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Reducing SCUBA Data at the James Clerk Maxwell Telescope

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Abstract. The Submillimetre Common-User Bolometer Array (SCUBA) is now operational at the James Clerk Maxwell Telescope (JCMT). This paper describes the SCUBA User Reduction Facility (SURF) data reduction software that has been developed for use with SCUBA.

1. Introduction

The Submillimetre Common-User Bolometer Array (SCUBA) is the recently commissioned instrument on the James Clerk Maxwell Telescope (JCMT)[2] on Mauna Kea. SCUBA is a bolometer array which means that for the first time JCMT has imaging capabilities in the submillimetre.

In order to maximize the number of bolometers in the array, they were packed on a hexagonal (rather than rectangular) grid. This means that the software has to reconstruct the data into an image. Moreover, because the bolometers are larger than half the beam width, the image cannot be fully sampled in a single exposure. In order to fully sample the image, the secondary mirror is "jiggled" to several adjacent positions and the software has to keep track of what sky position is associated with each data measurement. Finally, because of how SCUBA is mounted (on the Nasmyth platform), the sky rotates as the telescope tracks; this is also something the software must correct for.

2. SCUBA Observing modes

There are three major SCUBA observing modes, and these need some individual treatment from SURF, the Scuba User Reduction Facility, which is run off-line by the user:

Photometry: This mode is used to measure the flux of a point source. In its simplest guise the observation involves pointing a single bolometer at the source, measuring the signal, chopping and nodding to reduce the effect of sky emission, and integrating to build up the signal-to-noise. SCUBA also

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[2]http://www.jach.hawaii.edu/

allows for 2 or 3 bolometer photometry (chopping on the array), simultaneous photometry using the long and short wave arrays, and jiggling on source to reduce the effects of seeing.

Jiggle-mapping: This is the main imaging mode for sources which are smaller than the array (i.e. less than about 2 arcmin). As the SCUBA arrays are not fully-sampled and not on a rectangular grid, images can not be taken in the same way as for an optical CCD array. At least 16 individual secondary mirror, or 'jiggle', positions (each of 1 second) are required to make a fully sampled image (64 jiggles are required if both the long and short wave arrays are being used simultaneously). The SURF data reduction package must take these data, combine them and regrid them onto a rectangular grid.

Scan-mapping: Scan mapping, as the name suggests, is performed by the telescope scanning across an area of sky while simultaneously chopping. During the scan, care is taken that enough bolometers measure the same patch of sky so that the image is fully sampled, so it does not require jiggling or additional scans. This mode is suitable for sources that are extended. SURF combines the two beams that result from the chopping into a single-beam map.

3. SURF – The SCUBA User Reduction Facility

The real-time SCUBA observing system first demodulates data in the transputers – it takes data at 128Hz but only supplies data every second. It also provides a 'quick-look' display of the data based on some rudimentary data reduction done in the transputers.

The demodulated data is then "raw data" as far as SURF, the off-line system, is concerned. SURF aims to provide publication quality data reduction and currently requires user input and feedback.

The 'quick-look' display provided by the transputers can also be eavesdropped by a remote observer using a WORF system (Economou et al 1996; Jenness et al 1997).

SURF (like the real-time system) is written in the Starlink[3] software environment and therefore runs on Sun Solaris, Digital Unix and Linux. Computationally intensive routines are written in FORTRAN as ADAM tasks that form part of a monolith. Applications such as data reduction pipelines (calling multiple tasks from the monolith), string handling routines (e.g., generating observing logs) and small data reduction tasks were more suited to modern scripting languages than to FORTRAN and it was decided to use the perl programming language (Wall et al. 1996) for these.

Since the software is written in the Starlink environment, Starlink's N-Dimensional Data Format (NDF) is used for all file I/O. This format provides for error arrays, bad pixel masks, storage of history information and a hierarchical extension mechanism and SURF makes full use of these features. In order to

[3]http://star-www.rl.ac.uk/

get the most out of using perl it was necessary to write a perl interface to the FORTRAN NDF and HDS libraries. This module (distributed separately from SURF) provides complete access to all of the routines in these libraries allowing for full control of the NDF and HDS structures from perl.

To improve maintainability of the package all source code is kept under revision control (RCS) and subroutine libraries are shared with the on-line observing system.

SURF provides the tasks necessary to convert raw demodulated SCUBA data into a regularly-sampled image:

- flatfielding the array

  The different response of each bolometer is removed. Note that the flatfield remains constant with time and does not need to be re-measured every night.

- correcting for atmospheric extinction

  This task simply calculates the extinction due to the atmosphere by using the zenith sky opacity (tau) and calculating the elevation of each bolometer during each 1 second sample.

- removing spikes (manually and in software)

  Occasionally spikes are present in the data (instrumental glitches, cosmic rays etc) and these can be removed manually or by using software.

- removing sky fluctuations from JIGGLE/MAP and PHOTOM data.

  The submillimetre sky is very sensitive to sky noise caused by fluctuations in the emissivity of the atmosphere passing over the telescope. These variations occur in atmospheric cells that are larger than the array and the resultant noise is seen to be correlated across the array. At present this sky noise is removed by analysing bolometers that are known to be looking at sky and removing this offset from the data.

- generating a rectangularly sampled image.

  As described earlier, SCUBA data is under-sampled (for jiggle data), taken on an hexagonal grid and subject to sky rotation. SURF calculates the position of each bolometer during each 1 second sample (in a number of coordinate systems: RA/Dec, Galactic, Nasmyth, Azimuth-Elevation or moving centre (planet)) and regrids these data onto a rectangularly sampled image.

Once the data have been regridded the image can be converted to FITS (a full astrometry header is provided), if necessary, and analysed in the normal way.

The latest version of SURF is freely available from the SURF home page[4]. Additionally the software is distributed by Starlink and available on their CD-ROM.

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[4]http://www.jach.hawaii.edu/jcmt_sw/scuba/

4. Future

This software is being developed actively at the Joint Astronomy Centre and we hope to implement the following features in the next few months:

- Improve the automated data reduction by using a perl interface to the ADAM messaging library (already in development) and the UKIRT ORAC system (Economou et al. 1998). This will be implemented at the telescope, triggered by the SCUBA observing system, and off-line, triggered by the observer.
- At present sky noise removal has not been implemented for SCAN/MAP (since, unlike jiggle-map data, there is no concept of a 'sky' bolometer). It is hoped to implement a system for handling sky noise in due course.
- Implementing an Maximum Entropy reconstruction algorithm for SCAN/-MAP data (e.g., similar to the DBMEM implementation for the single pixel UKT14 (Richer 1992)) in addition to the standard Emerson, Klein and Haslam algorithm. A maximum entropy implementation would treat the reconstruction of the map as a direct linear inversion problem and would result in an image that is deconvolved from the beam. This technique has the advantages of enforcing positivity in the image, a proper treatment of correlations in the two dimensional data and allowing for the possibility of resolution enhancement for high signal-to-noise data. It is also hoped that this implementation will be able to handle sky-noise removal by treating sky-noise as additional free parameters for the reconstruction.

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