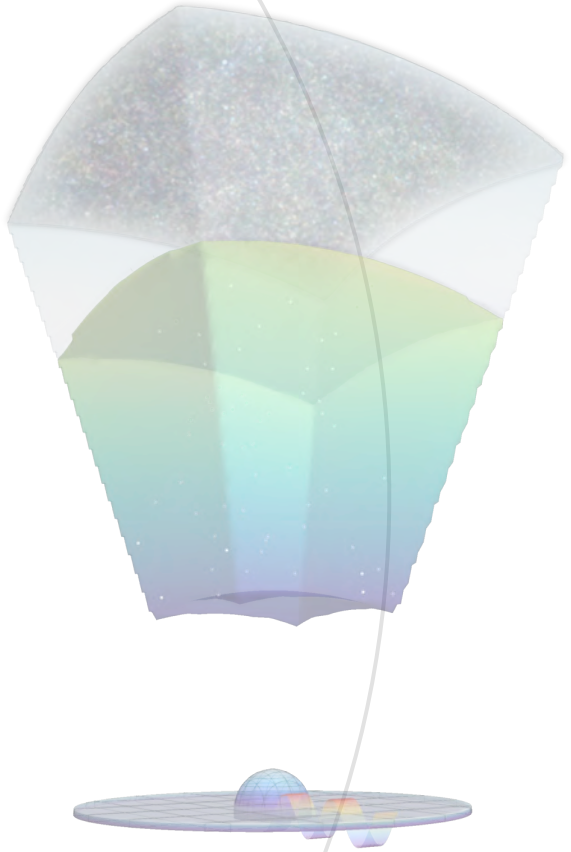
DESHIMA

on-chip imaging spectrograph based on MKID technology



arXiv:1107.3333v1 [astro-ph.IM]

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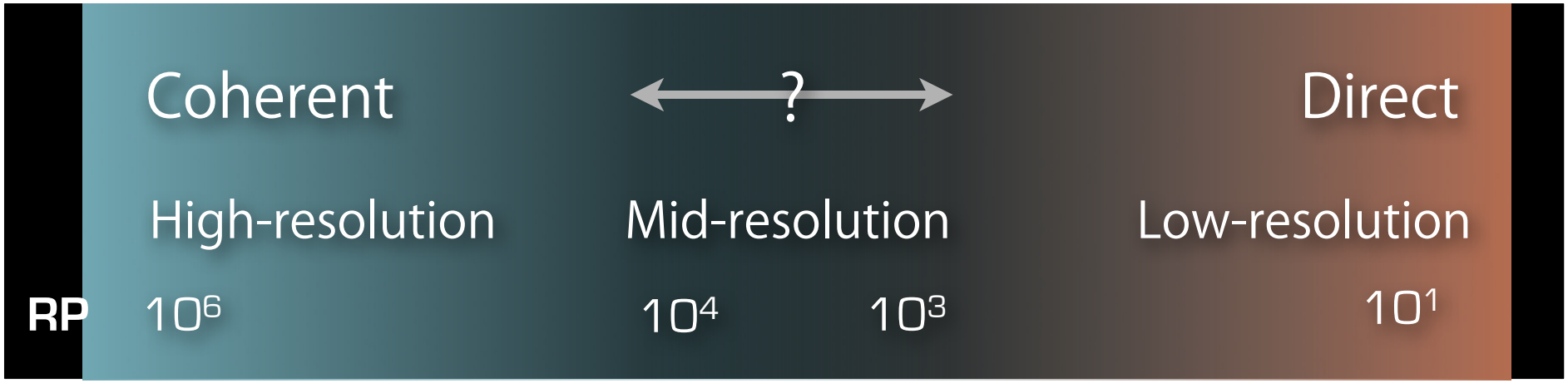
Cosmology with Nanotechnology

Coherent v.s. Direct detection



- Recent advances in direct detection technology:
  - Exponentially growing number of detectors [>10,000]
  - Improving sensitivity (detector noise limit → photon noise limit)
  - Spectrometers using on-chip transmission line technology

Approach from the coherent side as well!

Coherent v.s. Direct detection

- Photon-noise limited direct detector v.s. nearly-quantum noise limited coherent receiver
- Sensitivity

$$\mathrm{NEFD_c} = \frac{2\sqrt{2}kT_{\mathrm{sys}}}{\eta A\sqrt{B}} \qquad \mathrm{NEFD_d} = \frac{\sqrt{2kT_{\mathrm{eff}}hf}}{\eta A\sqrt{B}}$$

