

New eyes for a dark world

Every photon counts in astronomy and a new technology aims to deliver even more of the distant light that arrives at a telescope's lens, as **David Appell** reports

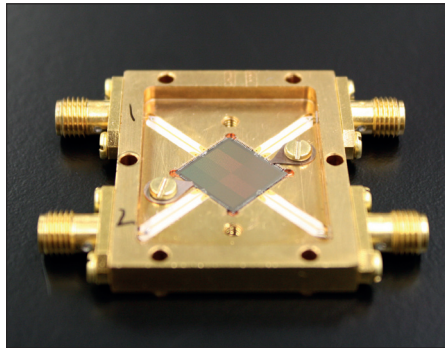
"It's a quantum jump in capabilities," claims Ben Mazin, an astrophysicist at the University of California, Santa Barbara, when discussing a new "camera" that he has been working on for nearly 10 years. The device, called a microwave kinetic inductance detector (MKID), was first developed in 2003 for observations at sub-millimetre wavelengths. But recently it has been redesigned to detect visible and near-infrared light – an aspect that has excited many astronomers.

The advantage of this technology is in its ability to count more photons over a wider range – being able to detect around 70% of incoming photons at blue wavelengths and 30% in the infrared. Not only that, but the detector can also determine the photon's energy as well as time of arrival to within a microsecond. "It's as big a leap as going from film to charge-coupled devices (CCDs) because you're getting energy information along with wavelength," adds Mazin.

MKIDs were first conceived around the turn of the century by Jonas Zmuidzinas of the California Institute of Technology and Rick LeDuc of the Jet Propulsion Laboratory, both in Pasadena, California (*Nature* **425** 817). Placed directly at the telescope's focal point, the devices were first used in sub-millimetre astrophysics – observing at wavelengths from about 300 to 1000 μm – to detect spectral lines coming from elements that make up molecular clouds and nebulae.

To boost the sensitivity of such devices and to make them work in the visible range, in 2003 Mazin began redesigning the MKIDs to make them suitable for installation in large (several hundred), CCD-like arrays. He came up with an MKID that is 4 cm^2 , with square pixels of length 222 μm . As reported at January's meeting of the American Astronomical Society in Austin, Texas, in 2011 the detector underwent its first demonstration. A 1024-pixel MKID was installed on the 5.1 m Hale Telescope at the Palomar Observatory near San Diego, California, and observed for four nights at wavelengths between 400 and 1000 nm.

The instrument was a success in observing interacting binary stars, quasi-stellar objects, supernovae and pulsars, with each pixel recording the arrival of photons to an accuracy within 2 μs – up to six orders of magnitude better than a CCD – and an energy



Counting on success A new photon detector made of superconducting materials can measure the time of arrival and energy of each incoming photon, promising many applications in astronomy.

uncertainty of about 10%. As *Physics World* went to press, the group was planning a run of 12 nights with a 2000-pixel MKID at the Lick Observatory near San Jose, California, on even fainter sources. The performance improvements and the ability to determine the energy of the incoming photons should allow quick, "point-and-shoot" observations of rapidly evolving sources and redshifts of galaxies (to $z = 4$) with high accuracy.

Advantages over CCDs

When a photon strikes a CCD made of silicon, it generates, at most, one electron – and only then if the incoming photon has enough energy to overcome silicon's band gap of 1.1 eV and the wavelength of the photon is less than 1127 nm in the near-infrared. Although CCDs work well and are used throughout astronomy, they do have some disadvantages in that silicon is transparent to radiation above 1127 nm and all of the information about the photon's energy is lost.

Instead of silicon, MKID detectors use superconducting circuits typically made from a thin film of titanium nitride (TiN). The incoming photon strikes a superconducting circuit and in doing so creates a much

larger disturbance than in a CCD – an avalanche instead of a blip. The photon breaks the Cooper pairs – electrons that are loosely bound in the superconducting material – to produce a large number of quasiparticle excitations that are created by the broken pairs. Because the superconductor's band gap is tiny, typically tenths of a millielectronvolt, tens of thousands of quasiparticle excitations are generated for every photon absorbed. This vast increase in quasiparticles changes the superconductor's inductance, which in turn creates a microwave excitation signal measured in a resonator.

To make the detectors work in CCD-like arrays, Mazin changed the geometry of the detector from a strip of the superconductor to single microwave resonator with a capacitor that served as a single pixel. By engineering each resonator to have a slightly different resonate frequency, this allows many resonators (pixels) to be probed simultaneously. So-called frequency domain multiplexing then allows thousands of such pixels to be read. The biggest drawback with this technique, however, is that the detector operates at very low temperatures of around 100 mK, requiring expensive cooling equipment.

