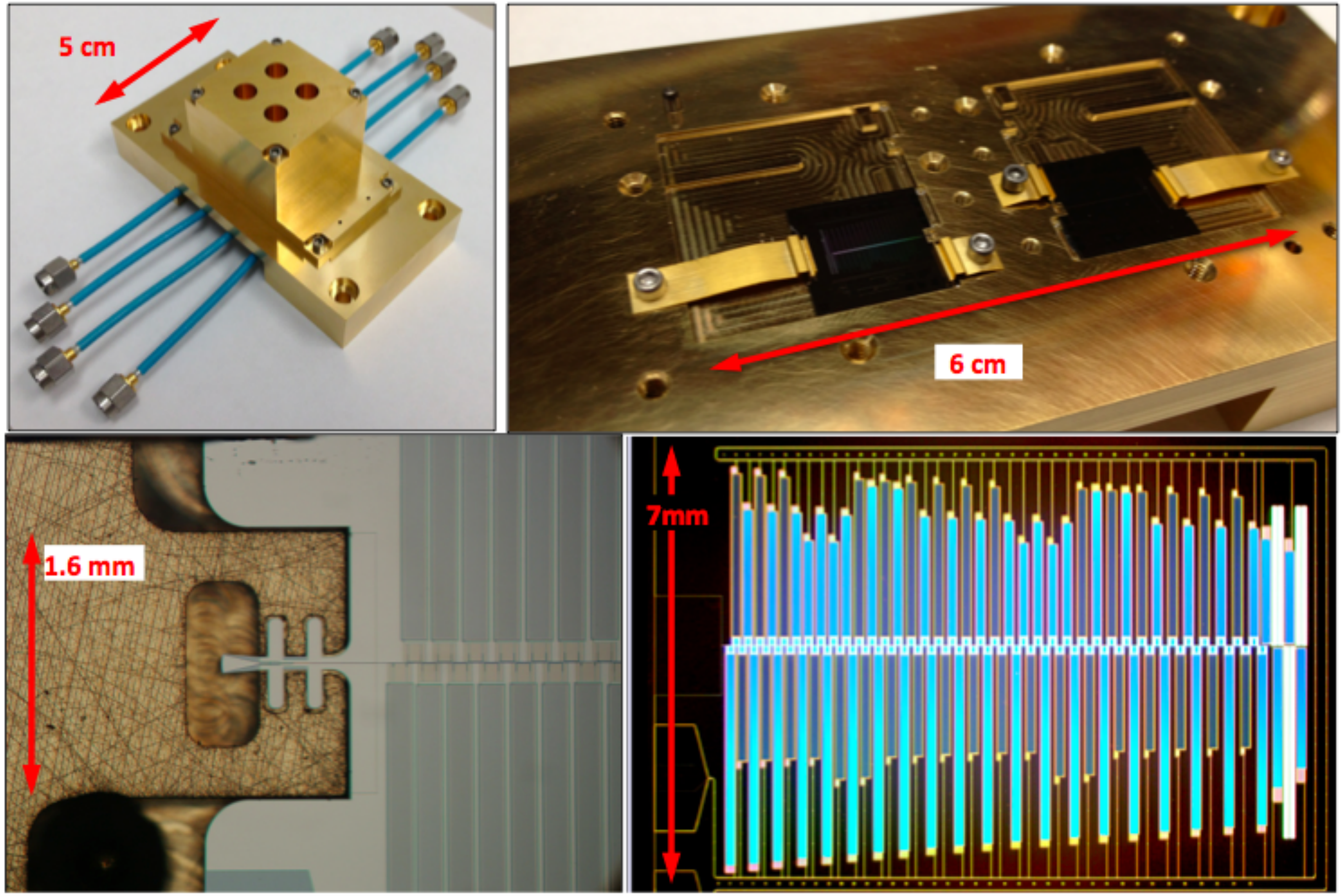
# SuperSpec an on-chip Spectrometer

Simon Doyle on behalf of the SuperSpec consortium

Cardiff University



# If it is not broke….then don't try and fix it!

Talk essentially finished → Fine tuning → Talk re-write begins

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**Lesson learned !**

# The SuperSpec Team

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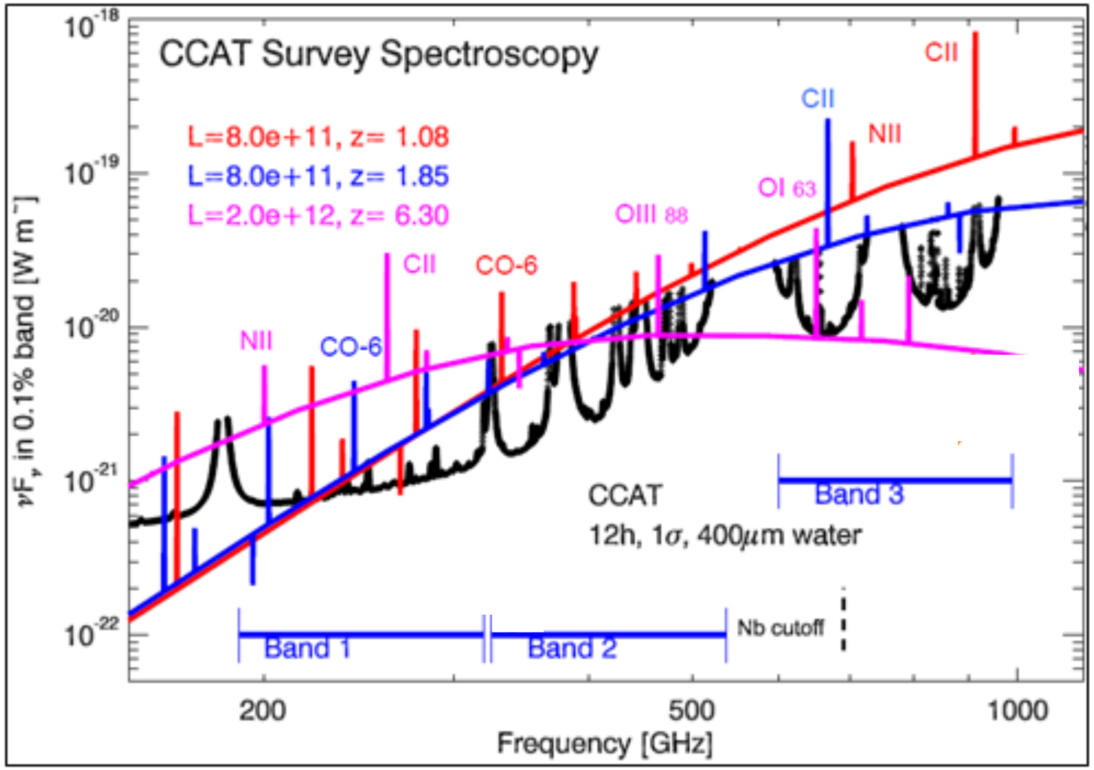
# By measuring CII (and CO) lines in high-redshift galaxies, efficient R~700 mm-wave spectrometers will enable:

- Redshift-finding for continuum sources to measure the high-z luminosity function and rate of star formation
- Measuring gas evolution through CII and CO / continuum ratios

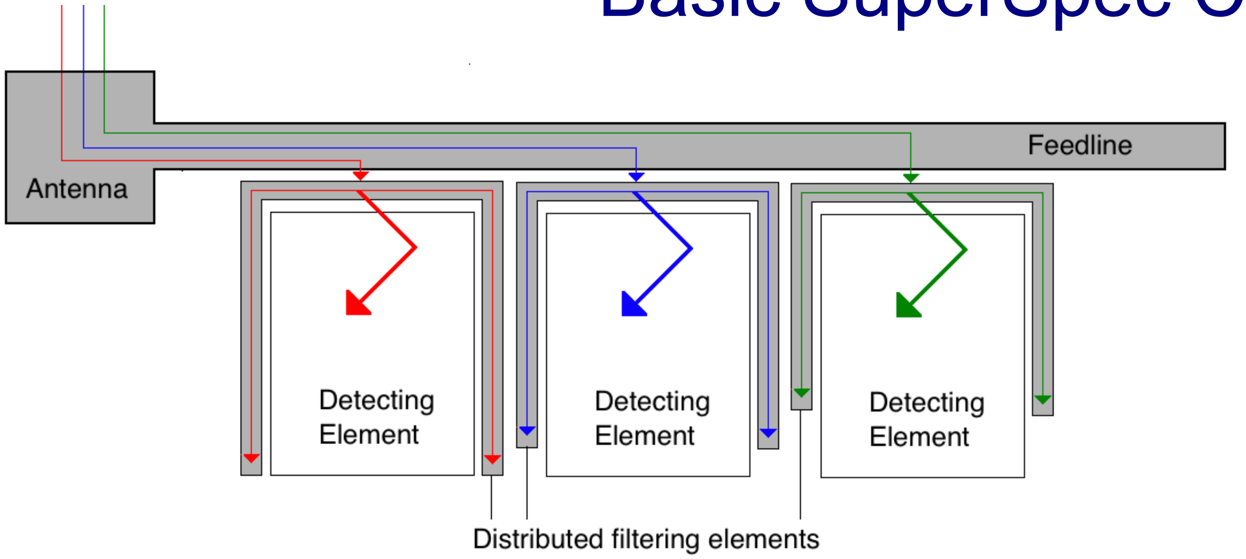
- Measuring the galaxy power spectrum, P(k), at z>4

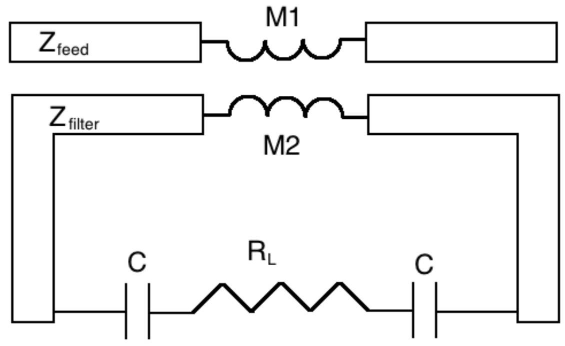
Source by source measurement with ALMA will be inefficient requiring several re-tunings to cover the 195-305 GHz spectral window.




(Image: C.M. Bradford)

# Basic SuperSpec Concept



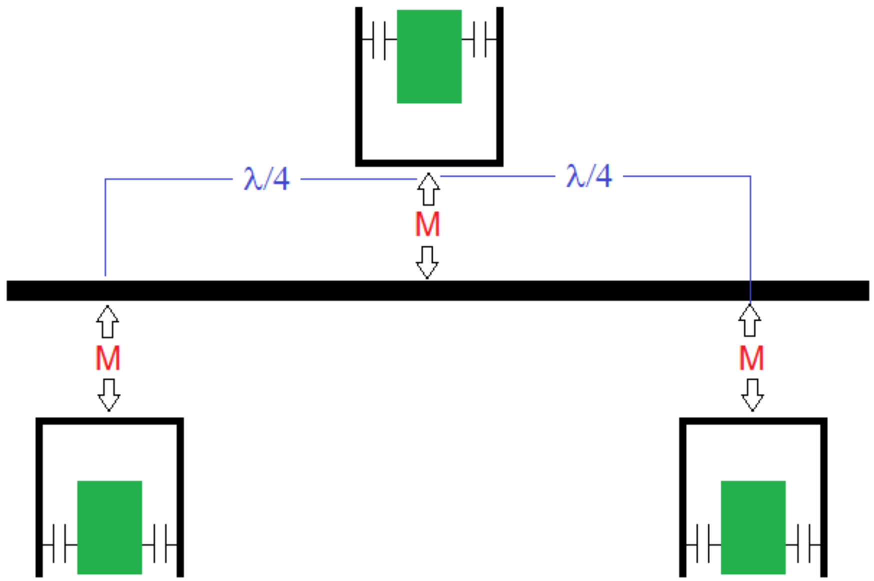




- Large number of ultra sensitive detectors ≈ 600 detectors per pixel for R=700 to cover 195-305 GHz atmospheric window – Kinetic Inductance Detectors.