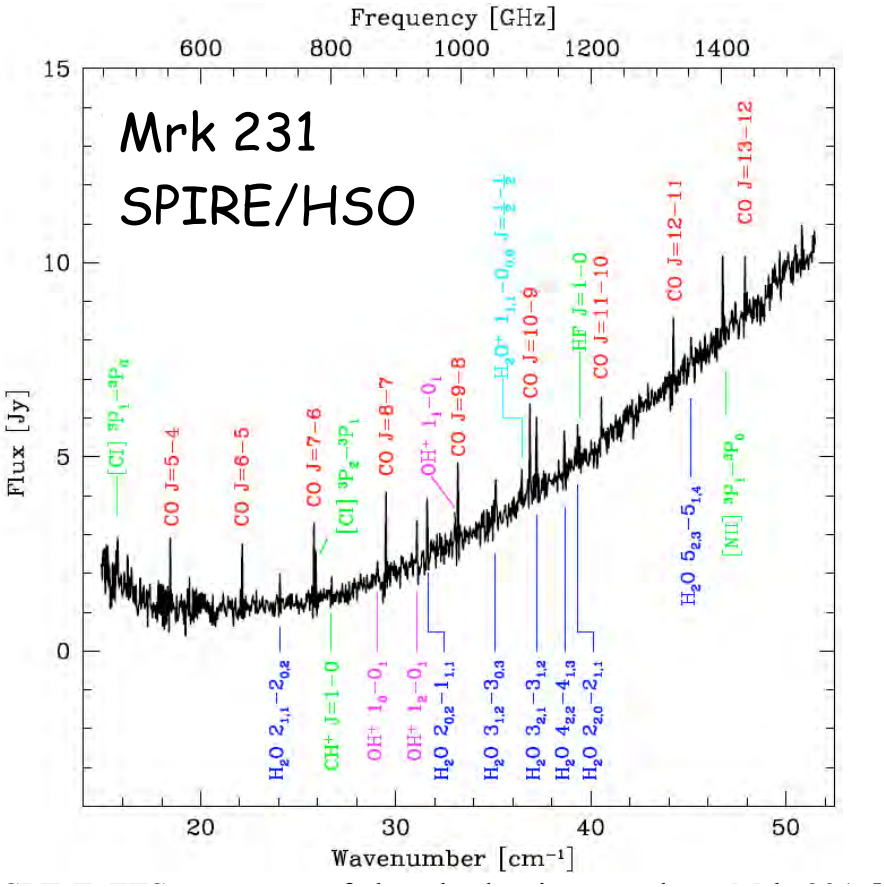
$$R = \frac{\mathrm{NEFD_d}}{\mathrm{NEFD_c}} = \frac{\sqrt{T_{\mathrm{eff}}hf}}{2T_{\mathrm{sys}}\sqrt{k}}$$ ~ 0.1, but η can bring it up to ~ 1.

- R does not depend on bandwidth B, but practically difficult to achieve RP >> 10^3 with direct detectors without scanning, and difficult to achieve bandwidth B >> 10 GHz with coherent detectors.

Direct detection spectroscopy

- Broad instantaneous BW
  - ~100 GHz with grating
- Low resolution: RP ≡f/df ≈ 10^3
- Difficult to achieve high RP
  - Size of optics ≈ RP × λ

    ~30m @ λ = 300 μm & RP = 10^5

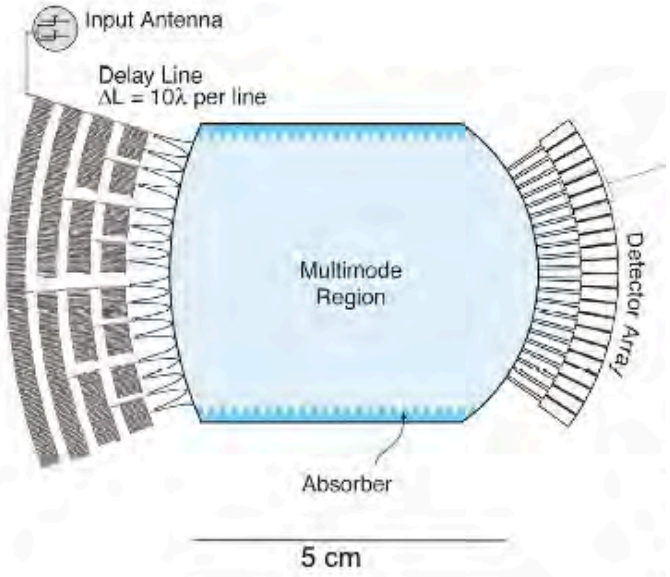


Van der Werf, P. et al. 2010, A&A, 518, L42

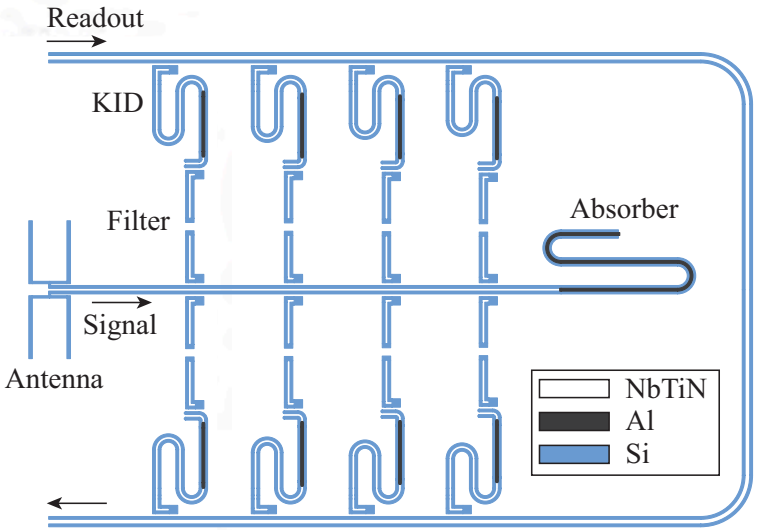
On-chip direct detection spectrometers

- Structures for shrinking the size of the 'optics' to combine high RP, high sensitivity, very broad BW, and compact instrument size

Delay line spectrometer (Moseley et al.)

