

SC/10.1

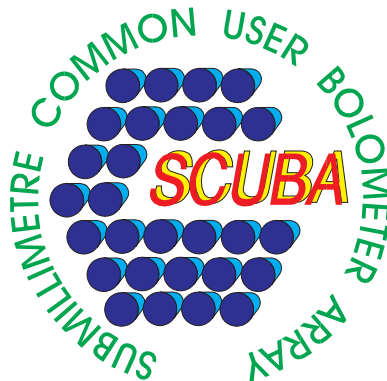
Starlink Project
Starlink Cookbook 10.1

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The SCUBA photometry cookbook



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1 Introduction

This document describes the basic reduction of photometric data taken with the Submillimetre Common-User Bolometer Array (SCUBA) at the James Clerk Maxwell Telescope. The adopted method is applicable to the full range of SCUBA's photometric observing modes: simple 'stare' type observations such as those performed with UKT14, small jiggle maps taken with a single pixel or either of the above but chopping between 2 or 3 bolometers on the arrays.

At the time of writing the fully commissioned photometry mode employs a single bolometer to make small 9-point maps centred on the source. This scheme has been shown to give better signal-to-noise under moderate submillimetre 'seeing' conditions than the traditional 'stare' method. However, the reduction procedure is still valid regardless of the adopted jiggle mode, for example, if a 7-point map or a scheme with no jiggling was used for the observation. Although not yet fully commissioned, it is possible to chop between two or three bolometers on the arrays and the reduction of these data is discussed briefly. In the future more elaborate methods, such as two and three position chopping, will be available and the document will evolve accordingly.

Our basic philosophy was to style the SCUBA photometry reduction graphical interface in a manner similar to that used for UKT14 [2] (i.e. COADD) but the observing modes and hence steps in the reduction process are particular to SCUBA.

This cookbook requires access to the Scuba User Reduction Facility (SURF) software [3] (for processing demodulated SCUBA data), KAPPA[4]¹ (for data display and post-processing) and CONVERT[5] (for exporting data to ASCII or FITS). SURF is available from the Starlinkhomepage.

2 Running up the software

The Scuba User Reduction Facility (SURF) software can be loaded by simply typing:

```
% surf

SURF - SCUBA User Reduction Facility
  Commands are now available -- (Version 1.0-0)

Type scuhelp for help on SURF commands.
Type "showme sun216" to browse the hypertext documentation.
```

3 The SURF commands

The SCUBA data reduction commands are summarized briefly in this section. On-line help for these commands can be accessed with scuhelp or by replying with ?? at any prompt.

¹This document assumes access to at least Version 0.10 of KAPPA.

There are six steps which need to be followed in order to produce the final coadded, but still uncalibrated, photometric result, namely `reduce_switch`, `change_flat`, `flatfield`, `extinction`, `scuphot` and `scucat`. In addition, data taken with the arrays may be corrected for sky noise variations by subtracting off the signal from surrounding bolometers using the `remsky` command. – see later in this section for a description of these commands.

The data reduction software takes the demodulated data as input and the format is `yyyymmdd_dem_xxxx` without the `.sdf` extension, for example, `19970711_dem_0025`. Additional files called `yyyymmdd_red_xxxx.sdf` are produced by the on-line data reduction software and include preliminary signal information.

The SCUBA log command, `sculog`², can be run to give a log of all the observations in a directory. All the journal software (`sculog`, `obssum`, `photsum`, etc.) as well as `reduce_switch` and `skydip` recognise the concept of a data directory. This means that the data (demodulated or reduced) does not need to be present in the current directory – the tasks will search for data in the directory specified by the `DATADIR` environment variable as well as the current directory. Using the unix C-shell this can be achieved by:

```
% setenv DATADIR /wherever/data/19970706/dem
```

which would instruct `obssum`, say, to search for data in directory `/wherever/data/19970706/dem`. Help on the log commands can be accessed with the `-h` option:

```
% sculog -h
```

```
Usage:
```

```
  sculog [-h] [-all]
```

```
Options:
```

```
-h[elp]           This message
-summary         Gives a one line summary of each file
-all            Catalog all sdf files regardless of numeric range
-begin nn        First scan number to be considered
-end nn          Final scan number to be considered
-demod           Only look at raw demodulated data files (ie _dem_)
-reduced         Only look at files reduced on-line (ie _red_)
-mode obs        Select observation modes
```

```
also
```

```
--begin=nn       First scan number (note the -- prefix)
--end=nn          Final scan number
--mode=obs        Select observation modes
```

```
Where nn is an integer and 'obs' is a comma delimited list of obsmodes.
```

```
Use 'perldoc sculog' for more information.
```

```
Author:
```

```
Tim Jenness (timj@jach.hawaii.edu)
```

The `photsum` command uses `sculog` to produce a brief description of each observation (like `usum` for UKT14). If the reduced data files are present then this summary will include signal and skydip tau values, e.g.,