- Low loss high frequency transmission lines and antenna structures – Niobium ($\nu_g \approx 700$ GHz) on low loss substrates such as $Si_2N_x$ or Diamond

- Modern micro-fabrication techniques – Deep UV / e-beam lithography

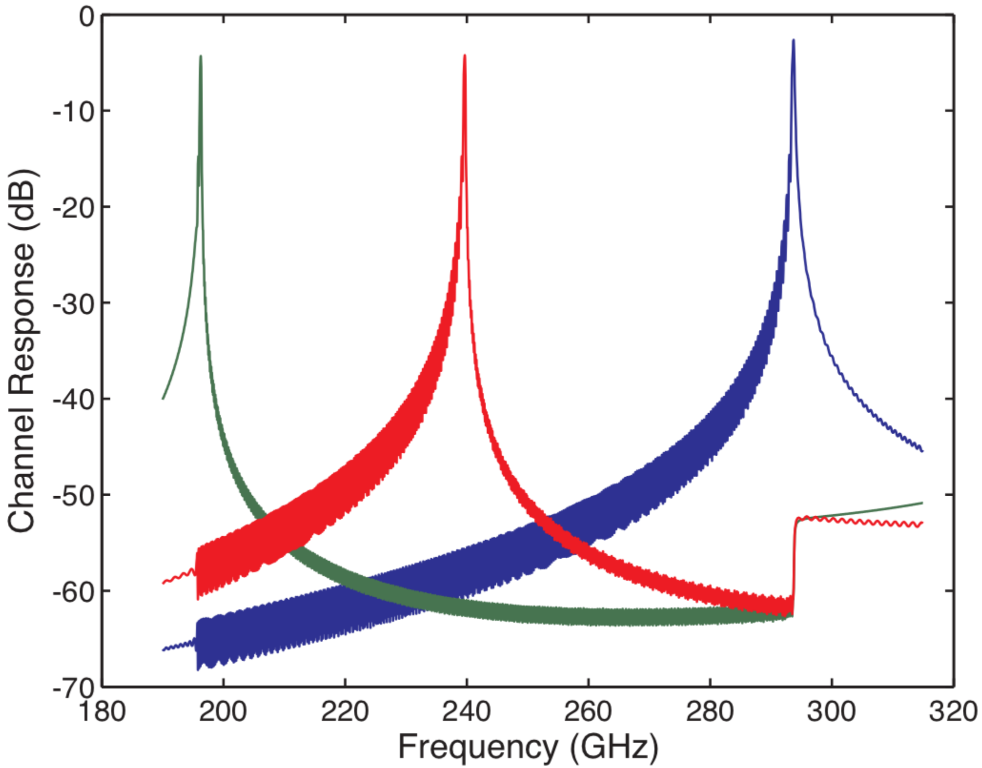
# Filter bank arrangement

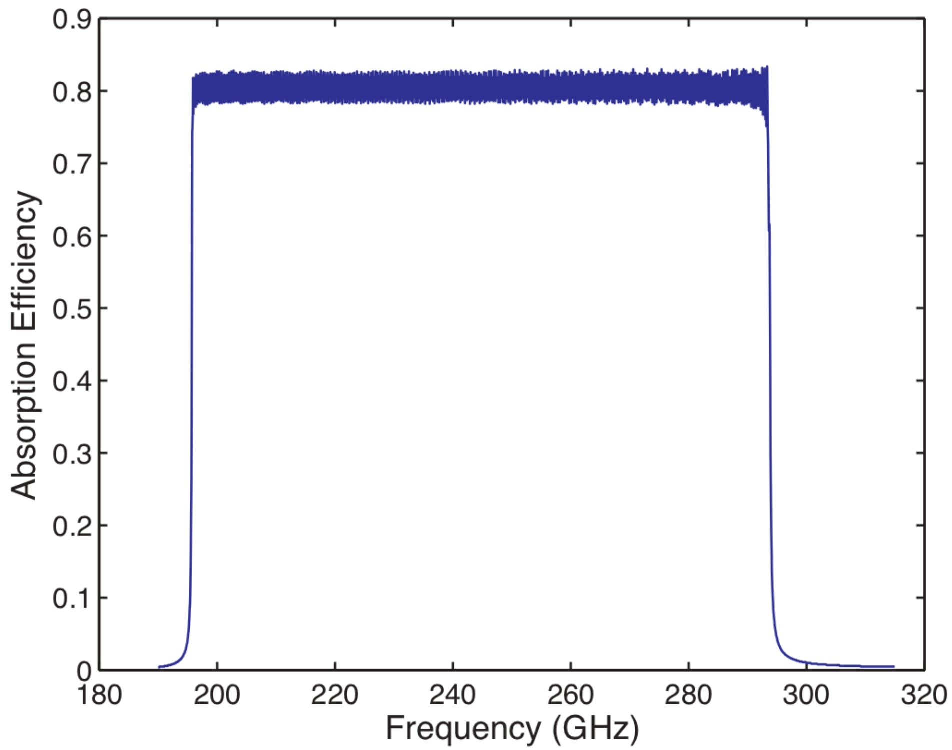



Incoming radiation is sorted by narrow band filters and coupled capacitively to a power detector (LEKID)

A single channel can couple to a maximum of 50% of the filtered radiation

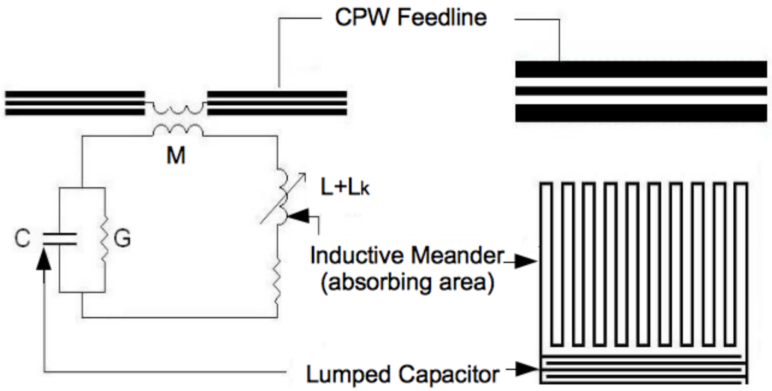
By spacing filtering elements by λ/4, and over sampling higher optical efficiencies can be achieved