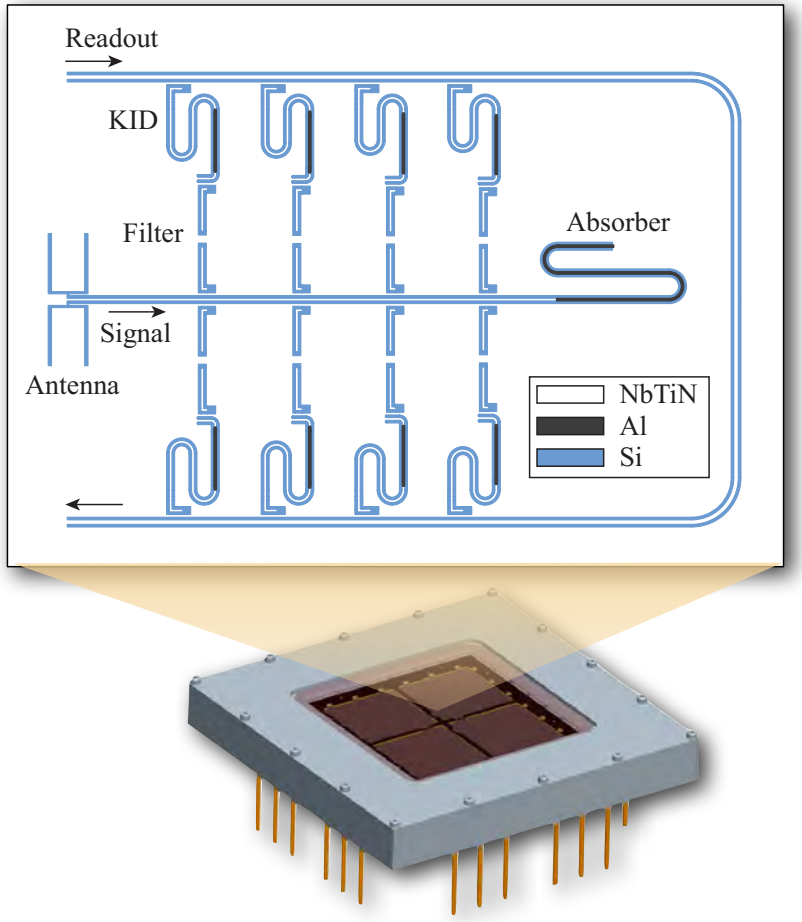


Filterbank Spectrometer (Endo, Barry et al.)

