SCUBA-2: A Large-Format TES Array for Submillimetre Astronomy

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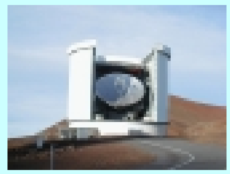
http://www.roe.ac.uk/atc/projects/scuba_two/

Introduction

SCUBA-2, which replaces SCUBA on the JCMT in 2006, will be the first CCD-like array for submillimetre astronomy. It will offer imaging of an 8x8 arcmin field of view at 850 and 450 microns simultaneously using two dc-coupled, monolithic arrays of ~10,000 bolometers. SCUBA-2 is expected to have a huge impact on the study of galaxy formation and evolution in the early Universe as well as star and planet formation in our own Galaxy. SCUBA-2's absorber-coupled pixels use superconducting transition edge sensors operating at ~120 mK for photon noise limited performance. The silicon detector arrays are deep-etched for thermal isolation and bump-bonded to a backplane that incorporates a SQUID multiplexer (see Poster Y26). The key technologies that make SCUBA-2 possible have applications wherever large-format arrays of detectors from the submillimetre through the X-ray spectral range are required.

The James Clerk Maxwell Telescope (JCMT) on Mauna Kea, Hawaii



Key features of SCUBA-2:

- **Simultaneous observing** at 450 and 850μm
- **Field-of-view:** 8×8 arcmin (16 times the area of SCUBA)
- **Array architecture:** 80×64 pixels in 2 arrays with spacing of 0.5Fλ (850) and Fλ (450)
- **Detectors:** Superconducting transition edge sensors
- **Arrays:** Micro-machined silicon detectors with hybridized SQUID multiplexer chips
- **Observing strategies:** Novel fast survey and imaging modes

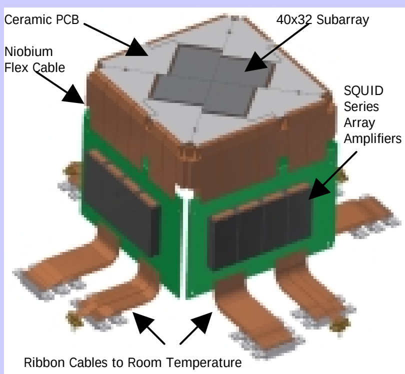
Estimated performance

Parameter	450 μm		850 μm	
	SCUBA	SCUBA-2	SCUBA	SCUBA-2
Per-pixel NEFD (mJy / √Hz)	400	75	90	32
Point source NEFD (mJy / √Hz)	400	107	90	22
Point source extraction speed	1	10	1	12
Large area mapping speed	1	648	1	784

Instrument Design

To achieve sky background limited performance the arrays are operated at ~120 mK. The cryostat is designed to operate without liquid cryogens to reduce operational costs. It uses a dilution refrigerator to cool the detector stage to 60 mK and the focal plane unit to 1 K. Pulse tube coolers cool the internal filters and optics at the 60 and 4 K stages.

A dichroic beamsplitter at the 1 K stage splits the beam into into components of wavelength 450 and 840 μm and directs them to two focal plane units (FPU). Each FPU fills the field of view with four subarrays as shown below. The subarrays have been shrunk to 40x32 pixels from the original 40x40 for more reliable patterning of the MUX on a 3" wafer. Niobium flex cables (see Poster G06) bring the multiplexed signals to series array amplifiers. The niobium flexes also provide a thermal break between the 60 mK stage and the 1 K stage. Ribbon cables bring the amplified signals out of the cryostat to a readout card incorporating an FPGA. Output values will be co-added and stored in the FPGA before being sent over a fibre optic link to a data collection PC (one per sub-array) at a rate of 200 frames per second.



SCUBA-2 Focal Plane Unit.

Science Drivers

The instrument challenge: Incorporate new developments in detector technology to build the first submillimetre "CCD" camera.