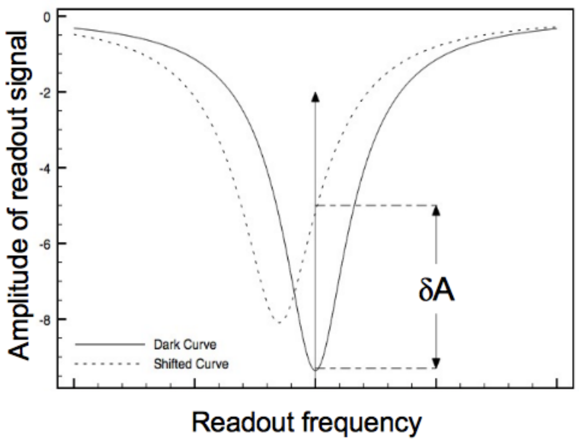


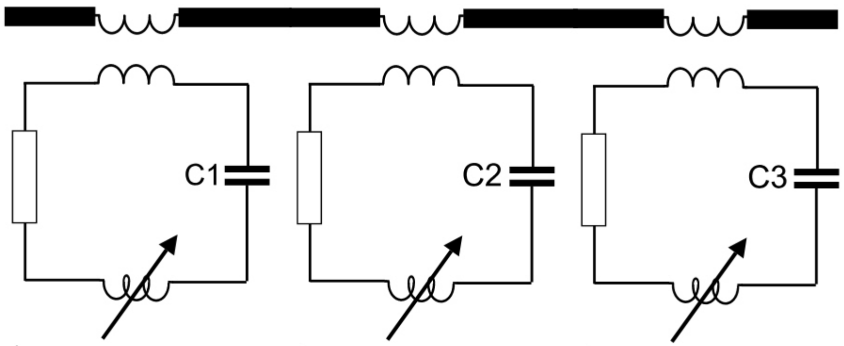



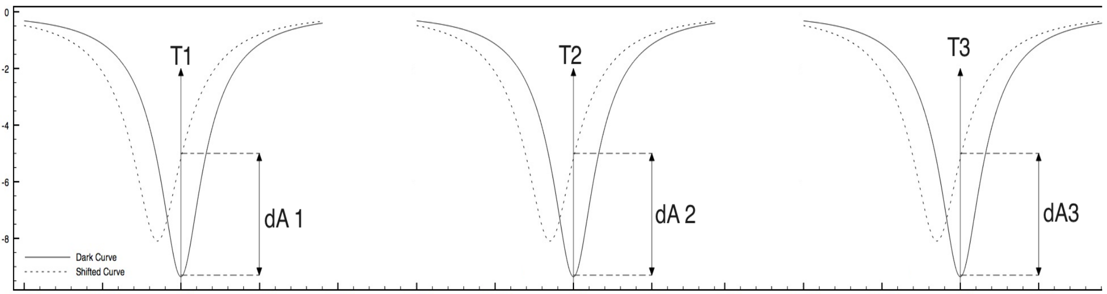

*From Kovacs and Zmuidzinas, internal memo*

# LEKID Basic Concept

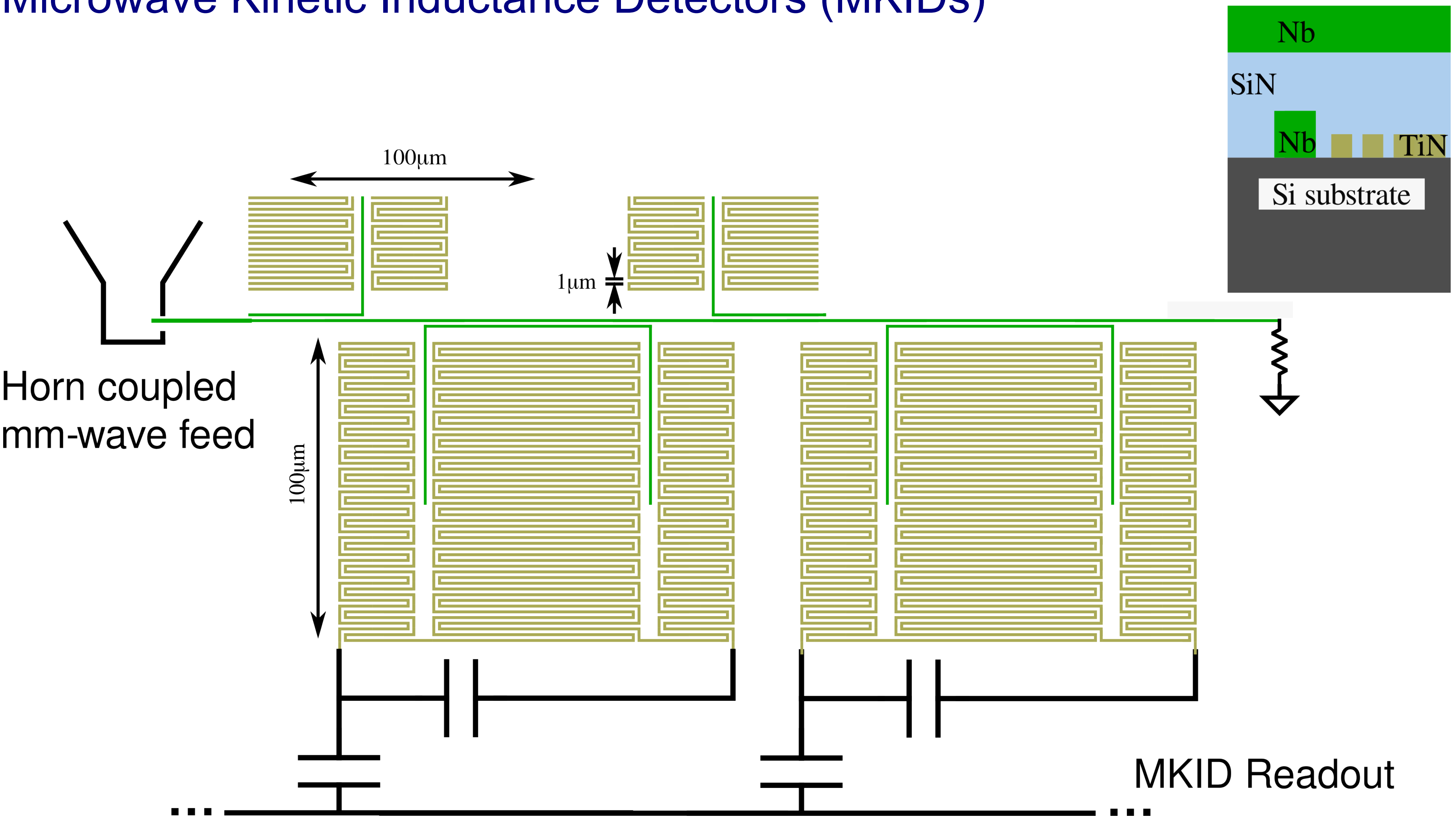


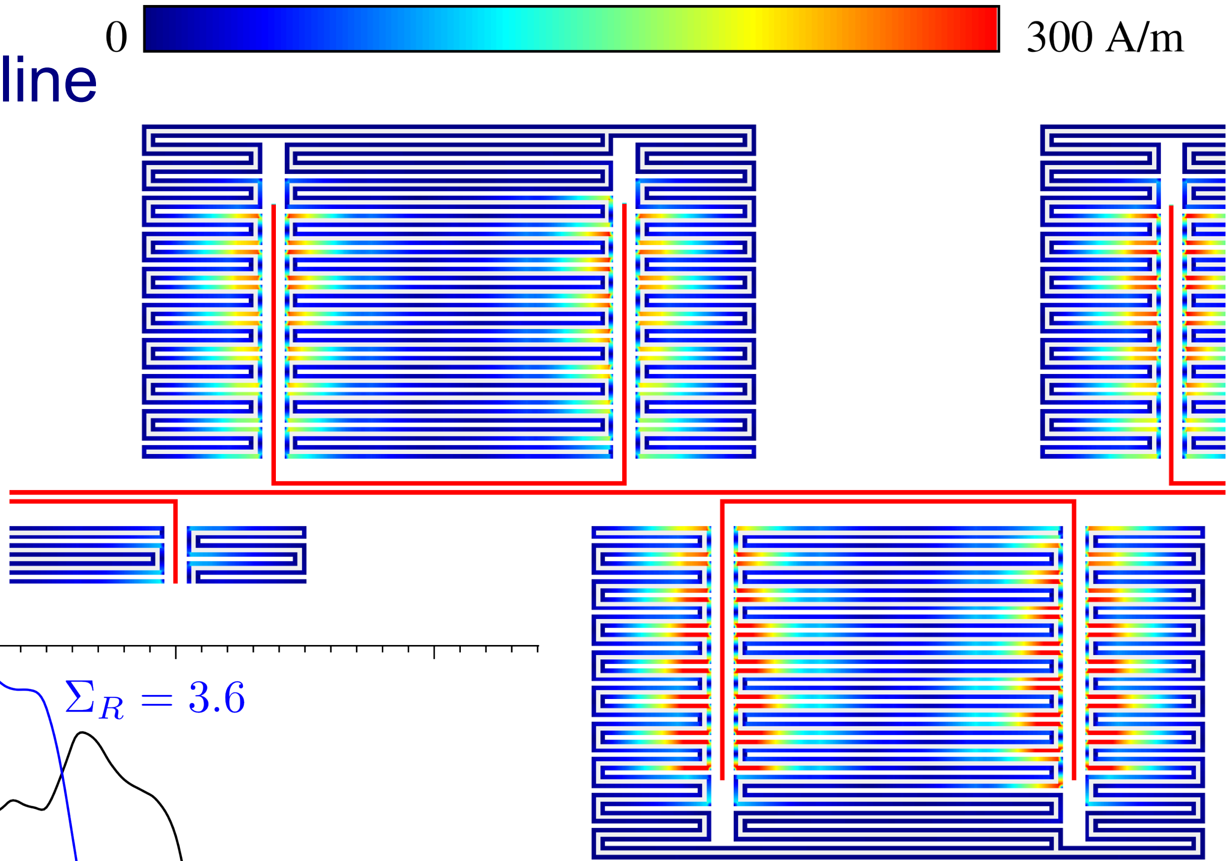