²Use `obssum` for one line summaries

```

% photsum -all -reduced
#      HST      Source  Meas/Int  Am  Filter  SubInst  Signal  S/N  Tau  Seeing
-----
42  20:17  mars      1/5    1.09  450N:850  LONG    4.80e+00  279.5  0.052  1.376
                                SHORT    3.10e-01  8.32
45  20:30  mars      1/5    1.07  450N:850  LONG    4.85e+00  375.7  0.044  1.376
                                SHORT    1.69e+00  185.
46  20:33  mars      1/5    1.07  450N:850  LONG    4.86e+00  275.6  0.044  1.376
                                SHORT    1.71e+00  116.
47  20:36  mars      1/5    1.06  350N:750  LONG    4.15e+00  518.0  0.045  1.376
                                SHORT    5.35e-01  242.
48  20:40  mars      1/5    1.06  850S:PHO  P1350   4.95e+00  458.5  0.045  0.487
49  20:43  mars      1/5    1.05  850S:PHO  P2000   4.22e-01  282.9  0.045  0.487
*****
50  20:46  SKYDIP    10/20          450N:850  SHORT:   0.936          0.062  0.487
                                LONG     0.211
-----
*****
51  20:54  SKYDIP    10/20          350N:750  SHORT:   0.943          0.062  0.487
                                LONG     0.411
-----
64  22:38  B21122+390  1/20  1.08  850S:PHO  P2000   2.74e-06  0.203  0.048  0.17
65  22:49  B21122+390  1/20  1.09  850S:PHO  P2000   2.12e-05  1.786  0.044  0.124
66  22:59  B21122+390  1/20  1.10  850S:PHO  P2000   2.50e-05  2.249  0.045  0.124
67  23:09  B21122+390  1/20  1.12  850S:PHO  P2000   1.79e-05  1.829  0.047  0.124
68  23:19  B21122+390  1/20  1.13  850S:PHO  P1350   1.14e-04  5.434  0.05  0.098
69  23:30  B21122+390  1/20  1.15  850S:PHO  P1350   1.18e-04  5.280  0.047  0.098
72  23:47  mars      1/5    1.20  850S:PHO  P2000   4.19e-01  415.3  0.046  0.096
73  23:51  mars      1/5    1.21  850S:PHO  P1350   4.65e+00  720.6  0.046  0.096
74  23:55  mars      1/5    1.23  450N:850  LONG    4.93e+00  548.5  0.046  0.096
                                SHORT    1.69e+00  187.
76  00:55  mars      1/5    1.53  350N:750  LONG    4.01e+00  633.3  0.051  0.144
                                SHORT    4.51e-01  514.
78  01:02  B21122+390  1/20  1.46  350N:750  LONG    1.33e-04  4.697  0.046  0.144
                                SHORT    4.39e-05  2.08
79  01:13  B21122+390  1/20  1.52  350N:750  LONG    1.11e-04  4.540  0.048  0.108
                                SHORT    3.10e-05  1.71

```

3.1 reduce_switch

Reduces the raw beam-switched data by subtracting the off-position from the on-position. The telescope will nod after each nine-point jiggle (or nine-second stare, etc.) which is thus referred to as a switch. At this stage the resulting signal can also be multiplied by the internal calibrator. At present this is not advised since the extent to which microphonically induced noise affects the signal at the chop frequency has not been fully investigated.

The SPIKE_LEVEL option can be used to remove spikes at an early stage. Each position in the map consists of 128 samples which correspond to one second of integration time. If SPIKE_LEVEL is given a value in the range 1–128 the one second of integration will be removed only if this number of spikes is exceeded. The current default SPIKE_LEVEL is 5.

3.2 change_flat

Used, when appropriate, to switch between flatfield files (see §3.3).

3.3 flatfield

Photometric data taken with the arrays should always be divided by the flatfield so that sky removal can be performed at a later stage. Of course, for two and three bolometer chopping the flatfield command must be used (see §6). The current flatfield file is called `photflat1.dat` and should ideally reside in the data reduction directory unless it is used as default by flatfield. Note that `photflat1.dat` does not yet contain values for the outer ring of SW bolometers. The `change_flat` command can be used to switch between flatfield files. Note that it is necessary to do this before applying the flatfield.

3.4 extinction

Applies an extinction correction to the flatfielded data. If more than one sub-instrument (a sub-instrument is defined as one of the arrays or one of the photometric pixels) was used for the observation then extinction will prompt for one of them. For the arrays, the choice is LONG or SHORT and for the photometric pixels (which will be looking at different parts of the sky) the choice is P2000, P1350 and P1100. Each observation will have to be reduced separately from this stage on. For long, coadded integrations it is likely that the transparency of the sky will change during the observation. The actual values of the extinction coefficients will usually be determined by skydipping before, after, and depending on the sky conditions, possibly in between the group of integrations that are to be coadded (note that it is standard practice to split a long integration into smaller chunks). If the first opacity differs from the second then the extinction is linearly interpolated between the relevant times. Note that extinction requires the sidereal time at which each extinction coefficient was determined but 0 can be given in each case if the extinction remained constant over the integration.

