Superlaidieji Detektoriai Astronomijai

Superconducting Detectors for Astrophysics

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Over the past four decades, superconducting detectors have moved from the early concept stage to deployment in major cosmological experiments and in instruments on leading telescopes throughout the world. Versions of these detectors have been developed across the electromagnetic spectrum, from microwaves to x-rays, with performance that often approaches fundamental limits. Superconducting detectors are used to trace water on small bodies in our solar system, to study the early stages of planet formation in protoplanetary disks, to map the history of star formation in galaxies over cosmic time, to study dark matter in distant clusters of galaxies, and to search for the signature of gravitational waves produced in the earliest moments of the universe. Superconducting detectors will soon be used to directly image exoplanets around nearby stars and will enable a new generation of ground-based instruments and space observatories.

The history of superconducting detectors dates back to the late 1930s [1,2] with the introduction of the superconducting bolometer, in which a superconducting strip biased on its resistive transition was used to sense small changes in temperature resulting from absorption of radiation. This device was not immediately practical and was superseded by the helium-cooled germanium bolometer developed in the early 1960s [3,4], which opened up infrared astronomy in the 1960s and 1970s and reached its zenith with the Herschel and Planck space missions [5,6].

Bardeen, Cooper, and Schrieffer's theoretical breakthrough [7], coupled with Giaever's development of the tunnel junction [8], stimulated new concepts such as the pair-breaking tunnel junction detector [9]. Indeed, by the 1980s, tunnel junctions enabled the first practical application of superconducting detectors in astronomy, when used in sensitive radio-style receivers for millimeter and sub-millimeter wavelengths [10,11]. A sophisticated quantum-mechanical theory is needed to describe their operation [12], and these SIS receivers were used on the Herschel Space Observatory [5,13] (Fig. 1) and enable the ALMA interferometer in Chile.

The superconducting bolometer made a return in the mid-1990s with the use of superconducting quantum interference device (SQUID) readouts [14], especially multiplexed versions [15] that opened a path to larger detector arrays [16,17]. However, the complexity of this technology spurred us to find a much simpler solution, the frequency-multiplexed kinetic inductance detector [18, 19] (Fig. 2), which is now being developed in over a dozen countries for deployment on large telescopes, from millimeter to optical wavelengths [20], and for use in future space missions [21].

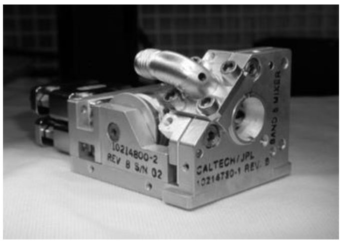

Fig. 1. 1.2 THz SIS mixer developed at Caltech/JPL for the Herschel Space Observatory [13].

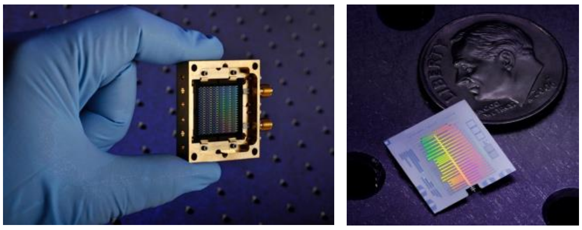

Fig. 2. Left: 484-pixel array of superconducting kinetic inductance detectors (KID) for 350 μm imaging. Right: An integrated KID-based millimeter-wave spectrometer.

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