Technology for Future Far-IR Missions: Demonstration of Wideband Millimeter-wave Spectroscopy with SuperSpec

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Program: Strategic

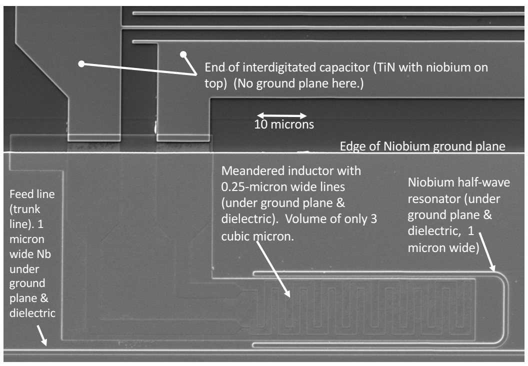
Project Objective, Benefits to NASA & JPL:

We are working to mature the critical technology enabling powerful future far-IR space missions such as the Origins Space Telescope (OST, formerly Far-IR Surveyor), and the Galaxy Evolution Probe (GEP) which require far-IR array formats of 10^5 or more in background-limited pixels. We are pursuing kinetic inductance detectors (KIDs), in particular we use lumped-element titanium-nitride (TiN) resonators, an approach pioneered at Caltech / JPL. The TiN KID is a versatile detector and the fabrication simplicity and high MUX factor is a natural fit to the large required formats. To pave the way for JPL flight opportunities, we aim to demonstrate these detector approaches in ground-based instruments on the next-generation telescopes like the large millimeter telescope (LMT), CSST and CCAT-prime.

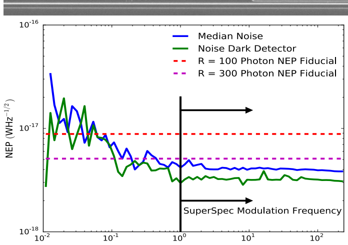
FY 18/19 Results:

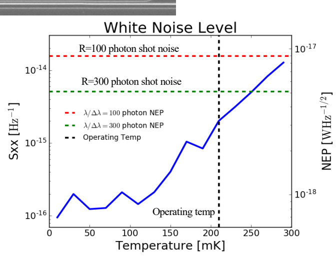
- **Improved SuperSpec detector sensitivity, now photon-noise limited for R=300 spectroscopy in the millimeter band from mountaintop sites.**
  - Also demonstrated even lower noise at 120 mK: 7e-19 W/sqrt(Hz), best KID sensitivity in North America.
- **Designed and fabricated new 110-channel science grade filterbank chip.**
  - Reverting to ¾ wave spacing based on poor efficiency in 300-channel ¼-wave-spaced chips.
  - Finding good efficiency in initial tests of 110 channel device.
- **Preparing for demonstration at Large Millimeter Telescope (LMT), in 2019.**
  - Cryostat is modified, final debugging underway now with readout lines and optical filters. System accommodates 6-chip, (3-beam x 2 pol) demonstration instrument.

SuperSpec Sensitivity : photon noise limited.

