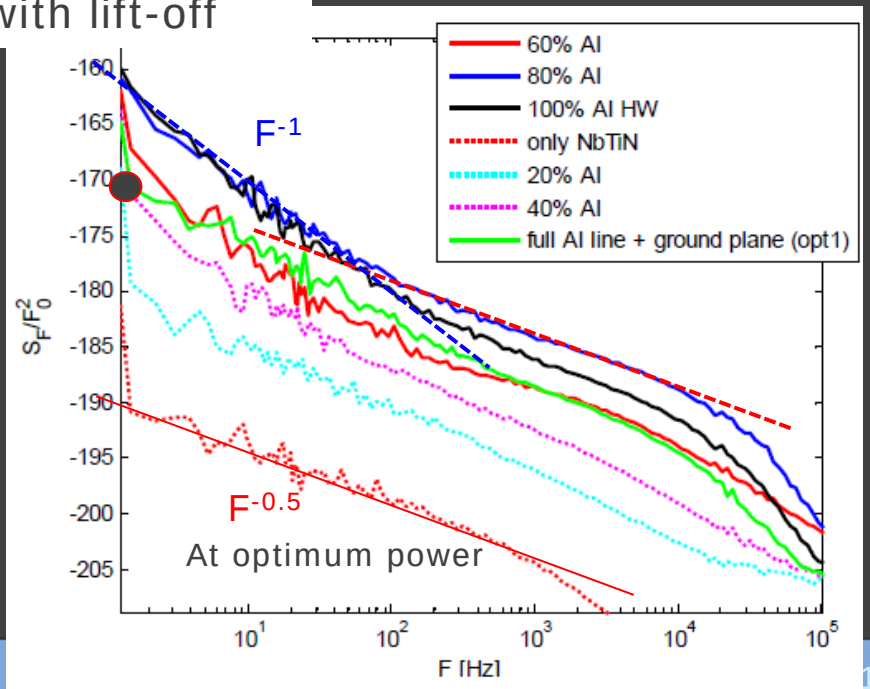
Test chip performance
Lift- off devices

1 min Ar+ RF cleaning prior to Al deposition, definition with lift-off

- No effect of interfaces
- Frequency noise determined soleley by Al
  - Widening NbTiN section has no influence
  - Noise scales with Al length
- Noise spectra with much Al have 1/F below 100 Hz
  - $F^{-0.7}$ for 100% Al on Si resonators