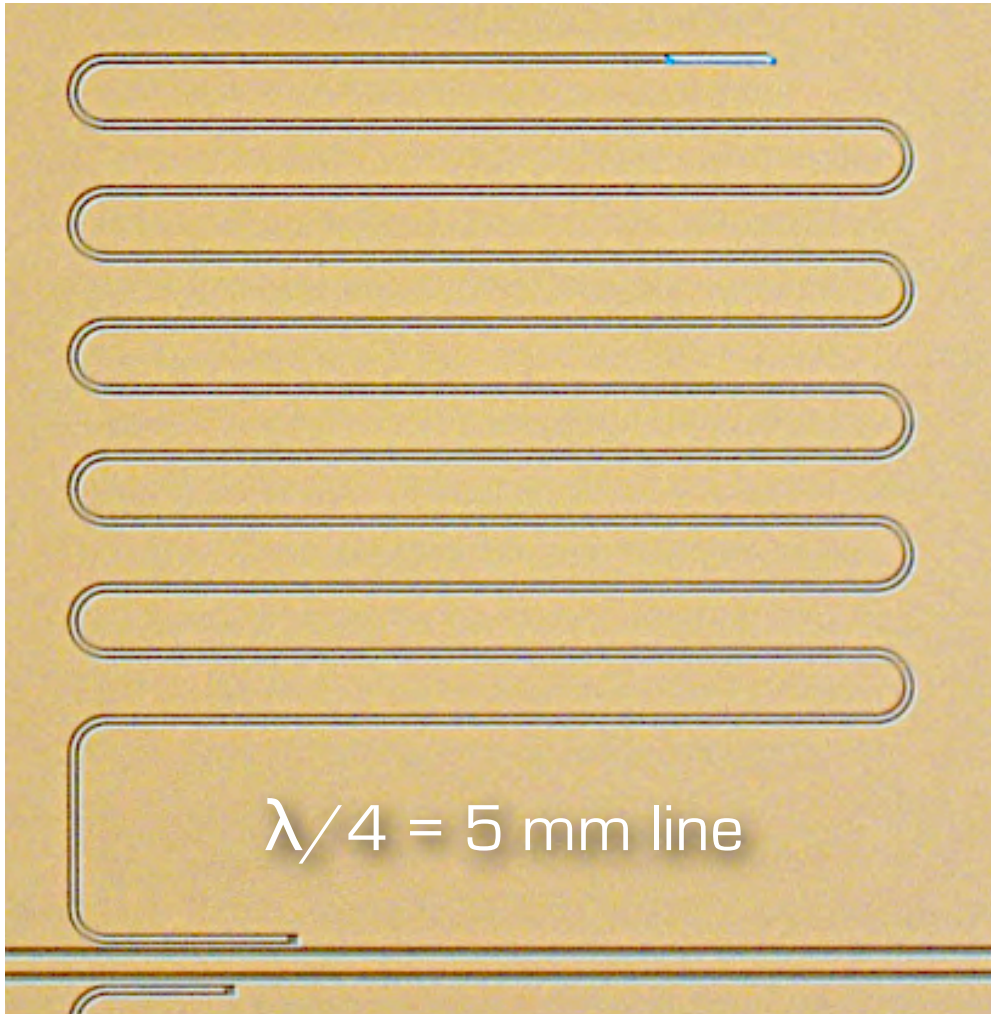


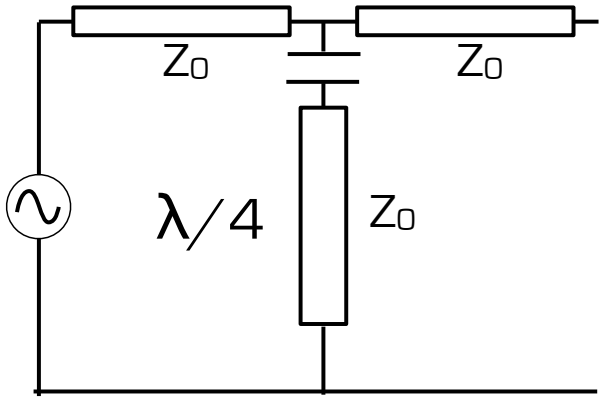
DESHIMA: On-chip Imaging Spectrometer using Superconducting Resonators

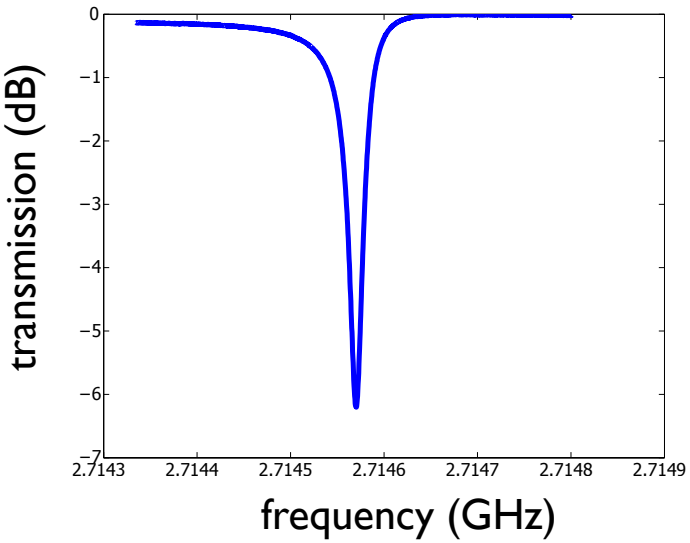
- DESHIMA: Delft SRON High-z Mapper
- Uses superconducting resonators as detectors and as a filterbank
- Goal performance:
  - Instantaneous coverage of 320-950 GHz
  - RP: f/df = 1000
  - 9 pixels
  - Photon-noise limited sensitivity
- 8000 MKIDs in total