3.5 remsky

Allows subtraction of the signal from sky bolometers. Tests during the commissioning period showed that, for faint sources, the signal is often dominated by atmospheric variations or sky noise. Furthermore, such variations were found to be correlated across the arrays and can thus be corrected for. At present the sky removal algorithm simply subtracts from the signal bolometer a mean or median signal level from a user specified list of sky bolometers. The mean method allows bolometers that are a specified number of standard deviations from the mean to be dropped. Sky subtraction is done on a jiggle-by-jiggle basis and so the sky point is measured 9 seconds after the source point for the default 9-point jiggle pattern.

Sky removal should be used with caution. Possible pitfalls include subtracting the signal level from a bolometer at the chop position (for chop throws of less than about 90"), using the inner ring of bolometers for a source that may be extended, or selecting bolometers that are microphonic or dominated by 1/f noise. For point sources and the mean sky subtraction method, we recommend using the inner ring of the long-wave array (h6,h8,h13,h14,g15,g16) and the non-noisy bolometers from the second ring out on the short-wave array (d10,e2,d7,c12,c2,b5,b10,c5,c16). For the median method a longer list can be given.

3.6 scuphot

Takes the extinction corrected data and averages the nine points together to produce a final signal for each switch. An ASCII summary file is produced by `scuphot` which contains the basic parameters of the observation such as source name, coordinates, filter name as well as tabulated values of the signal and its variance for each data point. Also included is the value of the coadded result and its variance. See §5.1 for an example of such a file.

3.7 scucat

Concatenates the individual photometric observations to produce a final coadded data set. Note that the user specified output file is appended with the bolometer names that were used in the observation (see the section on multiple bolometer chopping for examples (§6)). It is recommended that this command be executed even if the data set consists of one observation – otherwise the nomenclature becomes unwieldy when plotting the data. Specifically, the plotting routine will require an extension of the form `.bolometer_peak` to be added to the output of `scuphot`. For example, if the `scuphot` output file `red25_phot.sdf` is an observation with the central pixel of the long-wave array then it will be identified by `red25_phot.h7_peak` if it is not processed by `scucat`.

Data that have already been concatenated with `scucat` can be added to `scuphot` output. This feature is useful if previously reduced data from one night need to be coadded with newly reduced data from another. Note that you will be prompted for a bolometer name after entering the file name of the previously concatenated dataset.

4 Displaying and despiking the data

The command `qdraw` uses the KAPPA routine `linplot` to display clearly the concatenated photometric data values. If you wish to plot the data in a different format then `linplot` will do the job (making sure that the KAPPA tasks are initialised using the `kappa` command; refer to the documentation or type `linplot` prompt to see the available options. However, `qdraw` is recommended owing to the ease with which data can subsequently be despiked.

To plot the data simply type

```
% qdraw <filename> mode=4 device=xwindows
```

where the input file is the output of `scucat`. This will give a plot of the data with the ordinate autoscaled to 5σ either side of the mean. Note that any data points further than 5σ from the mean are effectively hidden from you. The mean level and the $\pm 3\sigma$ levels are indicated by dashed lines and error bars are suppressed for clarity. Numerical values of the mean signal, standard deviation and error in the mean are given for the full data set and the data set after clipping at the 3σ level. The `qdraw` routine will accept the same options as `linplot` so refer to the documentation if you wish to change the display parameters.

Further clipping can then be performed with the KAPPA command `drawsig`. For example,


```
% drawsig nsigma=2.5 device=xwindows
```

will clip the data at the 2.5σ level, again indicated by dashed lines on the plot and the statistics for the new clipping level will be given as before.

It is also possible that the data set will contain one or more large spikes in which case an iterative despiking method would be the best choice. In this case a new binary file with the bad points removed can be created with the command sigclip, e.g.

```
% sigclip <filename> 3.0
```

will clip the data at 3σ creating a new file of the form filename_clip.sdf which can then be plotted with qdraw and drawsig.

5 Sample reductions

The following two sections show sample reductions of real photometric data, first by the long winded method of typing each of the SURF commands in turn and then using the perl [6] script scuquick which provides some level of automation.

For the first example, I'll use two 20 integration observations of the radio galaxy 3C 31 which were made at 2.0 mm during the astronomical commissioning on a poor night (the zenith optical depth at 225 GHz was about 0.1). I'll use change_flat to change the flatfield file although, since we are using one of the photometric pixels, flatfielding is not necessary.

