Superconducting Detector Arrays for UV, Optical, and Near-IR Astrophysics

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January 28, 2014 (HP68). The power of astronomical observations is limited by the collecting area of the telescope and the sensitivity of its sensors. In the last half century, the collecting area of ground-based telescopes has improved by a factor of four, from the 5.1 m Hale Telescope at Palomar to the twin 10-m Keck Telescopes. The sensitivity of detectors has grown on a per-pixel basis by roughly a factor of 20 as the field has transitioned from photographic plates to semiconducting detectors. The improvement in size and quality of these optical and near-IR detectors has been even more impressive. These improvements have fueled tremendous discoveries, but such detectors are rapidly reaching a limit in the per-pixel performance, with improvements only coming in the total size of the final mosaic[1].

We have adapted Microwave Kinetic Inductance Detectors, or MKIDs, for use in the UV, optical, and near-IR [2]. MKIDs consist of a superconducting LC tank circuit with a resonant frequency in the GHz region. Photons (or particles) hitting the inductor break Cooper pairs and cause a change in the surface impedance of the superconducting film through the well-known kinetic inductance effect. This change in surface impedance changes the resonant frequency, allowing a microwave probe signal consisting of a sine wave at the original resonant frequency of the MKID to readout the low-frequency changes in phase and amplitude caused by the photon. These low-frequency changes look like a phase pulse that rises quickly and decays with a time constant equal to the quasiparticle lifetime in the superconductor (typically 10-100 microseconds). The pulse height of this phase pulse gives the energy of the incident photon to several percent accuracy. The arrival time can be determined to several microseconds. There are no false counts: cosmic rays can be rejected since they will trigger many pixels at the same time, and there is no read noise or dark current in a MKID.

One of the largest benefits of MKIDs is that they have built-in frequency domain multiplexing (FDM). Each MKID has a unique resonant frequency, chosen during lithography, and nearly perfect transmission away from the resonance. This allows thousands of MKIDs to be read out over a microwave feed line by exciting each MKID with a unique sine wave contained in a frequency comb. A 2024 pixel MKID array is shown in Figure 1. MKIDs have the potential to scale to Megapixel arrays.

We have recently integrated these arrays into ARCONS [3], an instrument for the Palomar 200 inch telescope. ARCONS has already produced two science papers [4,5], the first astronomy papers based on MKID data at any wavelength, as well as the image shown in Figure 2. Even with our prototype MKID arrays, ARCONS is one of the most powerful instruments in the world for high-time, low-energy resolution astrophysics.

10,000 pixel MKID arrays have just come out of the fab, and we will continue expanding their use to observations of a wide variety of astrophysical phenomena. MKIDs will be central to many important science goals in the coming decades, including looking for planets around nearby stars and determining the redshift of billions of galaxies for Dark Energy surveys [6]. These arrays may also have uses in other disciplines where detecting every photon and its energy is important, like quantum key distribution and biological imaging.

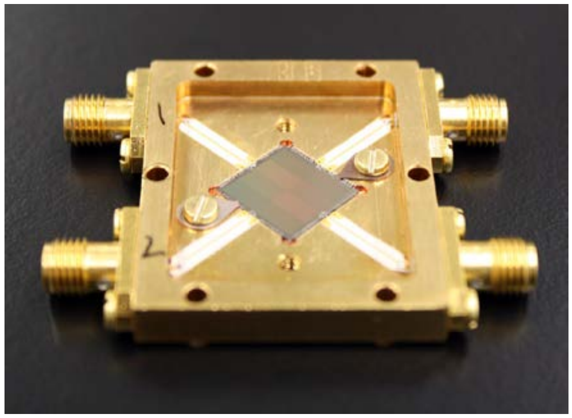

Fig. 1. (Reprinted with permission from Proceedings of the Astronomy Society of the Pacific). A 2024 pixel MKID array mounted in a microwave box.

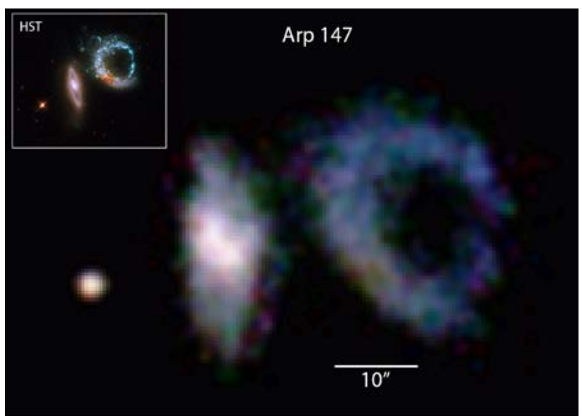

Fig. 2. (Reprinted with permission from Proceedings of the Astronomy Society of the Pacific). A mosaic of the interacting galaxies Arp 147 taken with ARCONS at the Palomar 200" telescope. This image was reconstructed from 36 pointings of 1 minute each on a 6x6 arcsecond grid. The color is reconstructed from the spectra returned by the MKIDs. The inset shows an image of Arp 147 takes with the Hubble Space Telescope.

References

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