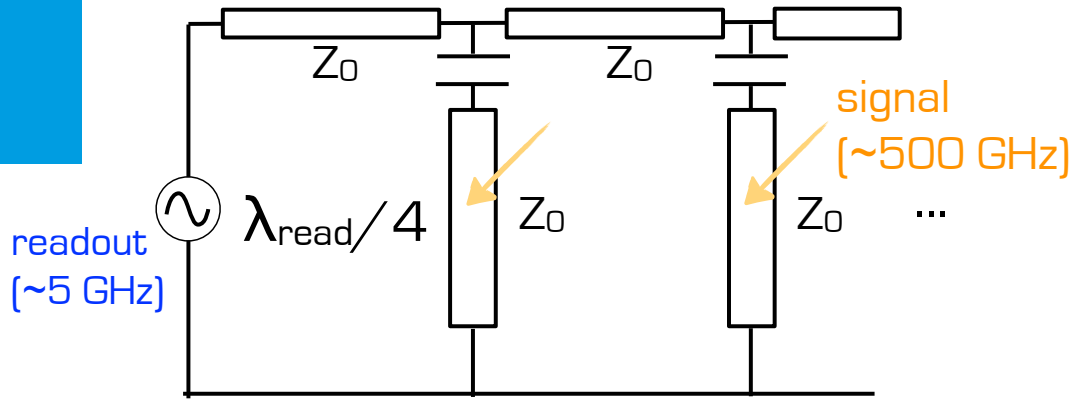
Key element: Superconducting Resonator

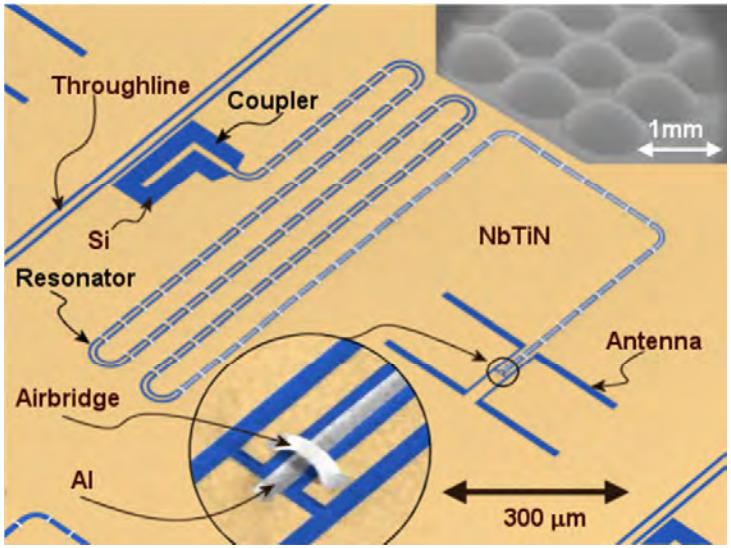


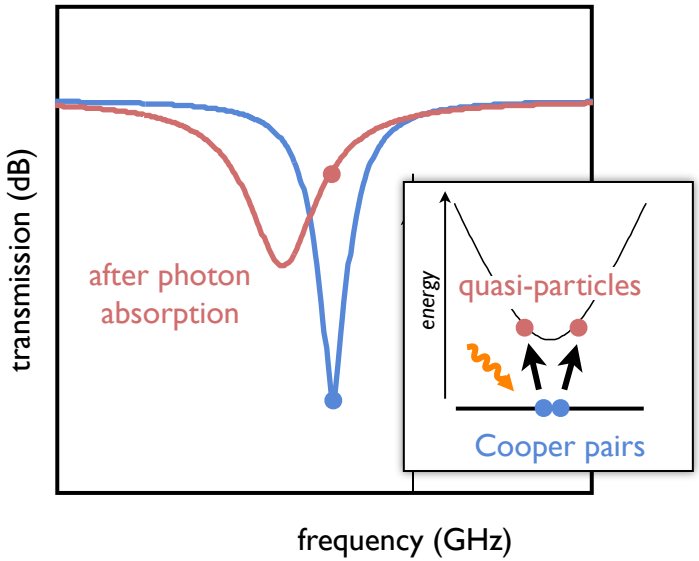




Microwave Kinetic Inductance Detectors (MKIDs)