5.1 Example reduction – long method

The first observation is #70:

```
% reduce_switch
IN - Name of input file containing demodulated data > 19970807_0070
USE_CALIBRATOR - Should the data be divided by the internal calibrator /NO/ >
SURF: run 70 was a PHOTOM observation of object 3C31
SURF: file contains data for 2 switch(es) in 1 exposure(s) in 20 integration(s)
in 1 measurement(s)
SPIKE_LEVEL - De-spike level /5/ >
OUT - Name of output file to contain reduced switch data > red70
% change_flat
IN - Name of input file containing demodulated map data /@red70/ >
SURF: run 70 was a PHOTOM observation of 3C31
NEW_FLAT - The name of the file containing the new flat-field > noiseflat.dat
% flatfield
IN - Name of input file /@red70/ >
SURF: run 70 was a PHOTOM observation of 3C31
OUT - Name of output file > red70_flat
SURF: applying flatfield from noiseflat.dat
% extinction
IN - Name of NDF containing demodulated data /@red70_flat/ >
SURF: run 70 was a PHOTOM observation with JIGGLE sampling of object 3C31
```

```

SURF: file contains data for 1 exposure(s) in 20 integration(s) in 1
measurement(s)
SURF: observation started at sidereal time 2 35 59.4417688 and ended at 2 52
07.164001
SURF: file contains data for the following sub-instrument(s)
- P2000 with filter 2000
FIRST_TAU - First zenith sky opacity measured > 0.1
FIRST_LST - Sidereal time of first opacity measurement; hh mm ss.ss > 0
SECOND_TAU - Second zenith sky opacity measured > 0.1
SECOND_LST - Sidereal time of second opacity measurement; hh mm ss.ss > 0
OUT - Name of output NDF > red70_ext
% scuphot
IN - Name of input file containing demodulated data /@red70_ext/ >
SURF: run 70 was a PHOTOM observation of 3C31
SURF: file contains data for 1 exposure(s) in 20 integrations(s) in 1
measurement(s)
ANALYSIS - Which reduction method /'AVERAGE'/ >
OUT - Name of container file to hold map and time-sequence data > red70_phot
FILE - Name of ASCII file to contain results summary // > red70_phot.dat

```

The ASCII file, red70_phot.dat, contains the following:

```

% cat red70_phot.dat
Output from REDS reduction of a PHOTOM observation
Reduction date      : Mon May 19 12:04:08 1997
Observation definition: 3c31.obs
Date of observation  : 1996:8:7
Time of observation  : 15:52:07.659988
Run number          : 70
Object              : 3C31
Sub-instrument      : P2000
Filter              : 2000
Centre coords       : RB
Latitude            : +32:08:43.3
Longitude           : 01:04:39.10
Offset coords       : UNKNOWN
x offset            : 0
y offset            : 0
Sample coords       : NA
Sky error removal   : FALSE

Photometric analysis : AVERAGE

Bolometer: G6
Weight: 1

Integration Peak   Error      S/N     Peak_x   Peak_y
  1   0.294E-04  0.461E-02   0.006  0.000E+00  0.000E+00
  2   0.146E-03  0.461E-02   0.032  0.000E+00  0.000E+00
  3   0.168E-03  0.460E-02   0.036  0.000E+00  0.000E+00
  4   0.174E-03  0.461E-02   0.038  0.000E+00  0.000E+00
  5   0.103E-03  0.459E-02   0.023  0.000E+00  0.000E+00
  6   0.116E-03  0.460E-02   0.025  0.000E+00  0.000E+00
  7   0.182E-03  0.461E-02   0.039  0.000E+00  0.000E+00

```

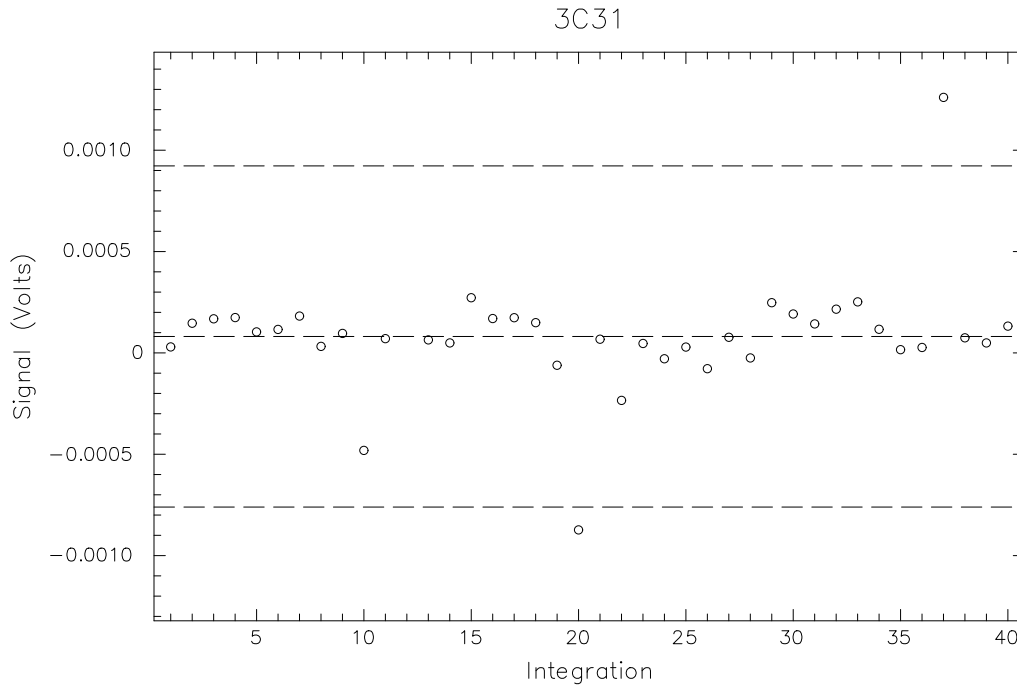


Figure 1: Concatenated data for observations #70 and #71. The mean and plus and minus 3σ levels are indicated with the dashed lines.

