National Aeronautics and Space Administration

Technology for Future Far-IR Missions: Demonstration of (Large-Format) Wideband Millimeter-Wave Spectroscopy with SuperSpec

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Program: FY22 R&TD Strategic Initiative

Strategic Focus Area: Long-Wavelength Detectors - Strategic Initiative Leader: Charles Lawrence

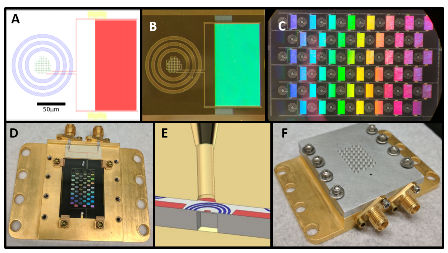
Objectives

Our objective is to demonstrate new large format, ultrasensitive kinetic inductance detector arrays that demonstrate readiness for future cryogenic far-infrared astrophysics missions, most importantly our probe PRIMA. In addition to these conventional, planar arrays for classical spectrometers, we are demonstrating a new on-chip superconducting photonic spectrometer with an integrated array of high-sensitivity KIDs, this will greatly reduce the of a wideband direct-detection spectrometer. Specifically, we aim to:

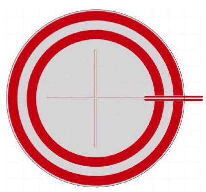
1) Demonstrate an optical noise-equivalent power (NEP = measured noise over measured response) of 2.5×10^{-19} W $Hz^{-1/2}$ or better in a direct-absorbing thin-film aluminum KID detector which multiplexing suitable for an PRIMA spectrometer.

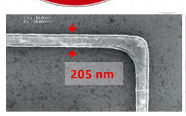
2) Demonstrate the SuperSpec on-chip spectrometer technology at the Large Millimeter Telescope (LMT).

Approach and Results 1: Low-NEP Aluminum KIDs

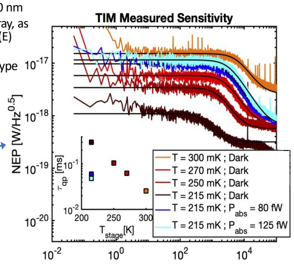


Lumped-element KIDs developed by our group for the TIM balloon experiment which pave the way for PRIMA. (A) Mask layout for a single resonator. The meandered inductor (green) is surrounded by an optical choke structure (blue). An interdigitated capacitor (red) sets the resonance frequency of the pixel, and two coupling capacitors (yellow) allow readout via microstrip feedlines. (B) A microscope image of a single pixel. All pixel elements of the prototype array are patterned with 40 nm aluminum film. (C) A microscope image of the 45-pixel prototype array, as fabricated. (D) The array in its enclosure. The die is 30mm × 22mm. (E) The optical power is coupled into a feedhorn and travels through a circular waveguide that is terminated by the inductor. (F) The prototype feedhorn block installed above the 45-pixel array.



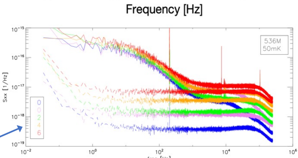


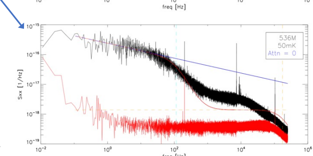
New dual-polarization 'cross' absorber now using the same setup as at right. This device is a has an inductor / absorber volume of 10 cubic microns.



Measured sensitivity of TIM devices validates models for aluminum KIDs. Response and rolloff depend on the quasiparticle lifetime, which reaches values as high as 300 micro-seconds for these devices.

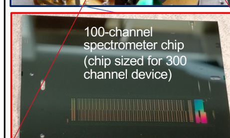
New setup in BlueFors dilution fridge for high-sensitivity KID testing with rapid turn around.

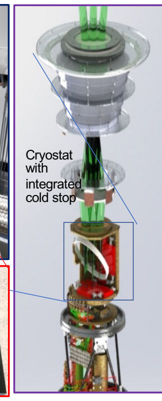


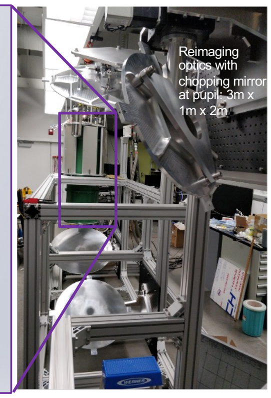


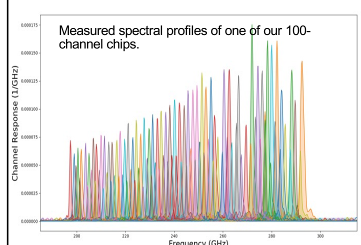
Initial measurements of new low-volume device at 50 mK in new KID test facility. Lifetimes appear long (~1 ms!), and low-frequency noise is low: very promising. Further study is underway. Inset in top is attenuation (dB) of readout power

Approach & Results 2: SuperSpec Chip Spectrometer









Readout electronics using 6 ROACH-2 boards

SuperSpec shipment departing JPL for the LMT telescope in September 2022.

LMT telescope now operational with full 50m

Significance and Benefits to JPL and NASA

We are setting the stage for PRIMA and even greater future far-IR spaceborne astrophysics capabilities. Our funded balloon-borne experiment TIM will field large KID arrays, but not at the sensitivity required for space. This program builds on that expertise and testing infrastructure to demonstrate the sensitivity needed for a cold space telescope. With the on-chip spectrometer, we both demonstrate JPL KIDs in a scientific application, and pave the way to massive imaging spectroscopy in the millimeter and long-submillimeter bands. This will be used first on the ground in one or more large tomographic intensity mapping experiments targeting the epoch of reionization in redshifted [CII] emission, a transformational scientific approach now under development by multiple groups. Eventually the technology will open up the longest wavelengths (beyond ~500 microns) on future far-IR space missions such Origins.

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Publications:

*Design and testing of kinetic inductance detectors for the terahertz intensity mapper. L. Liu, R.M.J. Janssen et al. Proc SPIE 12190, 2022.

*SuperSpec: On-Chip Spectrometer Design, Characterization and Performance. J. Redford et al., JLTP September 2022.

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