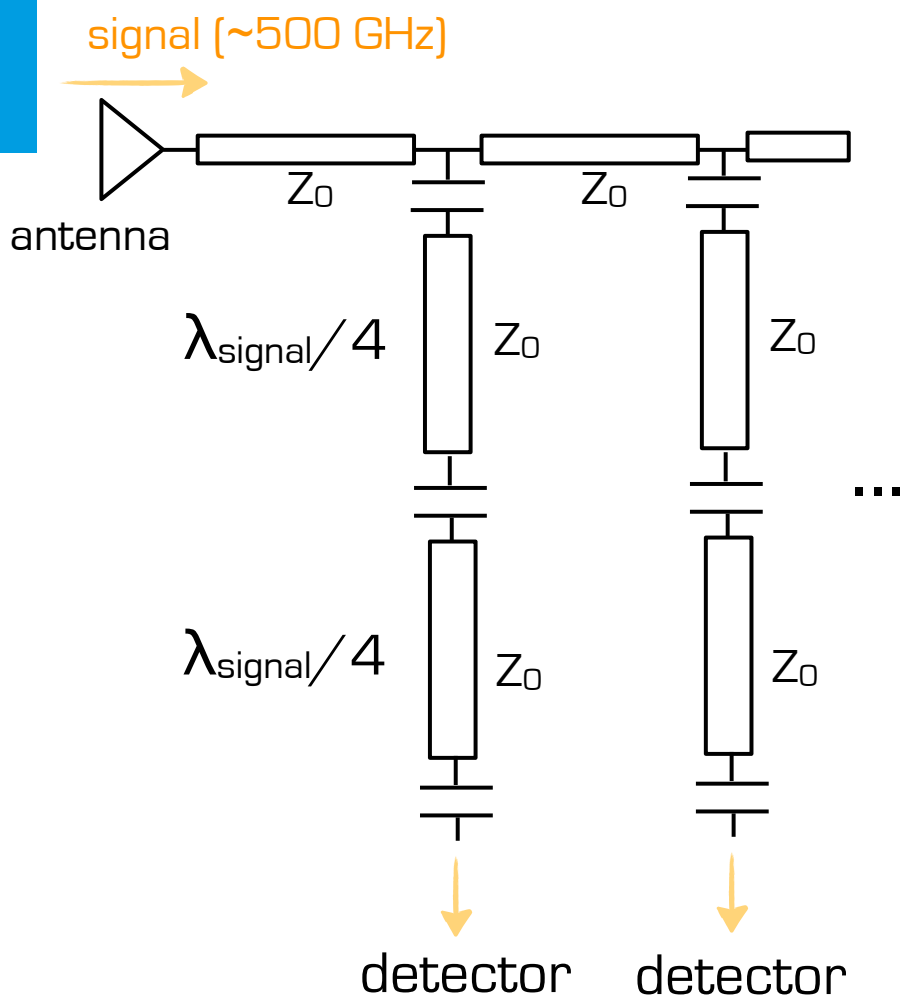


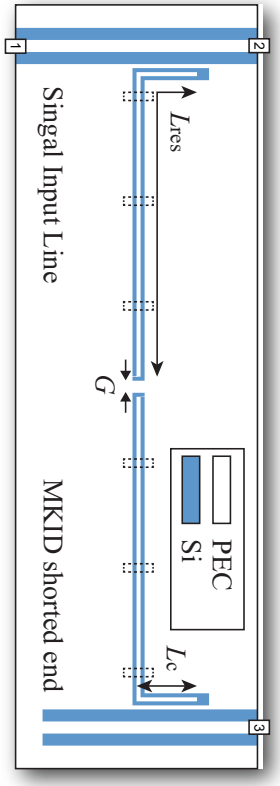


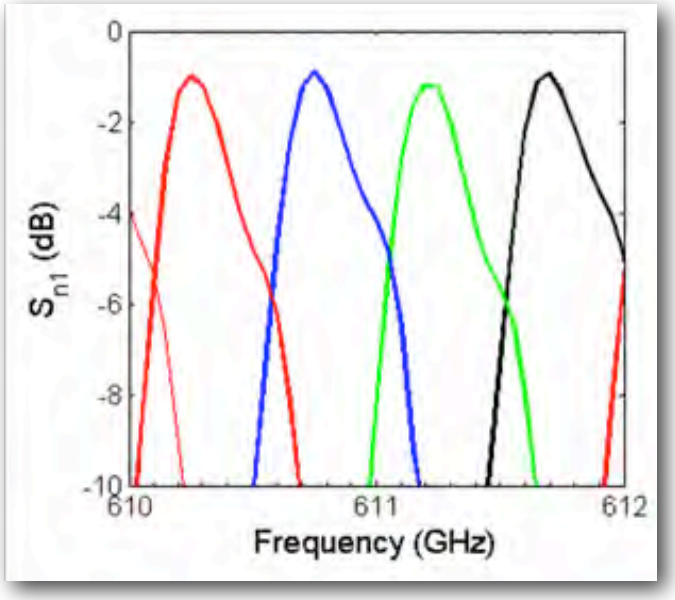


- Photon noise-limited NEP demonstrated down to loading powers ~ 100 fW
  (~ RP=10^3 on ground)