8	0.321E-04	0.462E-02	0.007	0.000E+00	0.000E+00
9	0.959E-04	0.462E-02	0.021	0.000E+00	0.000E+00
10	-0.481E-03	0.466E-02	-0.103	0.000E+00	0.000E+00
11	0.705E-04	0.466E-02	0.015	0.000E+00	0.000E+00
12	0.445E-04	0.496E-02	0.009	0.000E+00	0.000E+00
13	0.640E-04	0.468E-02	0.014	0.000E+00	0.000E+00
14	0.490E-04	0.470E-02	0.010	0.000E+00	0.000E+00
15	0.272E-03	0.469E-02	0.058	0.000E+00	0.000E+00
16	0.170E-03	0.471E-02	0.036	0.000E+00	0.000E+00
17	0.174E-03	0.471E-02	0.037	0.000E+00	0.000E+00
18	0.149E-03	0.473E-02	0.032	0.000E+00	0.000E+00
19	-0.609E-04	0.474E-02	-0.013	0.000E+00	0.000E+00
20	-0.874E-03	0.480E-02	-0.182	0.000E+00	0.000E+00

Measurement results:

Parabolic fit to coadded jiggle:

0.105E-03 0.385E-04 2.713 -0.170E+01 0.299E+00

Coadded result of individual integrations:

0.312E-04 0.584E-04 0.534

The same procedure is repeated (not shown here) for #71 to produce the file red71phot.sdf. We can then combine the two observations using scucat:

```
% scucat
OUT - Rootname of files to contain concatenated data > 3C31_2000
```

```

IN - Name of input file containing photometry data > red70_phot
SURF: Found data for the following bolometers: g6
SURF: This is a PHOTOM observation of 3C31. There are 20 integrations
IN - Name of input file containing photometry data /!/ > red71_phot
SURF: Found data for the following bolometers: g6
SURF: This is a PHOTOM observation of 3C31. There are 20 integrations
IN - Name of input file containing photometry data /!/ >

```

We are now in a position to plot and despiking the data (see Figure 1). Note that the bolometer name, *g6*, will be appended to the file name giving *3C31_2000_g6.sdf*.

```

% qdraw 3C31_2000_g6 mode=4 device=xwindows
NDF is 3C31_2000_g6
The default values have been adopted for parameter ABSLIM.
Current picture has name: DATA, comment: KAPPA_LINPLOT.
Using /home/jas/scuba/test/3C31_2000_g6 as the input NDF.

```

Clip (+/-)	mean	std. deviation	Error in mean
-----	----	-----	-----
	0.800321E-04	0.276960E-03	0.437913E-04
3.000	0.740715E-04	0.136353E-03	0.221194E-04

Clearly, this data set contains large spikes and the best despiking strategy is to remove the two biggest spikes that fall outside the 3σ levels and then replot the data. For this we use the `sigclip` command.

```

% sigclip 3C31_2000_g6 3.0
There was 1 element changed in the DATA array below the threshold.
There was 1 element changed in the DATA array above the threshold.
Clipped data written to 3C31_2000_g6_clip.sdf
% qdraw 3C31_2000_g6_clip device=xwindows mode=4
NDF is 3C31_2000_g6_clip
The default values have been adopted for parameter ABSLIM.
Current picture has name: DATA, comment: KAPPA_LINPLOT.
Using /home/jas/scuba/test/3C31_2000_g6_clip as the input NDF.

```

Clip (+/-)	mean	std. deviation	Error in mean
-----	----	-----	-----
	0.740715E-04	0.136353E-03	0.221194E-04
3.000	0.890766E-04	0.101563E-03	0.166969E-04

```

%
% drawsig nsigma=2.5 device=xwindows
Current picture has name: DATA, comment: KAPPA_LINPLOT.
Using /home/jas/scuba/test/3C31_2000_g6_clip as the input NDF.

```

Clip (+/-)	mean	std. deviation	Error in mean
-----	----	-----	-----
	0.740715E-04	0.136353E-03	0.221194E-04
2.500	0.890766E-04	0.101563E-03	0.166969E-04

All three obvious spikes have now been removed and there are no further spikes down to the 2.5σ level (see Figure 2). The source is detected at the 5.3σ level.