"In the long term I see the MKIDs as a technology that can replace conventional detectors in a lot of applications," says Mazin. He adds that MKIDs do not suffer from so-called dark currents – electronic noise from thermally generated electrons that build up in the wells of CCD pixels, which is especially troublesome for long exposure times. CCDs also endure "read noise" from the large amplification voltage of photoelectron signals. As MKIDs are able to detect events that leave significant energy in pixels, they can also eliminate the signal from cosmic rays.

Apps for big science

Having spent the last 10 years designing the instrument, Mazin is now planning on installing it on the Giga-z project, which aims to measure the redshift of a billion galaxies. He envisions that it will be able to take low-resolution images of 100 000 galaxies in as little as 15 min. Mazin hopes that his team can then follow up around two billion of the galaxies spotted by Giga-z by using the

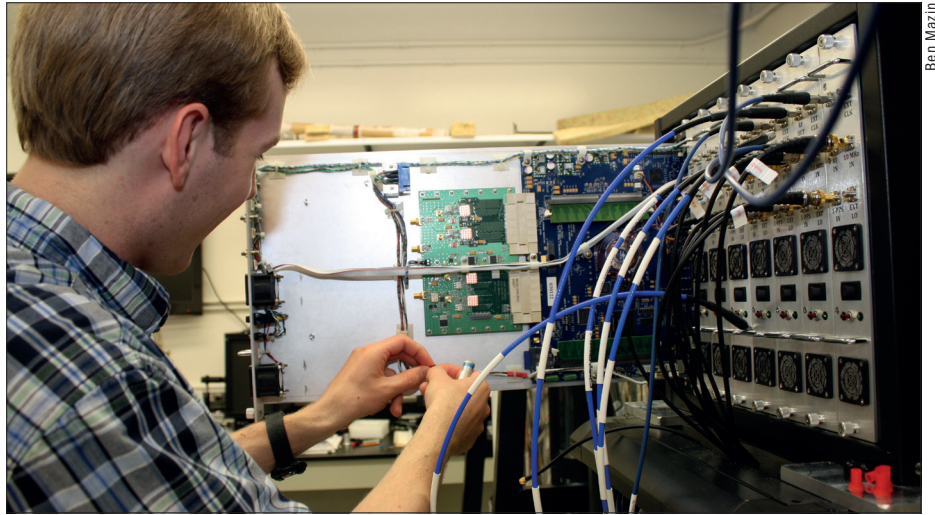
The advantage of this technology is in its ability to count more photons over a wider range

Astronomy

Large Synoptic Survey Telescope (LSST). LSST is a planned 8.4m, 3 billion-pixel camera that, when built in Chile by 2022, will survey the entire visible sky once a week. “As far as I know, LSST is the only survey that’s capable of following up a significant portion of the galaxies that are going to be discovered with Giga-z,” adds Mazin.

Astronomer Marla Geha of Yale University believes that MKIDs can be useful in searches for very faint dwarf companion galaxies orbiting the Milky Way, which she says is “wildly incomplete” at the moment. Indeed, 25 such satellites are known today, such as the Large and Small Magellanic Clouds, but as many as 500 are thought to exist, each with star counts from 10^3 to 10^8 . MKIDs would allow spectrographic follow-up after being plucked from the void by LSST. “It sounds like a technology that can be a game changer,” she says.

Interest in MKIDs has also come from a group of astronomers working on the Nanograv project. This aims to look for subtle variations in the periods of rotating pulsars caused by gravitational waves passing between the source and an Earth-based detector using the Green Bank Telescope in West Virginia and the Arecibo radio telescopes in Puerto Rico. Mazin envisions



Ben Mazin

Seeing better A member of Ben Mazin’s group at the University of California, Santa Barbara that is developing the MKID device to work with visible light.

a day when an MKID array is available at every big observatory, and even put into space on cryogenic-equipped satellites. Here the cryogenic requirement would not be an issue because the Planck and Herschel satellite observatories, for example, both operate at temperatures around 0.1 K.

While there is a burgeoning field of appli-

cations for MKIDs in astronomy, it remains to be seen whether there will be many commercial applications from these devices. For example, most of the needs from the military are in the infrared, and with much brighter sources. “You could say astronomers are some of the few people who care that much about every photon,” says Mazin.