National Aeronautics and Space Administration

High-Sensitivity Kinetic Inductance Detectors and On-Sky Demonstration for Origins Spectroscopy

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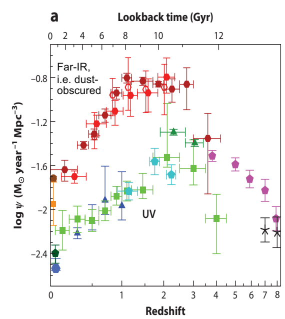
Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Long-Wavelength Detectors**

Objectives

Our objective is to demonstrate new large format, ultrasensitive kinetic inductance detector arrays that demonstrate readiness for future cryogenic far-infrared astrophysics missions such as the Origins Space Telescope or a probe-class version. In addition to these conventional, planar arrays for classical spectrometers, we also aim to demonstrate a new on-chip spectrometer with an integrated array of high-sensitivity KIDs, this will greatly reduce the mass and volume of a wideband direct-detection spectrometer. Specifically, we aim to:

1) Demonstrate an optical noise-equivalent power (NEP = measured noise over measured response) of 2.5x10-19 W Hz-1/2 or better in a direct-absorbing thin-film aluminum KID detector which multiplexing suitable for an Origins instrument. This requires developing a low-background cryogenic test facility for KIDs, improving our aluminum film quality, and designing low-volume devices, all verified with multiple fabrication and test cycles.

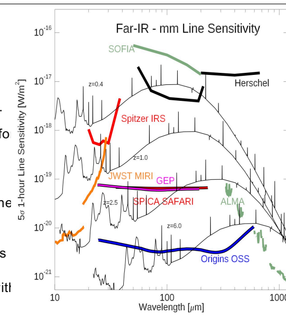
2) Produce science-grade extragalactic spectra with our on-chip KID-based spectrometer SuperSpec on the LMT.



Background

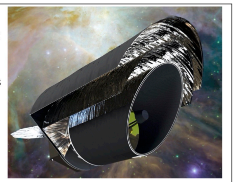
A large fraction of the total star formation and black hole growth throughout cosmic time has taken place in dust-obscured regions in which all of the optical / near-IR light is absorbed. The far-infrared through millimeter waveband accesses this component of the Universe.

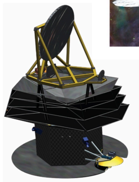
The success of Spitzer and Herschel has given rise to future concepts fo far-IR space astrophysics with cryogenic platforms both internationally and in the US. The most promising candidates now are the JPL-led Galaxy Evolution Probe (GEP) and the flagship-class Origins Space Telescope, a 5.9-m, 4-Kelvin observatory studied for consideration by the 2020 Decadal Survey. Both of these offer a powerful advance for spectroscopy, where observing speeds are increased by four to six orders of magnitude. The JPL-led Origins' survey spectrometer (OSS) is the workhorse instrument for Origins, and it sets the benchmark for scientific capability in the far-IR. It covers 25-580 microns in 6 bands, witl ~100,000 pixels, each 30 x more sensitive than previously flown.



Origins

- Flagship concept
- 5.8 m, 4 K aperture
- up to 120k pixels or more.



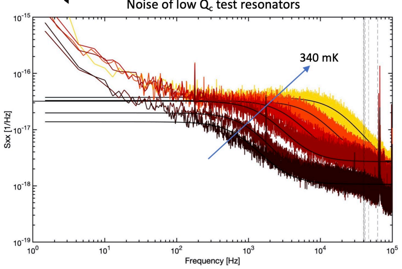


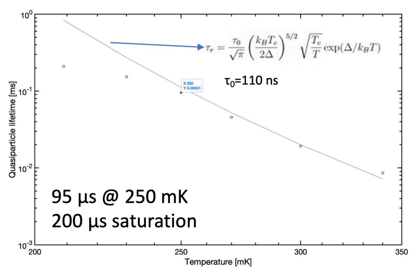
Galaxy Evolution Probe

- Example probe-class option that could be competed.
- 2m, 6 K aperture.
- 50 k pixels