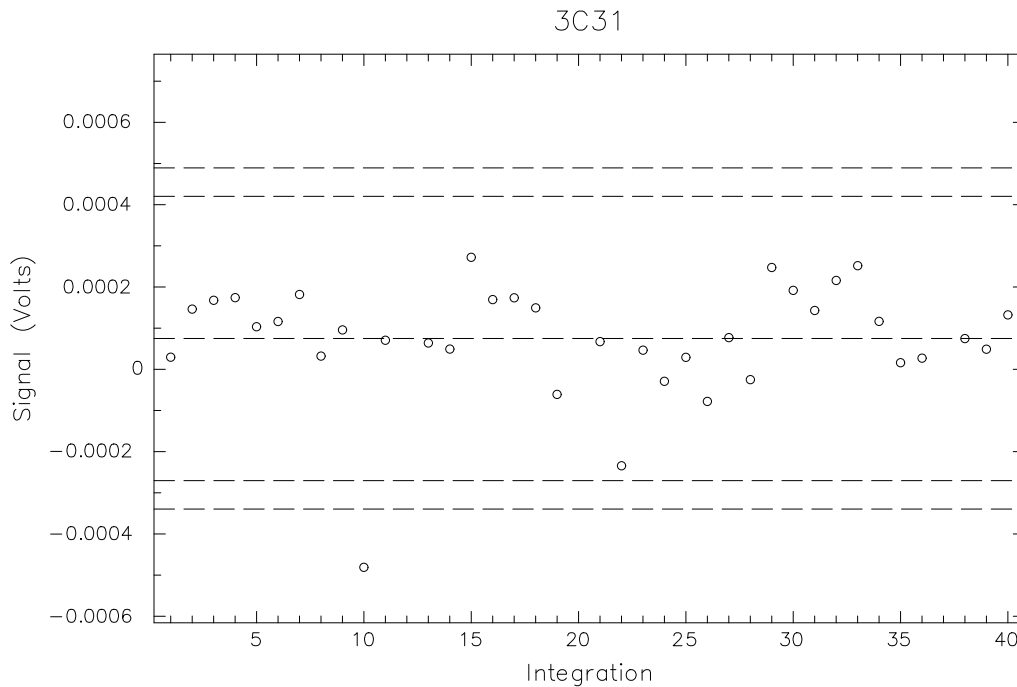


Figure 2: Concatenated data for #70 and #71 after removal of the two largest spikes with sigclip. The third spike is now excluded with a 3σ clip and there are no further spikes at the 2.5σ level.

5.2 Example reduction - scuquick

The PERL script scuquick can be used to save time by automating the reduction process up to and including the scuphot stage. Note that if many repetitive operations are to be performed then scuquick (or any other SURF command) will take options. For example,

```
% scuquick -remsky
```

will invoke the remsky command at the appropriate position in the reduction process. A list of available options can be accessed by typing

```
% scuquick -h
```

Usage:

```
scuquick [-h] [-change_flat] [-remsky] [-rebin] [-notau|tau f] [-sub s]
```

Options:

```
-h[elp]          This message
-quick          Run all tasks with the 'accept' flag (ie take defaults)
-quiet         Hide all messages generated by the script (note this is
               not the same as using MSG_FILTER=quiet which hides messages
               from the tasks)
-change_flat   Run the change_flatfield task
-remsky       Run remsky
-rebin        Regrid the data
```

```

-sub s      Select a specific sub-instrument (else selects all)
-notau     Use a tau value of 0 in extinction
-tau f     Use a constant value (f) for the tau. This is dangerous
           when reducing data containing multiple sub-instruments
           unless the -sub flag is used.

```

Notes:

```

Parameters for any task can be specified on the command line
as param=value. All other command line arguments are assumed to be
input NDFs.

```

The second example uses scuquick to reduce a long integration on the radio galaxy 8C1435+635 at 450 and 850 μ m. Note that scuquick will reduce data from both arrays unless instructed otherwise by use of the -sub option.

This data set was obtained under moderately noisy sky conditions so sky removal will be used in an attempt to correct for the sky variations. I'll just reduce the first demodulated data file here.

```

% scuquick -remsky
IN - Name of input file containing demodulated data > 19970502_dem_0052
SURF: run 52 was a PHOTOM observation of object 8C1435+635
USE_CALIBRATOR - Should the data be divided by the internal calibrator /NO/ >
SURF: file contains data for 2 switch(es) in 1 exposure(s) in 40 integration(s)
in 1 measurement(s)
SPIKE_LEVEL - De-spike level /5/ >
OUT - Name of output file to contain reduced switch data > r52
SURF: run 52 was a PHOTOM observation of 8C1435+635
SURF: applying flatfield from photflat1.dat