H15 batch made with lift-off



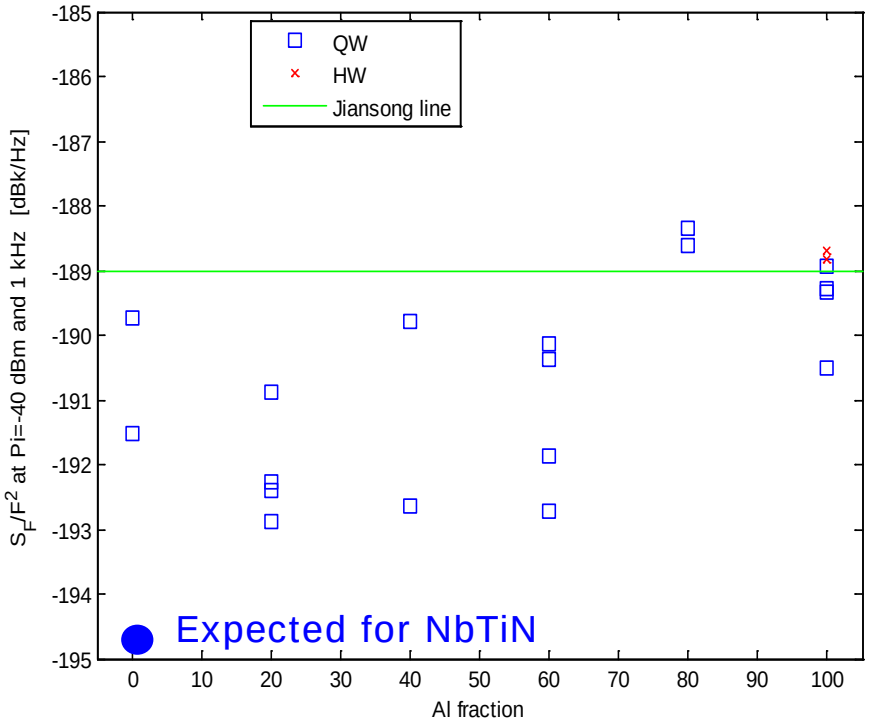


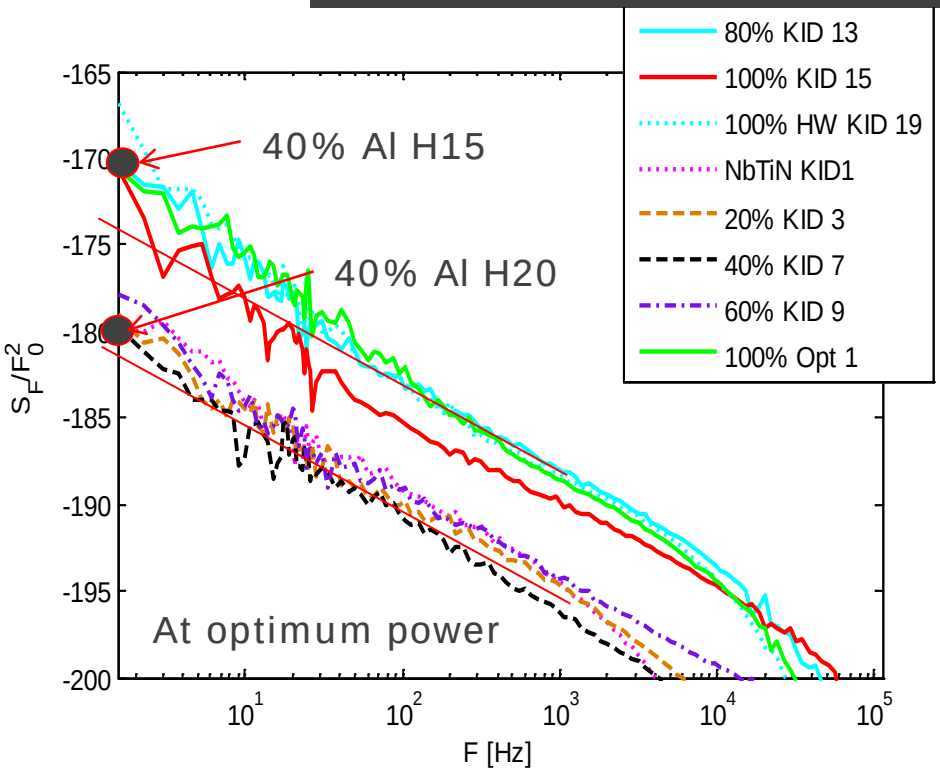
Test chip performance
wet – etch devices

No Ar+ etch prior to Al deposition, but buffered HF dip, definition wet etch

- Frequency noise only weak function of Al length
- Noise level higher for pure NbTiN resonators
- Hybrid frequency noise low, especially at low F: – 10 dB at 1 Hz