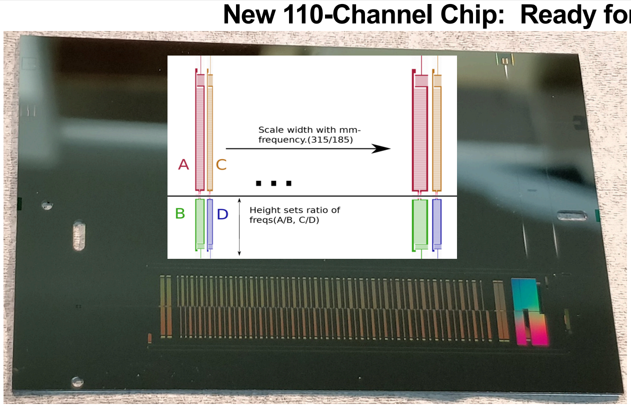


LEFT: Detail of the SuperSpec 3rd generation architecture featuring a new small-volume inductor to increase frequency response per unit power. The Nb microstrip feedline at bottom traverses horizontally and couples to each channel. The half-wavelength U-shaped resonator provides the filtering. The meandered inductor inside the resonator is the active part of the detector, making this smaller with the narrow lines has improved the sensitivity. Most of the chip area is the interdigitated capacitors, large to give the low-frequency readout and minimize TLS. BOTTOM LEFT: Noise equivalent power (NEP) measurement of the new device with the 3-cubic-micron inductor. Device noise is limited by generation-recombination noise at high frequencies, the ultimate sensitivity limit for a KID. Our devices are now background-limited for R=300, our target for science demonstration. The low-frequency excess is under investigation, likely two-level systems. For the near term at LMT, it is not a concern since SuperSpec will observe point sources and will chop a steering mirror at a few to 10 Hz. BOTTOM RIGHT: Run of white noise with temperature in dark measurements with a dilution refrigerator. While we will operate at 220 mK for our demonstration, the Tc=1 K TiN material can offer enhanced sensitivity down to ~120 mK. Below this temperature, either the number density of free electrons in the material can not be reduced, or some other noise floor becomes important.





New 110-Channel Chip: Ready for Science



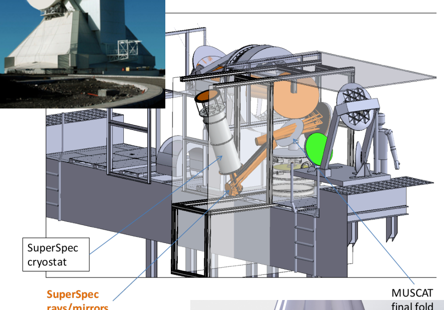
To address optical efficiency problems we have encountered with our 300-channel chip, we have developed a 110-channel chip shown at left. This chip is drop-in compatible with the cryostat housing designed for the 300 channel device, but channels are spaced at ¾ wave in this chip, in contrast with the ¼ wave spacing used in the 300 channel chips. The ¾-wave spacing demonstrated in our earlier 50-channel devices shows better optical efficiency than the 300-channel devices, an aspect not captured in either EM simulations or circuit-based simulations. These 110-channel devices are under test now.

The radiation propagates from left to right on a microstrip line in the center of the patterned area. The vertical structures are interdigitated capacitors. The overlay is a schematic of the readout approach.

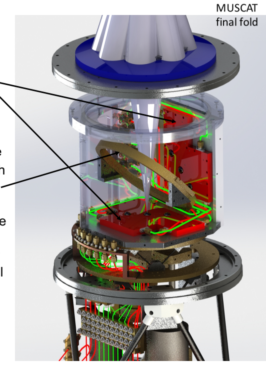
Frequencies range from 100 to 450 MHz. Since the inductors are so small, the capacitors must be large and the dominate the patterned area. This is a challenge given the close linear spacing of the channels. We developed a We developed a new method of optimally utilizing the area of the chip for capacitor layout. We break the readout frequency band into four logarithmically-spaced banks. Since all of the inductors are identical by design, the resonant frequency scales as 1/sqrt(C). Each of the four banks is designed so that the frequency scales over a factor of sqrt(300/200); in this way the capacitance C (and thus capacitor area) in each bank has the same scaling as the millimeter-wave frequency.

Preparing for LMT demonstration

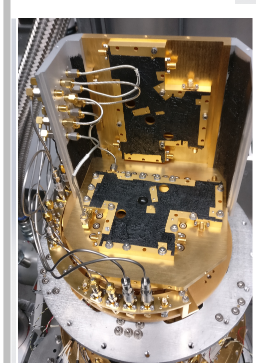
LMT, run by INOAE in Mexico. Now being fitted out to 50 m with high-performance panels, and expect 65 microns RMS surface. SuperSpec will use a relay on the right-hand Nasmyth, sharing large reimaging mirrors with MUSCAT demonstration camera.

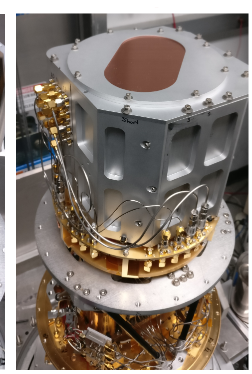


3-chip packages, 1 for each polarization.



Demonstration instrument housed in existing cryostat. We will field 6 chips: 3 beams x both polarizations. A polarizing grid separates the light into two linear polarizations which couple to the two 3-chip packages. The full system is cooled to 210 mK. Each 300-channel chip will be read out individually with a single circuit, delivered by one coaxial line in, and one coaxial line out.





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Publications:

J. Redford et al., 2019 paper on Chips and Demonstration Instrument at Low Temperature Detectors Conference
K. Kirkare et al., 2019 paper on Sensitivity Measurements at Low Temperature Detectors Conference

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