# Realization of the filter bank spectrometer using lumped element Microwave Kinetic Inductance Detectors (MKIDs)

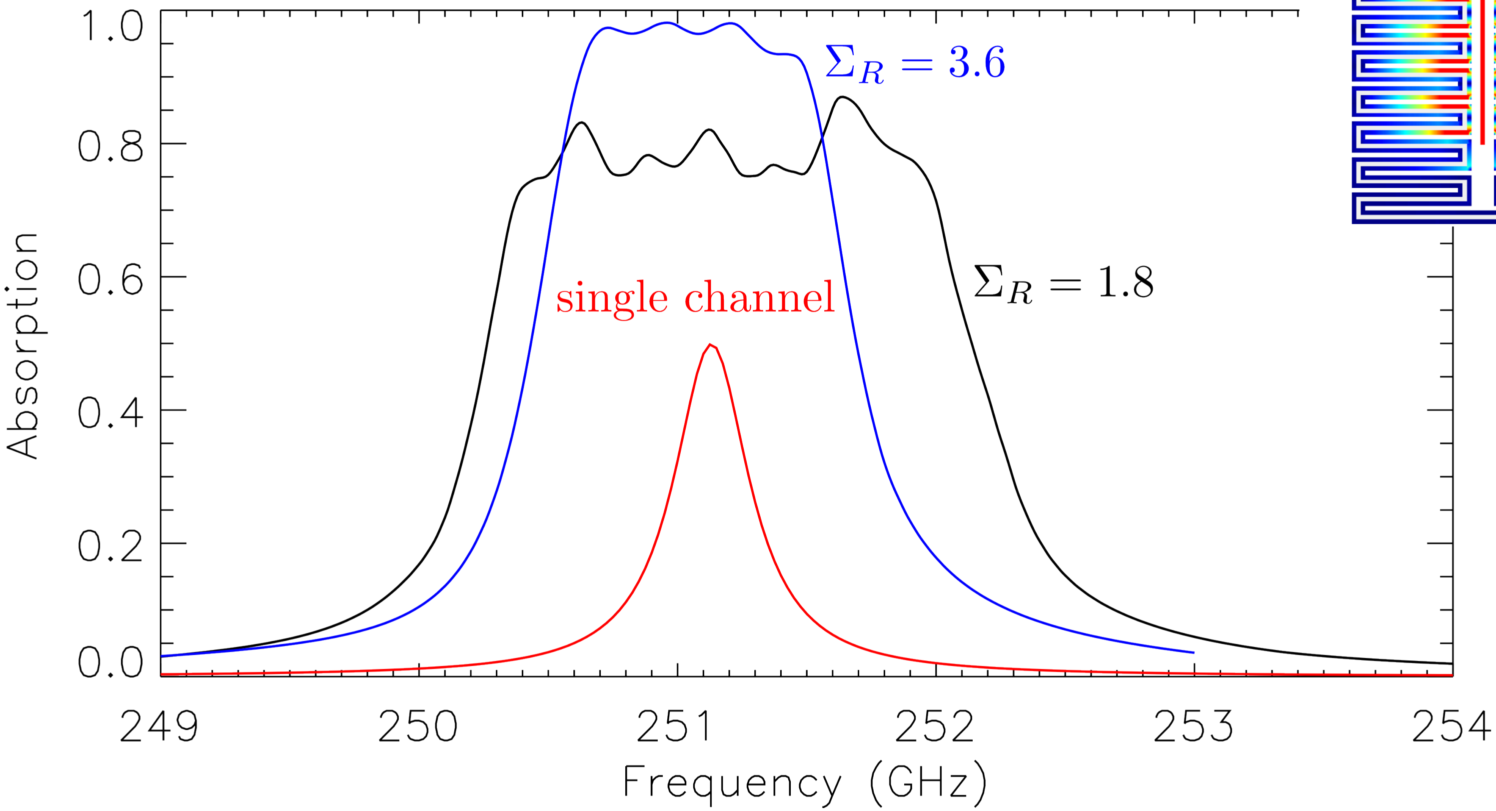


# SONNET simulation of 8 resonators on a single feedline

$$R = Qi/2 = Qc/2 = 700$$

$$\Delta f = f_0 R \Sigma_R$$



# Detector design requirements

- Demand near photon-noise limited operation:

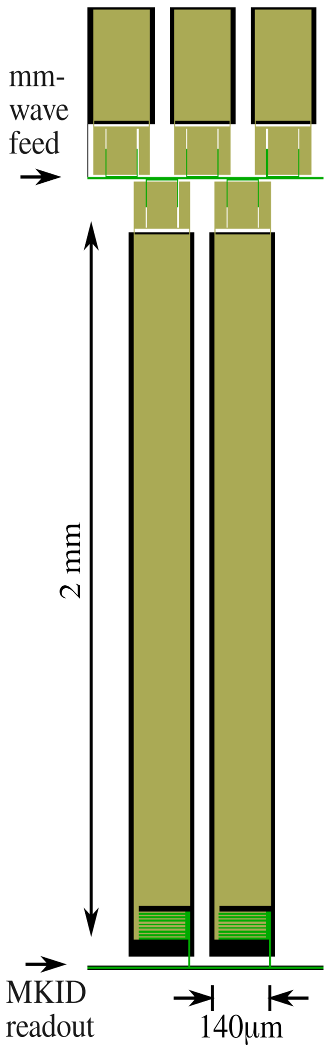
$$NEP \approx 2 \times 10^{-18}\ \mathrm{W/Hz}^{1/2}$$

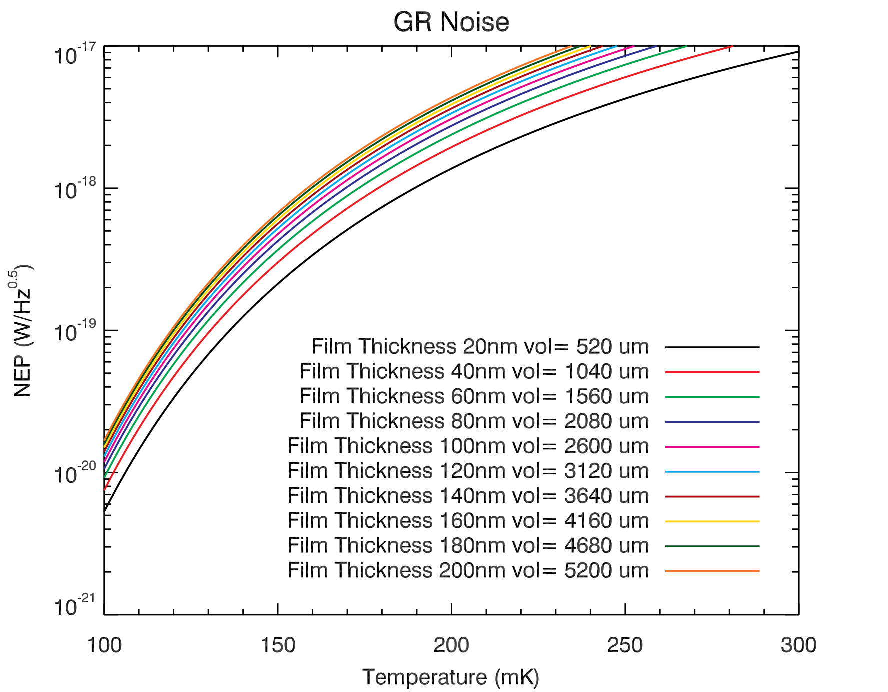
- MKID readout frequencies of 50-500 MHz – to simplify readout electronics

- Multiplex ~600 detectors per octave:
  If f0 scatters with $\sigma=10^{-3}$
  N=600/Octave, $Q_r=10^5$ ➔ < 5% loss through clashes

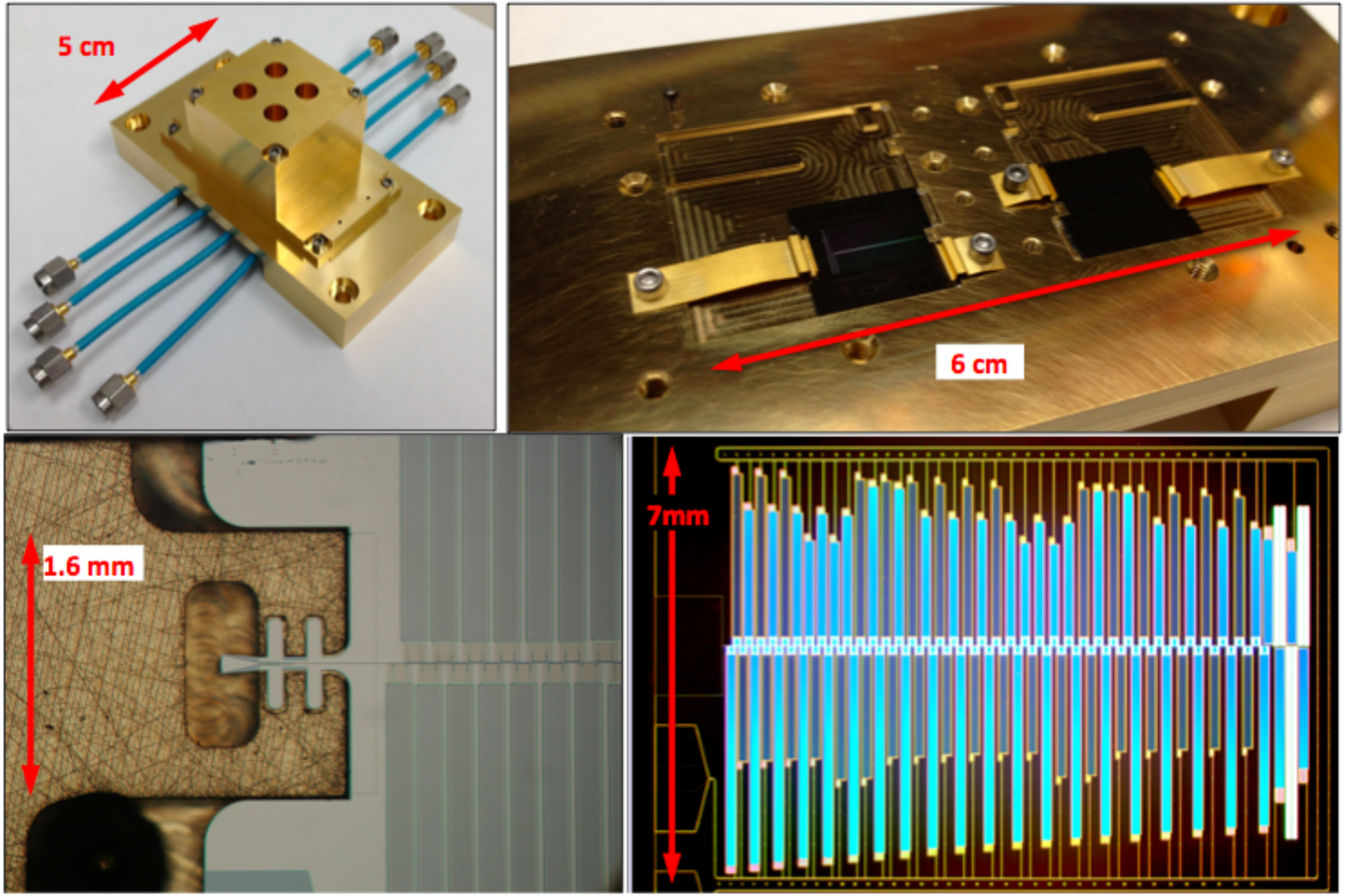
- Volume of typical detector ≈ 130μm³ TC 2K (TiN)