H20 batch made with lift-off





System test for A-MKID test camera

He7 test cryostat

goretex @ 300K

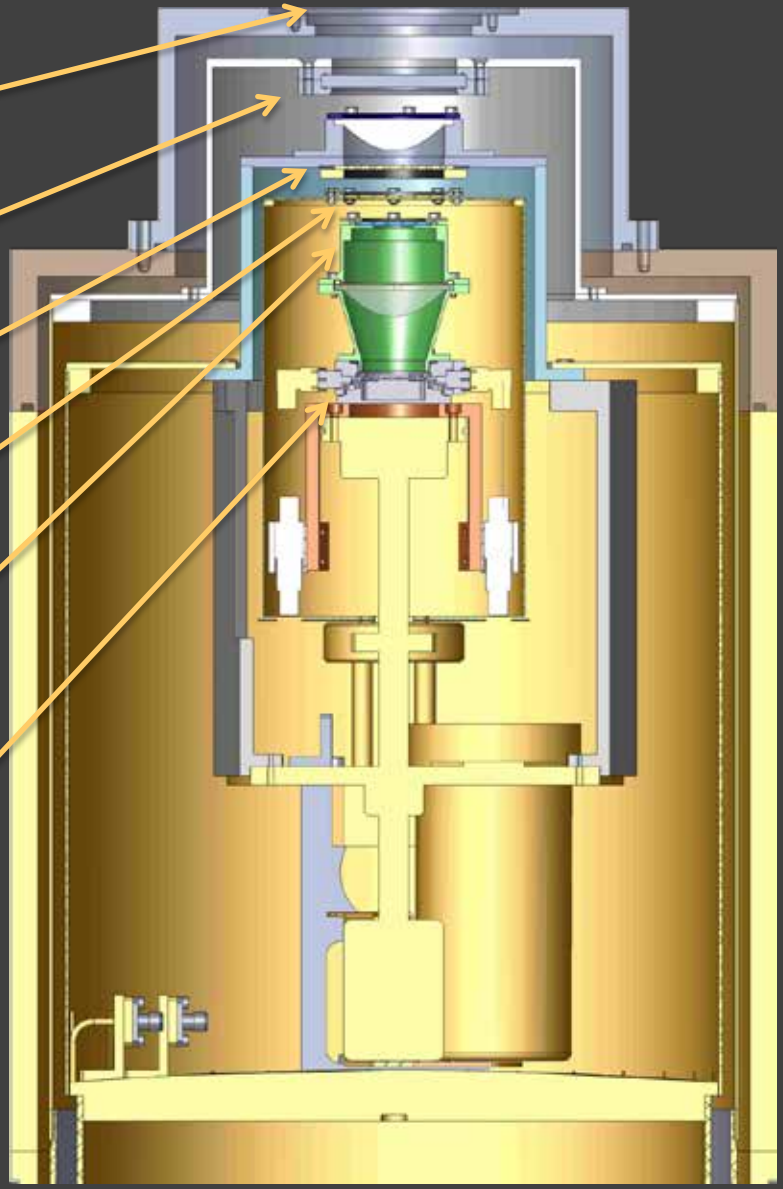
LP filter 0.8 THz @ 77K

LP filter 0.6 THz @ 4K

LP filter 0.4 THz @ 1K

BP filter @ 0.3 K

Detector array



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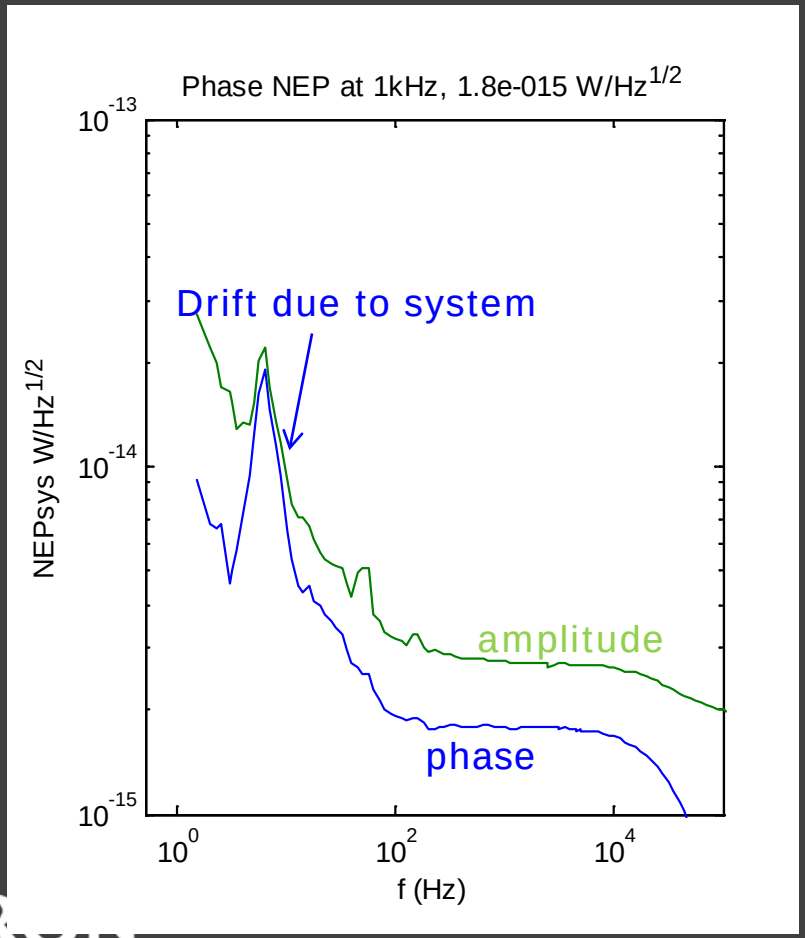
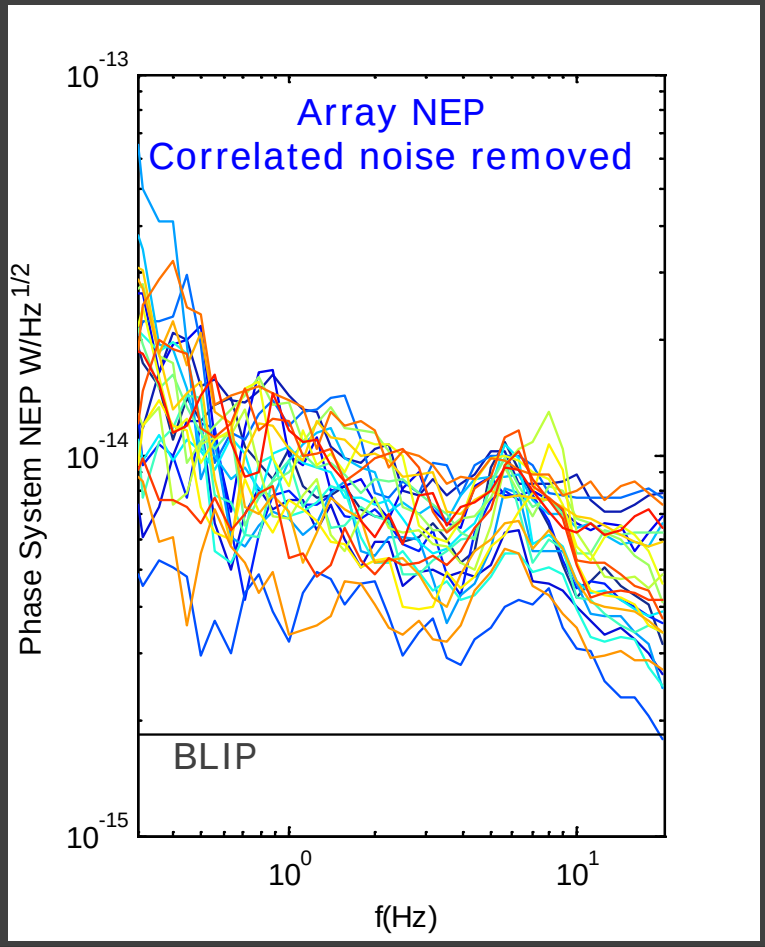
System test for A-MKID test camera