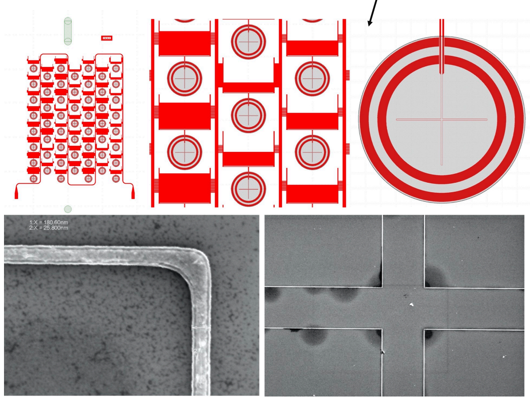
Approach and Results

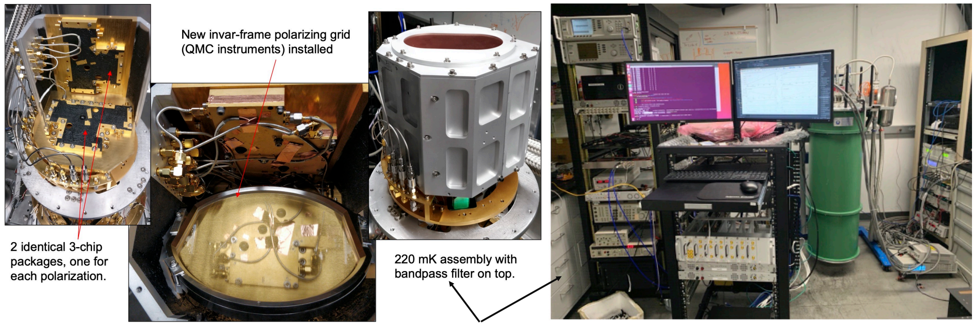
Quasiparticle lifetime is a key attribute of aluminum KIDs. Longer lifetimes translate to greater sensitivity. At left are measurements of generation-recombination noise in new aluminum KIDs (existing design). The rolloff shows at high frequencies measures the lifetime. The temperature dependence matches Mattis Bardeen theory (left, bottom), and we find values approach 200 μs with the new evaporated aluminum film, as compared with ~35 μs with our previous films.





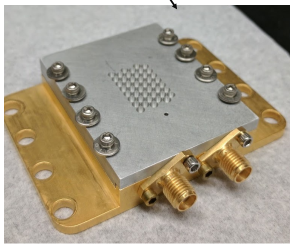
New low-volume KID approaches are key to improving sensitivity since response to power scales inversely with volume with other properties held constant. We have designed and built this device and it is under test now. Images zoom clockwise from top left. Top left shows the 45-pixel test chip that mates with our feedhorn-coupled assembly. The devices are patterned in 30 nm aluminum, and the absorber is a cross to couple both polarizations from a circular waveguide. The high yield in these narrow-line (180 nm) devices is encouraging. Initial dark measurements look promising, and optical NEPs will be measured in the next 6-8 weeks.





SuperSpec demonstration instrument is being prepared for deployment at the Large Millimeter Telescope (LMT). The instrument will field 6 chips covering the 200-300 GHz band, configured to couple to 3 sky positions in both polarizations. One KID readout circuit is used for each chip. We expect to be on sky in January.

45-pixel test chip package, used with cryogenic blackbody



Significance and Benefits to JPL and NASA

We are setting the stage for future far-IR spaceborne astrophysics, and insuring that JPL will be in the driver's seat. 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 infrastructure to demonstrate the sensitivity needed for a cold space telescope.

With the on-chip spectrometer, we both demonstrate JPL KIDs in another 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 including the South Pole Telescope, and CCAT-Prime consortia. Eventually the technology will open up the longest wavelengths (beyond ~500 microns) on future far-IR space missions such Origins or even a probe. Spectroscopy at these long wavelengths with conventional grating systems is volume and mass prohibitive, even on something as large as Origins.

Publications

NPP Postdoc Reinier Janssen presented some of the aluminum KID work at the Low-temperature detectors (LTD) conference, and is preparing proceedings now. Joe Redford presented the SuperSpec wrok at the same venue, and is also preparing proceedings.

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