- Suppression of TLS noise
- extrapolation from similar TiN devices suggests this is achievable



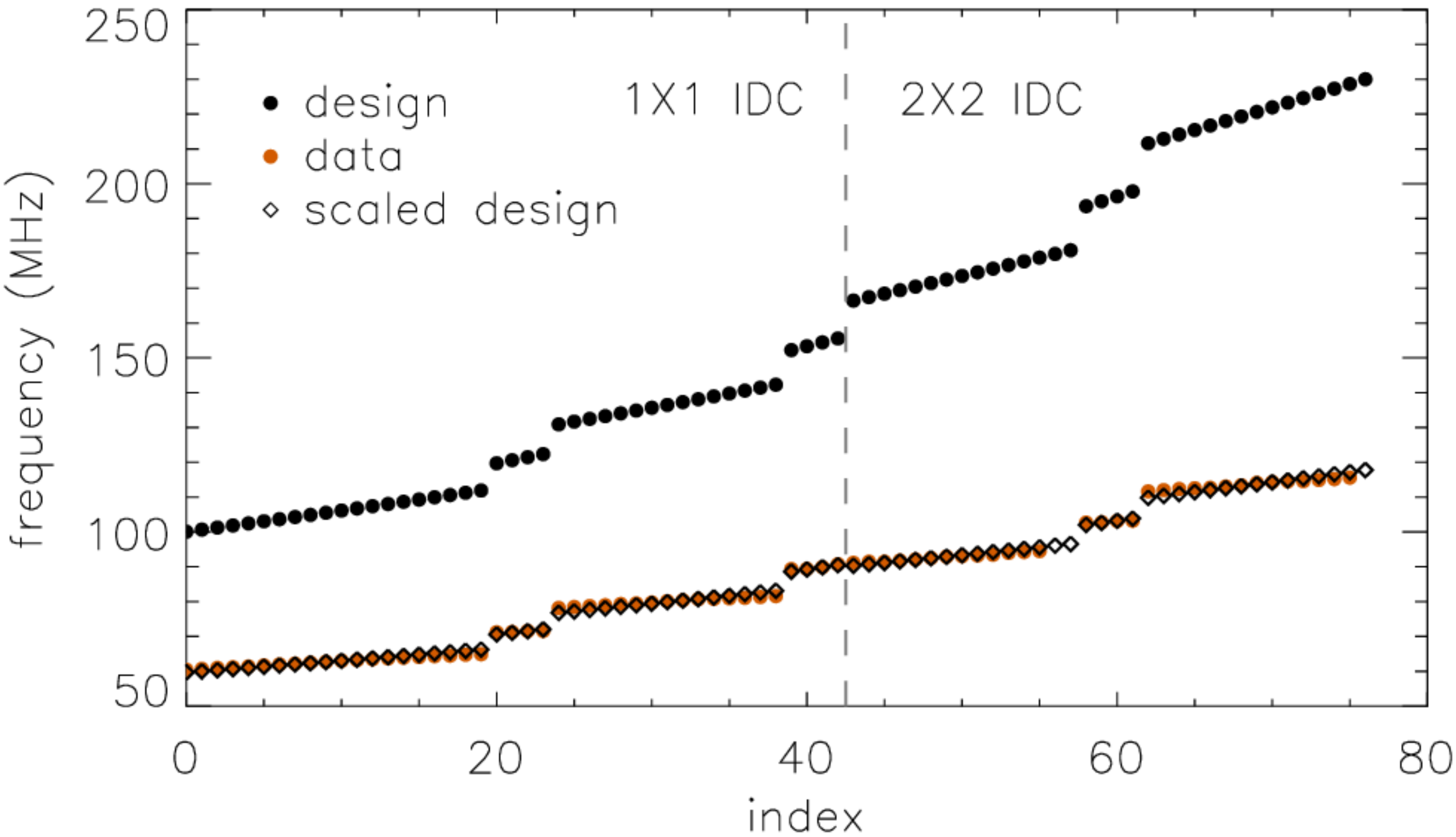



# First Test device



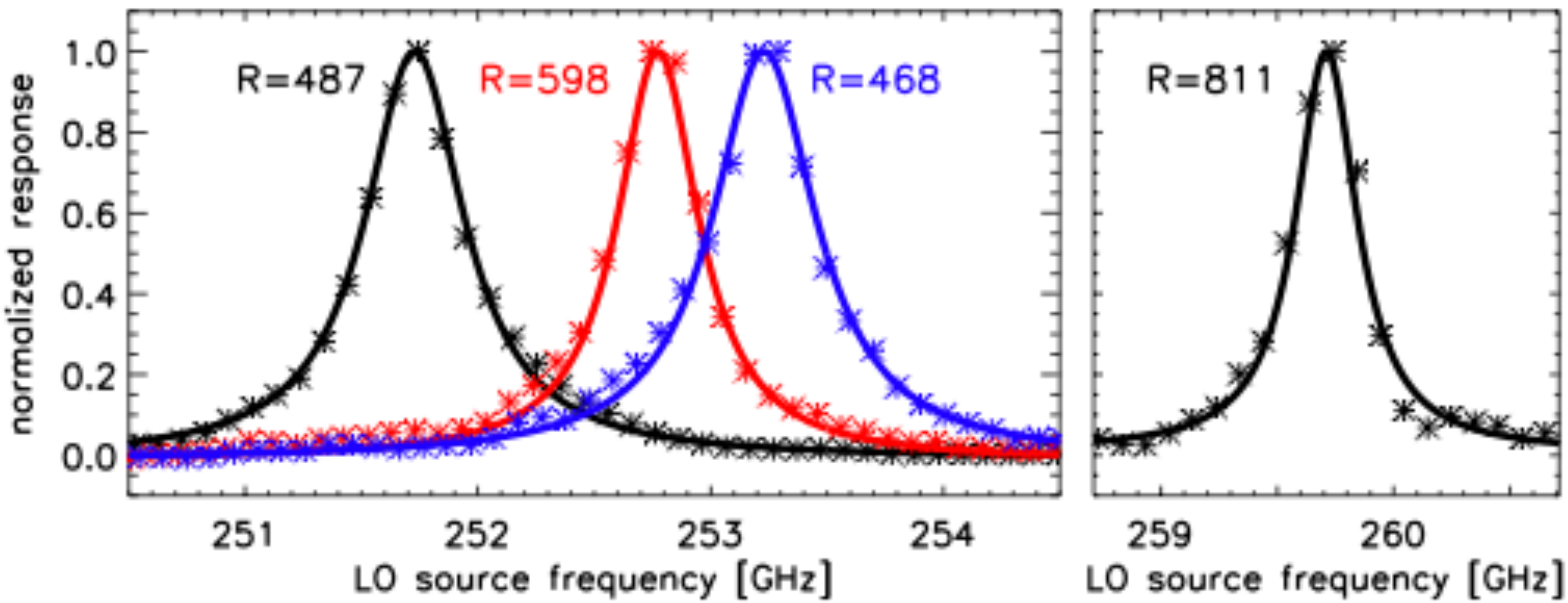
# Yield looks promising!

6 out of 7 tested dies pass 300K resistance measurements
In cryogenic tests of one die: 74 / 77 standard channels are present
At least 3 / 4 low-frequency termination kids




$$f_{\text{scaled}} = f_0 + A\, f_{\text{design}} \quad \text{(1X1 and 2X2 case fitted seperately)}$$

# Device Response to a Swept Coherent mm source



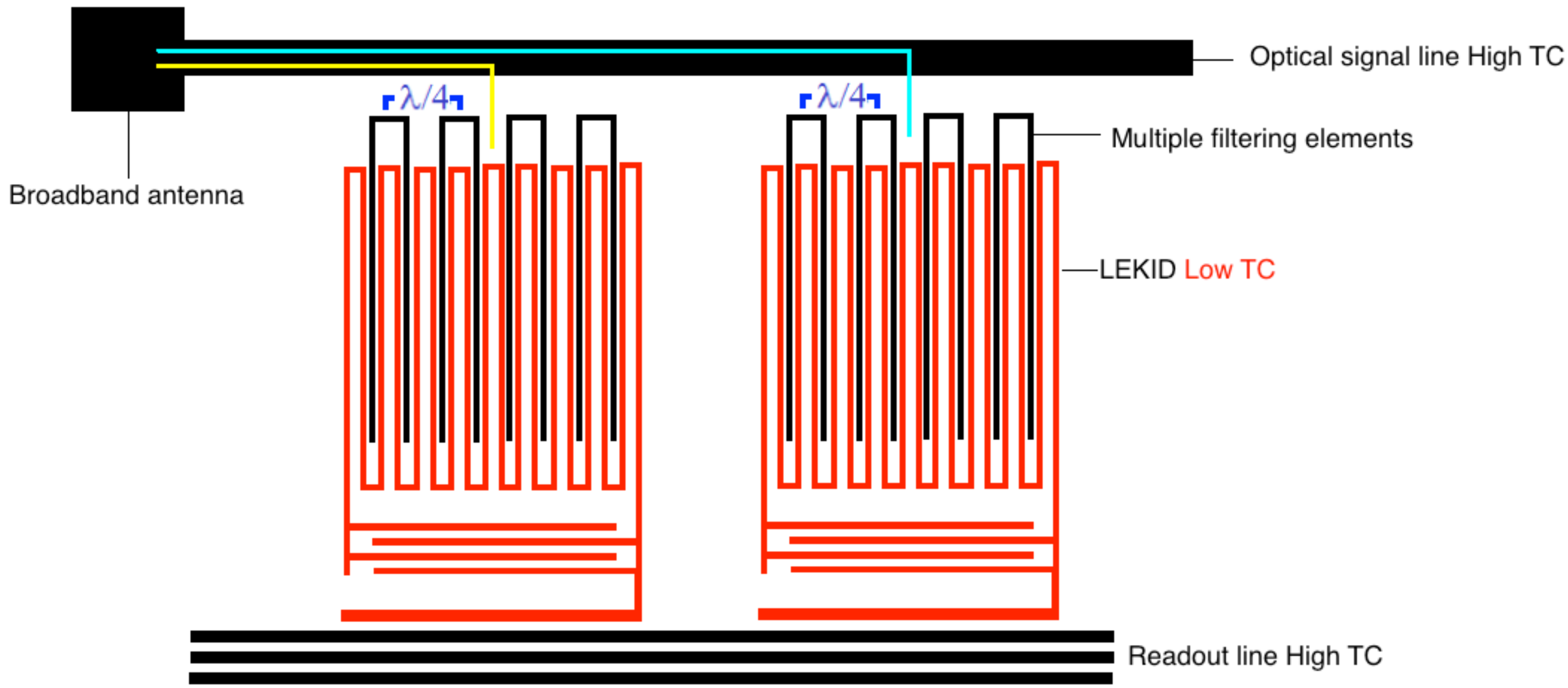

Filter banks appear to be working with target R achievable

## Current work and future plans

- Responsivity, and noise measurements ongoing.
- Dedicated cryostat, pulse-tube, He-sorption fridge are now being integrated.
- Short term goal: a few-pixel, 2-band Nc~600, R~700, observation-grade demo within 1-2 years.
- Investigation into alternative dielectric layers such as Diamond and SOI wafers
- Long term goal: proposed *X-Spec* instrument for CCAT with hundreds of channels

# Other possibilities

## Photometric filtering by coupling multiple “U” resonators to a single LEKID



# Conclusion

- The concept of an integrated 195-305 GHz on-chip spectrometer has been demonstrated showing that the target spectral resolution can be achieved with current fabrication techniques.
- Test devices show that the high detector yield can be achieved for the current detector architecture.
- Results shown are preliminary, device sensitivity tests are still ongoing.
- In principal this approach can be scaled to higher frequencies although new dielectric materials may need to be considered.