H20 with etching full system measurement

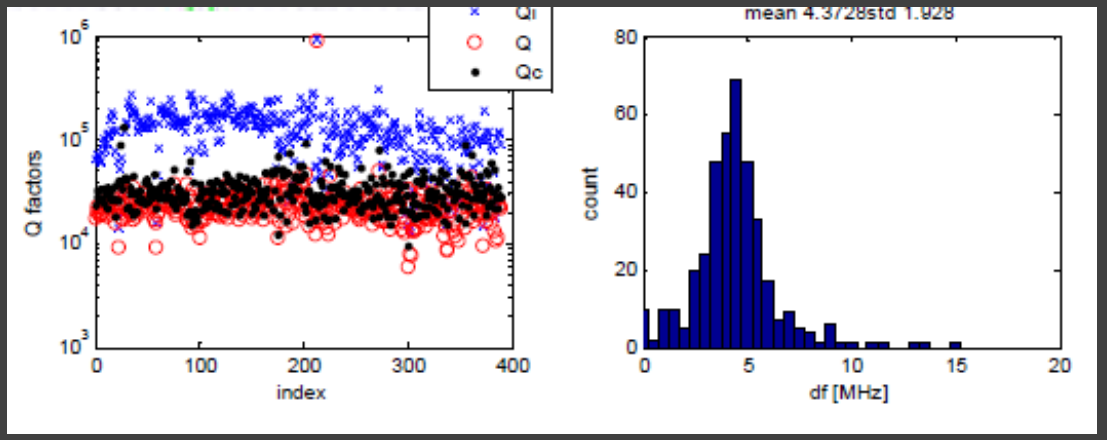
- 1/f significantly reduced
- 1/f noise is now from the system and can be (partly) removed