On-chip Filterbank

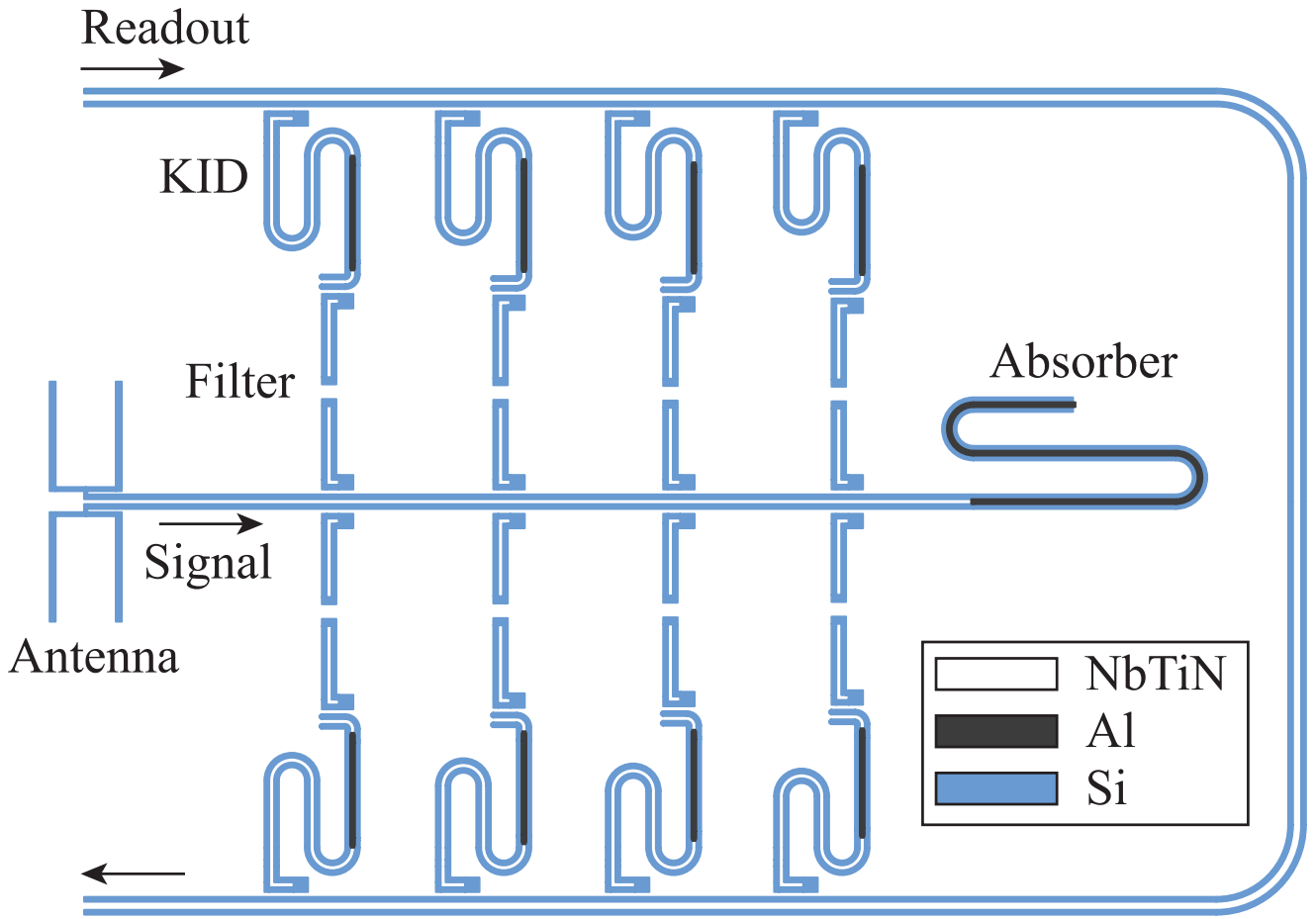






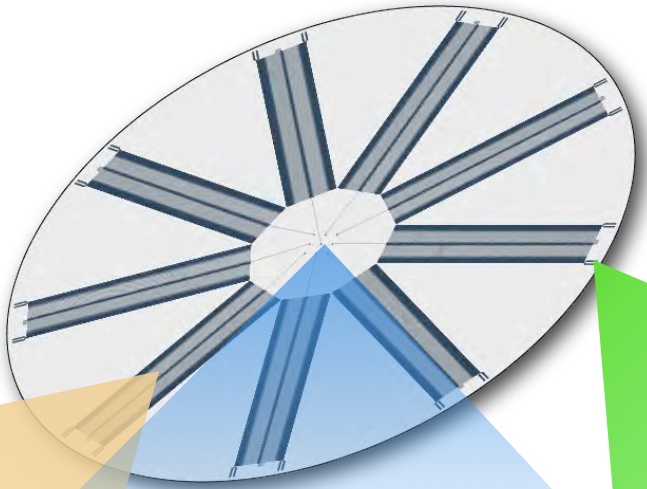
RP ~ 10^3

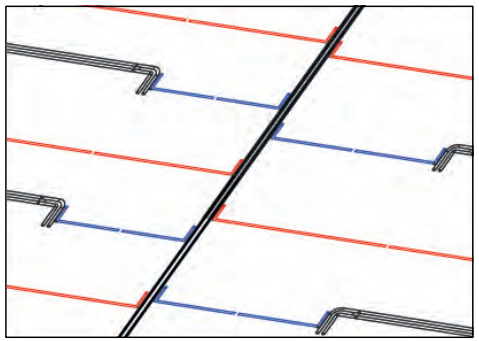
MKIDs and filter bank combined



GOAL: 920 channels / 1 antenna

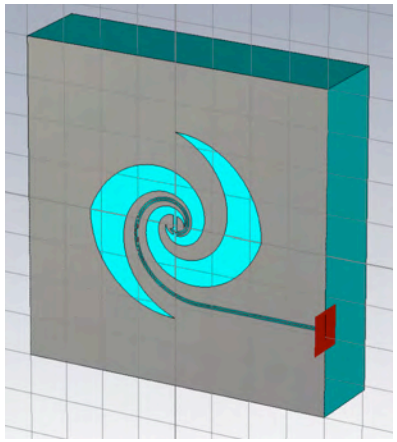
DESHIMA on a 4-inch Si Wafer



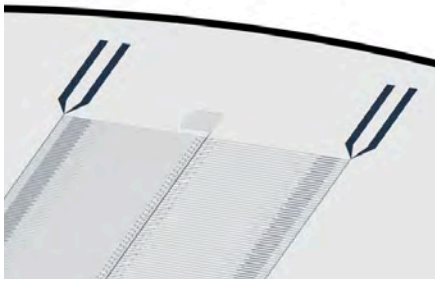


920 color filterbank

(320-475 and 600-950 GHz)