```

Processing the LONG sub instrument

```

SURF: run 52 was a PHOTOM observation with JIGGLE sampling of object 8C1435+635
SURF: file contains data for 1 exposure(s) in 40 integration(s) in 1
measurement(s)
SURF: observation started at sidereal time 14 54 12.45781 and ended at 15 14
46.826715
SURF: file contains data for the following sub-instrument(s)
- LONG with filter 850
- SHORT with filter 450
FIRST_TAU - First zenith sky opacity measured > 0.18
FIRST_LST - Sidereal time of first opacity measurement; hh mm ss.ss > 0
SECOND_TAU - Second zenith sky opacity measured > 0.18
SECOND_LST - Sidereal time of second opacity measurement; hh mm ss.ss > 0
Extinction corrected data has been written to file r52_ext_long.sdf
SURF: run 52 was a PHOTOM observation with JIGGLE sampling of object 8C1435+635
BOLOMETERS - The Sky bolometers, [a1,a2] for an array /['d10','c16','c12',
'c2','b9','b10','b11','c5','c16','d10','e2','e3']/ > [h6,h8,h13,h14,g15,g16]
MODE - Sky removal mode /'MEAN'/ >
ITER_SIGMA - Sigma level to drop points from mean iteratively /-1/ > 3.
CLIP - Do you wish to clip the bolometers? /NO/ >
Sky corrected data has been written to file r52_sky_long.sdf
SURF: run 52 was a PHOTOM observation of 8C1435+635
SURF: file contains data for 1 exposure(s) in 40 integrations(s) in 1

```

```

measurement(s)
ANALYSIS - Which reduction method /'AVERAGE'/ >
Processed photometry data written to r52_phot_long.sdf and r52_phot_long.dat

Processing the SHORT sub instrument

SURF: run 52 was a PHOTOM observation with JIGGLE sampling of object 8C1435+635
SURF: file contains data for 1 exposure(s) in 40 integration(s) in 1
measurement(s)
SURF: observation started at sidereal time 14 54 12.45781 and ended at 15 14
46.826715
SURF: file contains data for the following sub-instrument(s)
- LONG with filter 850
- SHORT with filter 450
FIRST_TAU - First zenith sky opacity measured > 1.0
FIRST_LST - Sidereal time of first opacity measurement; hh mm ss.ss > 0
SECOND_TAU - Second zenith sky opacity measured > 1.0
SECOND_LST - Sidereal time of second opacity measurement; hh mm ss.ss > 0
Extinction corrected data has been written to file r52_ext_short.sdf
SURF: run 52 was a PHOTOM observation with JIGGLE sampling of object 8C1435+635
BOLOMETERS - The Sky bolometers, [a1,a2] for an array /['h6','h8','h13','h14',
'g15','g16']/ > [d10,c16,c12,c2,b9,b10,b11,c5,c16,d10,e2,e3]
MODE - Sky removal mode /'MEAN'/ >
ITER_SIGMA - Sigma level to drop points from mean iteratively /-1/ > 3.
CLIP - Do you wish to clip the bolometers? /NO/ >
Sky corrected data has been written to file r52_sky_short.sdf
SURF: run 52 was a PHOTOM observation of 8C1435+635
SURF: file contains data for 1 exposure(s) in 40 integrations(s) in 1
measurement(s)
ANALYSIS - Which reduction method /'AVERAGE'/ >
Processed photometry data written to r52_phot_short.sdf and r52_phot_short.dat

```

and similarly for the rest of the data after which `scucat` and `display/despoke` procedures can be followed as before. Note that I took the 'default' sky bolometers which correspond to the inner ring of the long-wave array in this case - in fact these are not strictly the default but rather the last combination that were used. I recommend reducing the data both with and without sky removal since under very stable conditions the signal-to-noise can be degraded by removing the sky. A useful aid is a plot of signals from the source bolometer and sky removal bolometers. There are a variety of ways of doing this: Appendix A describes how to get ascii output for any bolometer; here I'll use `SURF` and `KAPPA` commands to investigate the effects of the adopted sky removal. Firstly, we can use `scuphot` and `scucat` to write out data for all bolometers in a file - in this case observation #52 as before. I'll use the extinction corrected data because these have been processed by flatfield;

```

% scuphot allbols=true
IN - Name of input file containing demodulated data // > r52_ext_long
SURF: run 52 was a PHOTOM observation of 8C1435+635
SURF: file contains data for 1 exposure(s) in 40 integrations(s) in 1
measurement(s)
ANALYSIS - Which reduction method /'AVERAGE'/ >
OUT - Name of container file to hold map and time-sequence data > r52_all
SCUPHOT: All bolometers selected
FILE - Name of ASCII file to contain results summary /!/ > r52_all.dat