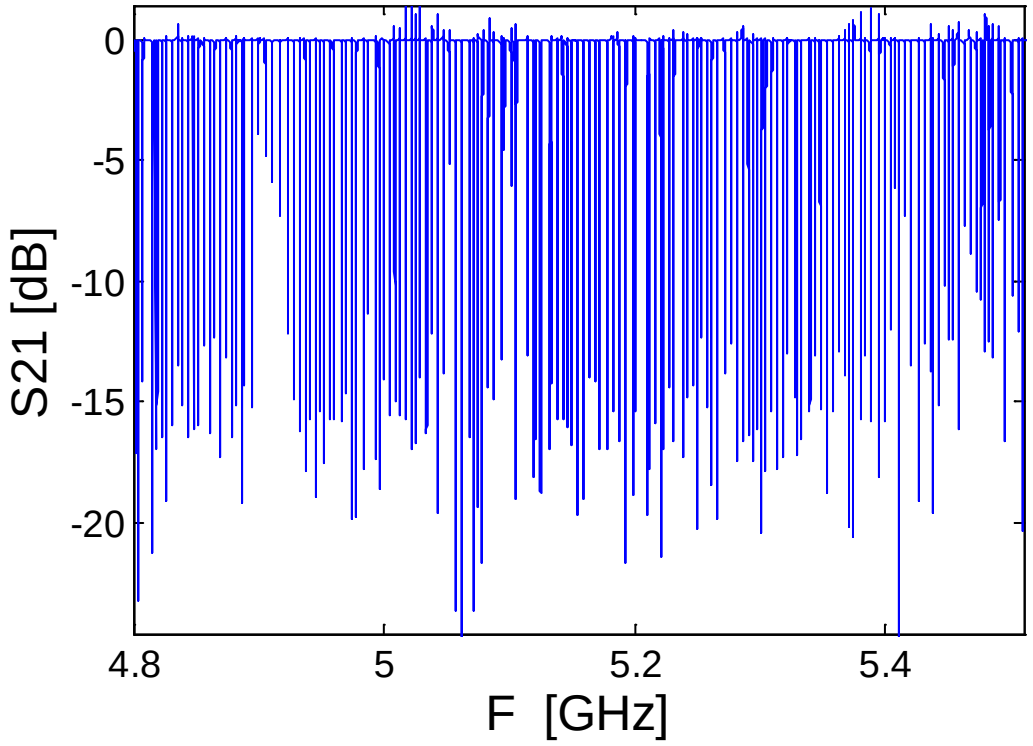


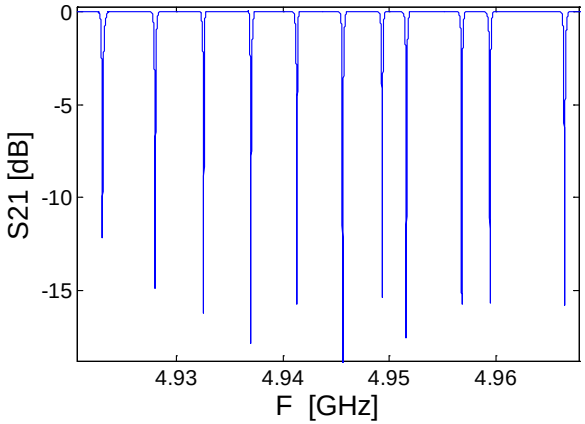


F spacing

- 4±2 MHz dF
- Q=20.000
- Only for large arrays!

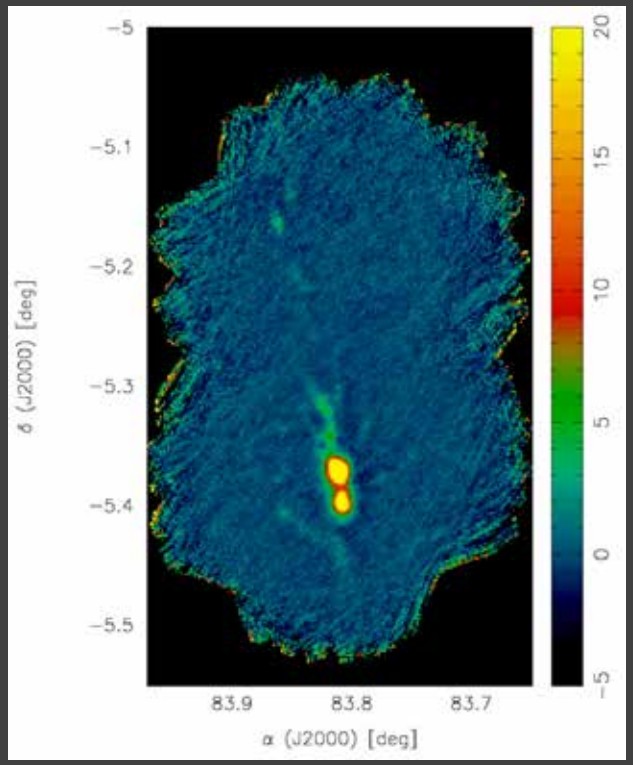






Conclusions

- We are developping large arrays for the A-MKID camera and NIKA
  - Noise properties differ from 1 layer KIDs, especially at low F
  - NbTiN-Al interface does not play a role
- Devices are photon noise limited at high modulation frequencies
- Approach BLIP in band of operation



Results

H10 with lift off measured with cryogenic BB

- Photon noise limite performance
- 1/F from the device dominates below 10 Hz