A Guide to the New JCMT 850μm MKID Camera Performance

We are building a 3rd generation, 850μm wide field camera with intrinsic polarization mapping capability for JCMT and potentially for future East Asian submillimetre facilities.

The new instrument will build upon the experience and success of SCUBA-2, to provide an order of magnitude increase in mapping speed (20x for polarisation mapping). This is achieved by means of a larger field of view, improved per-pixel sensitivity and with improved stability and uniformity of the detector array.

These notes are provided to guide the writing of science "white papers", in terms of minimum guaranteed performance for the new instrument.

The SCUBA-2 Integration Time Calculator

https://www.eaobservatory.org/jcmt/instrumentation/continuum/scuba-2/itc/

can be used as a guide, using a factor of 10 (20 for polarization) time improvement accordingly, for good weather.

Guaranteed mapping speed increase	10x compact[1], 10x large[2] maps	20x for polarimetry mapping
Aspirational mapping speed increase	20x large maps	40x for large polarimetry maps

Instrument Description

This will be a single colour instrument. The choice to build a dedicated 850μm camera is determined by two factors. Firstly, we can better optimise the optical design of the instrument for a single wavelength. The rejection of excess out of band power and prevention of stray light is key to the instrument performance. Secondly, the sky conditions on Maunakea are by far, better suited to observing in the 850μm window. This is where JCMT and the new instrument will make the greatest science impact, as has been demonstrated with SCUBA-2. 450μm capability will be provided in a future second MKID instrument or upgrade in 2024.

The full field of view (FoV) of the instrument will be 12 arcmin diameter (effectively twice as large as SCUBA-2). The focal plane will be filled with 3,636 1fλ spaced feedhorn coupled pixels. Each pixel is comprised of two detectors, that measure orthogonal linear polarisation. By careful choice of the orientation of pixels across the focal plane, it will be possible to determine all Stokes parameters from a single scan observation, without the need for a rotating HWP. This

[1] CV Daisy Scans – Note that the larger Field of View, does not directly increase mapping speeds for Daisy scans, but increased per-pixel sensitivity does.

[2] Pong Scan

allows polarisation mapping as a matter of course, with no overhead or penalties, while mapping continuum intensities.

The detector technology is Microwave Kinetic Inductance Detectors (MKID), as developed by NIST, Boulder, for BLAST-TNG and TolTEC (for LMT). The new pixel design will be optimised for both 850μm and the prevailing sky conditions at JCMT. The MKID form a resonant circuit consisting of an inductive strip and an interdigitated capacitor. In the NIST MKID design arrays, the inductor is identical for each pixel, while each capacitor is trimmed to a unique value. The inductor is made from TiN/Ti multilayers, allowing the Tc to be tuned by varying the thickness and number of layers. The inductor also serves as the absorber that couples to radiation from the waveguide. The choice of Tc, inductor geometry and impedance matching determine the optimal coupling, polarisation efficiency and saturation power.

The 7,272 MKID are readout by probing their unique resonance frequency, which by design are separated in frequency space. Incident radiation changes the detectors' resonance frequency.

The JCMT MKID pixels will have smooth walled feedhorns. The feedhorns will be fabricated by stacking etched silicon wafers, creating a monolithic feedhorn array block mounted in front of the detector wafer. The feedhorn terminates in a waveguide section matched to the observing wavelength.

Comparing the expected performance of the new MKID array to that of SCUBA-2, keeping in mind that the SCUBA-2 TES array remains the best large format submillimetre detector array in operational use.

- The per-pixel sensitivity (dark NEP) of the new MKID array will be uniformly $< 4\text{x}10^{-17}$ $\text{W/Hz}^{½}$, across the whole array. This will be a factor of two more sensitive than the best individual SCUBA-2 850μm detectors and a factor of 3 improvement for the average across the 4 SCUBA-2 850μm sub-arrays, which have a large variation.
- The detector yield will be close to 100% for the new array. The typical on-sky yield of the SCUBA-2 array is 60%, with additional detectors rejected during data reduction due to high noise and flux jumps.
- The new MKID array will be much less sensitive to the thermal stability of the focal plane and magnetic field pickup, both of which impact SCUBA-2 data reduction. The MKID detector response will be linear across the full range of sky power. SCUBA-2 detectors are prone to flux-jumps, due to the limited dynamic range of available SQUID feedback.
- The per-pixel sensitivity on the sky will be a factor of 3 more sensitive than SCUBA-2.

The improvements in sensitivity (Dark NEP), uniformity and array yield flow directly from advances in the fabrication techniques and the much simpler design and fabrication process for a MKID array compared to a TES array. The on-sky sensitivity improvement includes reducing excess optical power and stray light.

Observing modes for the new 850μm MKID instrument

The new 850μm MKID instrument will initially use the existing SCUBA-2 CV Daisy and rotating PONG scan patterns.

The larger FoV will make the CV Daisy scan naturally larger on the sky and extend (currently 3 arcmin) the central area with uniform exposure time. The uniformity of the array and more sensitive pixels will enable a 10x reduction in time to achieve a given target RMS (in mJy/beam). We might find that the standard Daisy replaces the 15-arcmin Pong scan map.

The larger FoV of the new instrument almost doubles the exposure time in a larger Pong map, while more sensitive pixels guarantee a 10x reduction in time to achieve a given sensitivity in a map. In the best case, the mapping speed can be increased by a factor of 20. For the white paper, we suggest basing the proposed science upon what can be achieved with a 10x increase in mapping speed, while adding a short section on what becomes possible with a 20x increase.

More optimized observing modes and scan patterns, particularly for polarimetry will be investigated during the instrument assembly and commissioning.

Time line for the new 850μm MKID instrument and Future Instruments

We plan to have the new 850μm MKID instrument operational at JCMT by October 2022. This will then be followed with a second instrument or an upgrade MKID array to add 450μm capability. A larger heterodyne array is targeted for 2026 or sooner. Namakanui will operational at JCMT later this year, providing 86, 230 and 345 GHz Bands and polarisation. Space remains in the JCMT cabin for visiting instruments, technology development and testing new science ideas.

Target Date	Milestone
October 2022	New 850μm instrument on-sky at JCMT
October 2024	New 450μm instrument providing 10x faster mapping than SCUBA-2 (20x POL-2) or an upgraded array to provide multi-chroic pixels
January 2026	New Large Format Heterodyne Array. 8x faster mapping than HARP. 2 sidebands and frequency range of 220 – 370GHz