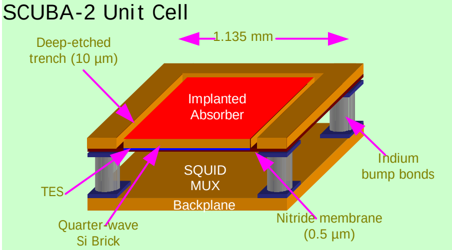
Maximize the survey potential
→ map large areas of sky >100 times faster than SCUBA

Deep imaging
→ to the confusion limit in only a few hours

Imaging at two colours simultaneously
→ study physical properties of dust emission

Improve the image fidelity and map dynamic range
→ have fully-sampled image planes; no sky chopping

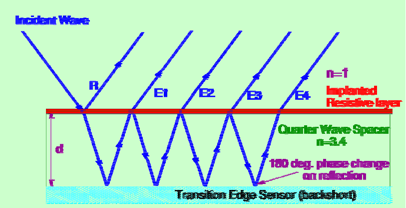
SCUBA-2 Unit Cell



The array architecture is based on a hybrid design that consists of an upper detector support wafer and a lower SQUID multiplexer (MUX) wafer held together with indium bump bonds. The bump bonds also provide the electrical and thermal connections between the wafers. The use of a cryogenic multiplexer is crucial since it makes it possible to instrument the full field-of-view with a practical number of wires.

Absorber-coupled Pixels

SCUBA-2's absorbers are essentially quarter-wave antireflection coatings. A pixel consists of a quarter-wave brick of silicon with a backshort and an implanted resistive layer on the top.



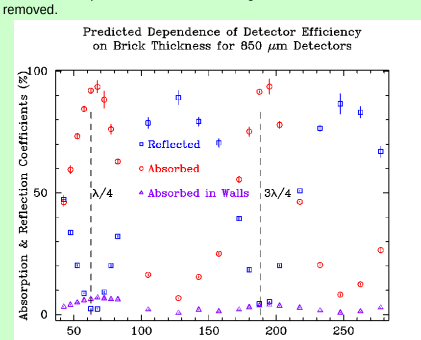
Incident radiation passes through the quarter-wave brick and is reflected by the backshort (the TES). There is constructive interference between the incident and emergent waves at the top of the slab. The energy of the radiation is dissipated in the resistive layer, heating up the pixel. The surface resistance of the resistive layer is 377 Ω/sq to match the impedance of free space.

Monolithic Subarrays

One 40x40 subarray test piece diced into shape required for final assembly. Each focal plane will consist of 4 subarrays butted together. Note that the subarray size is now 40x32 pixels.

Pixel Modelling

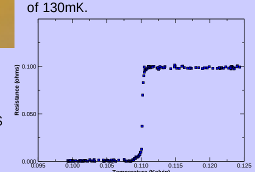
To verify the performance of the pixel design, we have have carried out an extensive programme of finite-element electromagnetic modelling with the Ansoft HFSS software package. The results led us to alter the pixel design to maximize the efficiency. Our original design had high silicon walls between pixels for mechanical strength. These have now been removed.



SCUBA-2 single-pixel test results

The pixels easily meet the noise equivalent power (NEP), speed, and power handling requirements for SCUBA-2. Dark NEPs of ~3 × 10^{-17} W/√Hz have been measured for devices with transition temperatures of 130mK.

Above: SCUBA-2 test pixel: 1×1 mm Mo/Cu TES on a Si nitride membrane. Heater leads are on the right and TES leads on the left.



Above: Superconducting transition is sharp, indicating a sensitive TES.

Left: Photograph of a test pixel showing a close-up of the TES leads and the slots in the nitride membrane that control the thermal conductance.

See Poster Y27 for the latest results.

Calibration

A cold shutter will take dark frames to compensate for any drifts in the detectors and read out electronics. We intend to monitor the response of the pixels by injecting signals based on maximum-length sequences (MLSs) into the bias or heater lines. A MLS is a pseudorandom binary sequence of length 2^N-1 bits which has the property that any N-bit subsequence within it is unique. This means that its circular auto-correlation is an impulse. The SCUBA-2 software will apply a MLS to a pixel and cross-correlate the resulting signal with the applied signal, yielding the pixel's impulse response.

Current Status

SCUBA-2 is due to be on the telescope in late 2005. Fabrication of the prototype detector subarrays is under way