MKID Development for SuperSpec:

An on-chip, filter-bank spectrometer for mm-wavelength astronomy

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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 $z>4$
A general filter bank (or cochlear) spectrometer:

Incoming radiation is sorted by narrow band filters

Each channel couples to a power detector

Channel width and spacing are independently adjustable
Realization of the filter bank spectrometer using lumped element Microwave Kinetic Inductance Detectors (MKIDs)
SONNET simulation of 8 resonators on a single feedline

\[ R = \frac{Q_i}{2} = \frac{Q_c}{2} = 700 \]
\[ \Delta f = f_0 R\Sigma_R \]
MKID design goals

- Demand near photon-noise limited operation:
  \[ \text{NEP} \sim 2 \times 10^{-18} \text{WHz}^{1/2} \]

- MKID readout frequencies of 50-500 MHz

- Multiplex \sim 600 detectors per octave:
  \[ \text{If } f_0 \text{ scatters with } \sigma = 10^{-3} \]
  \[ N = 600/\text{Octave }, Q_r = 10^5 \rightarrow < 5\% \text{ loss} \]

Absorb 190 GHz photons

3He sorption fridge

\[ \left\{ \begin{array}{c}
V_L \sim 130 \mu m^3 \rightarrow n_{qp} = 200 \mu m^{-3} \text{ w/ optical load} \\
\text{expect } Q_i \bigg|_{250 mK} = \sim 4 \times 10^{-5}
\end{array} \right. \]

Extrapolation from measured TLS noise in MAKO devices suggests we can meet our noise goals.
Prototype device layout.
Sonnet simulation of a single MKID resonator

Approximate equivalent circuit.

\[ f_0 = 157 \text{ MHz} \]
\[ Q_c = 2 \times 10^5 \]
\[ Q_i \geq 3.5 \times 10^5 \]
First Test device

1.08 \mu m
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

\[ f_{\text{scaled}} = f_0 + A f_{\text{design}} \] (1X1 and 2X2 case fitted separately)
Q distribution

design for $Q_c = 2 \times 10^5$ Measured $< Q_c > = 3.5 \times 10^5$

$\rightarrow$ consistent with frequency shift and design $C_c$

low temp limit $< Q_i > \sim 8 \times 10^5$
Prototype will use a smooth-walled feedhorn
Prototype will use same GPU-based readout as MAKO

Pentek 2x ADC, 2x DAC
500 MSPS $15k

C++ (CUDA) cuFFT

Nvidia m2090
~$2.8k

Server price $2k

CPU or Disk

Full instrument.
C/C++ programming.
250 MHz bandwidth
$30k for 2 lines ($15k/line)

1st stage: $3500
Weinreb SiGe Cryo Amps

2nd stage: $500
Miteq .001-500 MHz
The Future

- Responsivity, noise measurements of dark pixel underway.
- Feedhorn hardware is being fabricated.
- Test chip with inverse-bolometer thermal source underway.
- Dedicated cryostat, pulse-tube, He-sorption fridge are in hand, now being integrated.
- Short term goal: a few-pixel, 2-band Nc~600, R~700, observation-grade demo within 1-2 years.
- Long term goal: proposed X-Spec instrument for CCAT with hundreds of channels