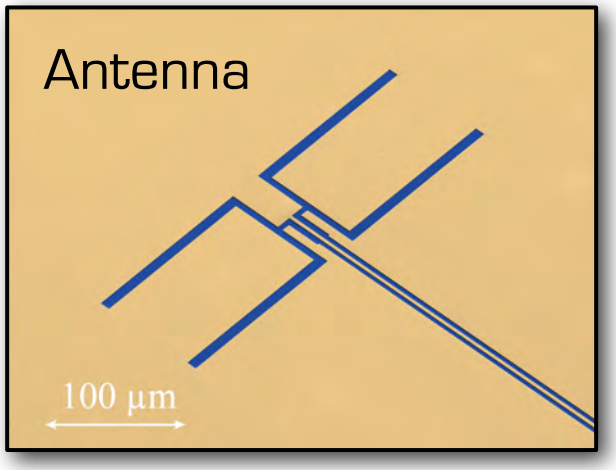
antenna x 9

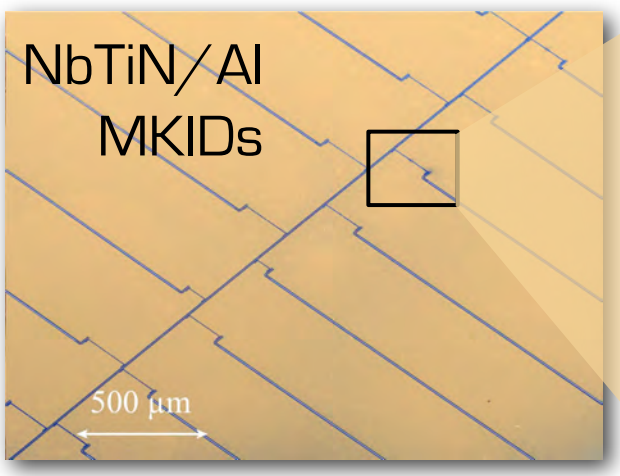


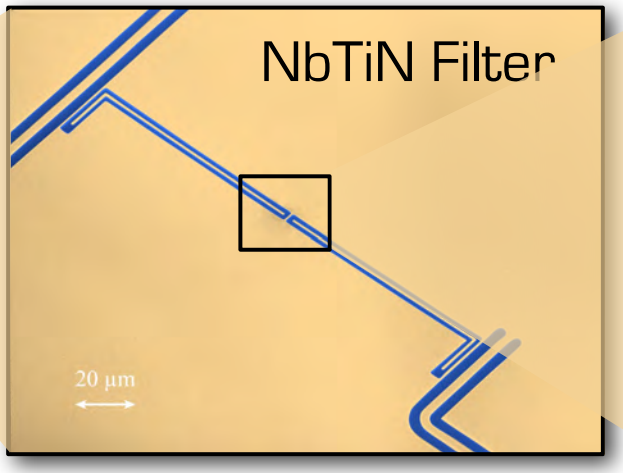
readout ports

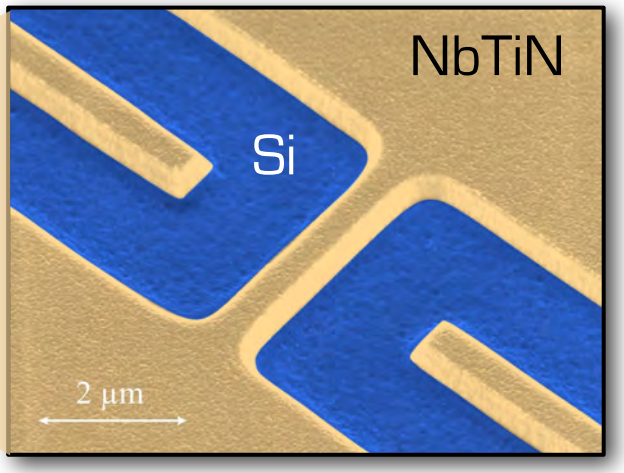
First Chip for Lab Demonstration

- Designed for the 650 GHz band
- Fabrication uses the same technology as MKID imaging arrays
- Electron beam lithography and dry etching for the filters
- First evaluations undergoing at SRON



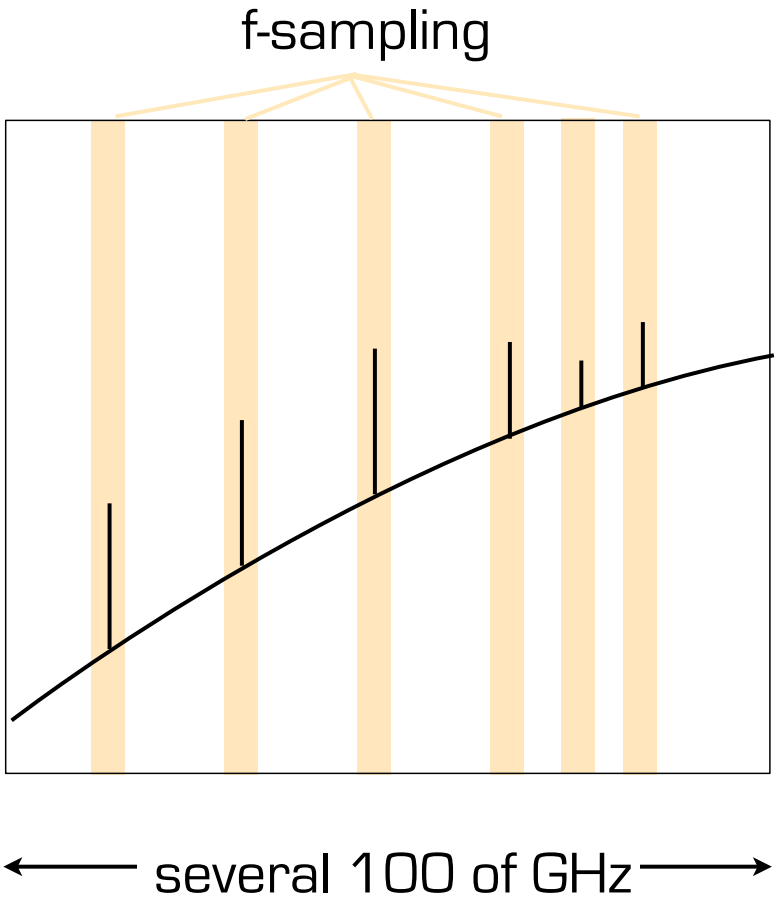






New observational modes using on-chip direct detection spectrometers

- Simultaneous observation of discrete frequency bands distributed over 100's of GHz (e.g., CO ladder)
- Z-machines with very broad instantaneous bandwidth (e.g., 350-950 GHz, 1000 colors x 10 pixels)
- Blind survey machines with limited BW but many pixels (e.g., 100 colors x 100 pixels.)



Conclusion

- Advances in technology are making the boundary between the territories of coherent and direct detection methods less obvious.
- On-chip direct detection spectrometers like DESHIMA could offer RP's as high as 10^4 with very wide bandwidth, opening up new modes of observations on CCAT.