```

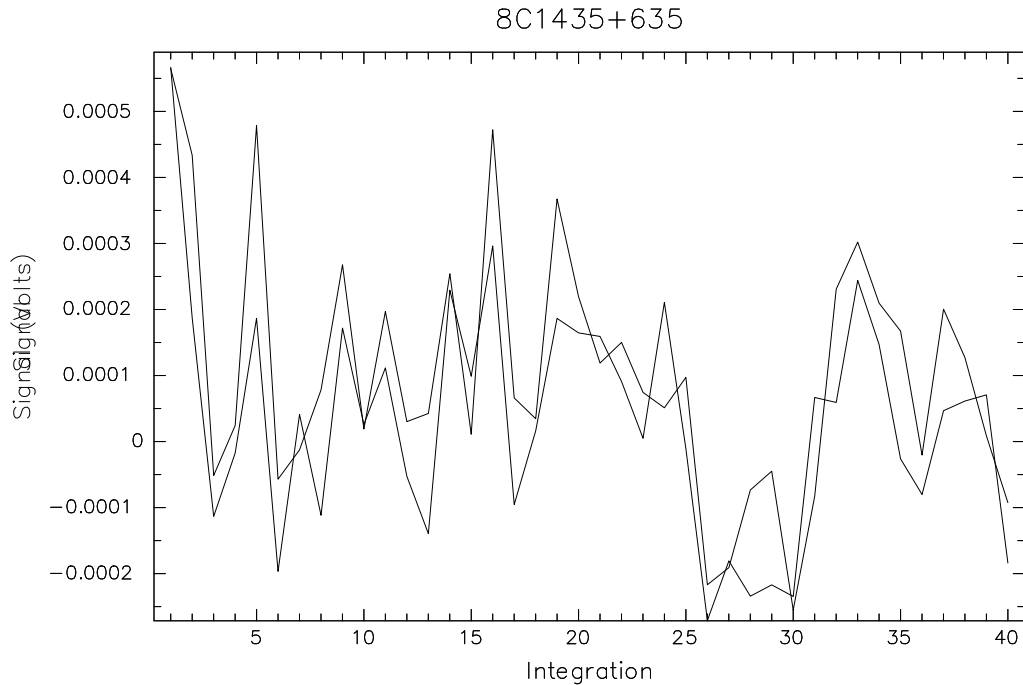


Figure 3: Comparison of the the signal from the central bolometer of the long-wave array with the mean signal from the six surrounding sky bolometers. Correlated sky noise is clearly seen in this case.

```
% scucat
OUT - Rootname of files to contain concatenated data > r52
IN - Name of input file containing photometry data // > r52_all
SURF: Found data for the following bolometers:
g1,g2,g3,g4,g7,g8,g9,g10,g11,g13,g14,g15,g16,h1,h2,h4,h5,h6,h7,h8,h9,h10,h11,h1
2,h13,h14,h15,h16,i1,i2,i3,i4,i5,i6,i7,i8,i9
SURF: This is a PHOTOM observation of 8C1435+635. There are 40 integrations
IN - Name of input file containing photometry data //!< >
```

Each bolometer now has a file called, e.g. r52_h7.sdf. The KAPPA commands add and cdiv can be used to get a mean sky value for the inner ring.

```
% add
IN1 - First input NDF /'r52_all'/ > r52_h6
IN2 - Second input NDF > r52_h8
OUT - Output NDF > sum
% add
IN1 - First input NDF /@sum/ > sum
IN2 - Second input NDF > r52_h13
OUT - Output NDF > sum1
% add
IN1 - First input NDF /@sum1/ > sum1
IN2 - Second input NDF > r52_h14
```



```

OUT - Output NDF > sum2
% add
IN1 - First input NDF /@sum2/ >
IN2 - Second input NDF > r52_g15
OUT - Output NDF > sum3
% add
IN1 - First input NDF /sum3/ >
IN2 - Second input NDF > r52_g16
OUT - Output NDF > sum4
% cdiv
IN - Input NDF data structure /@sum4/ >
SCALAR - Division constant /6/ >
OUT - Output NDF > inner_ring
%
```

and then use `linplot` to overlay the data (you can use e.g. `lincol=red` to get coloured plots),

```

% linplot r52_h7 device=xwindows mode=line
% linplot inner_ring device=xwindows mode=line noclear
```

Figure 3 shows the output from `linplot` which clearly shows that the signal and sky are correlated in this case.

6 Two and three bolometer chopping

It is possible to chop between two or three bolometers on the array, the main benefit being more time spent on-source during the observation. The reduction of these data is very similar to the single bolometer method shown in the preceding section. The only recognizable difference is that `scucat` will produce a concatenated output file for each bolometer. For example, if data were taken simultaneously with the long-wavelength array pixels `h7` and `h9` and the specified output file is `source1` then files `source1_h7.sdf` and `source1_h9.sdf` will result.

The most robust method of reducing these data is to observe a planet, such as Mars, in exactly the same way and then to calibrate each bolometer separately into flux units. The coadded result and its statistical uncertainty can then be calculated with standard formulae.

7 Is it correct to coadd the data sets? The K-S test

Photometric observations of faint sources often require that the source be observed for long periods, during which the atmospheric conditions and/or telescope related parameters such as pointing and focus may vary. These effects are particularly noticeable around sunrise and sunset, for example. The consistency of the entire data set can be investigated with the use of a two sample Kolmogorov-Smirnov (KS) test. Again, the method adopted for the SCUBA data reduction package is analogous to that used previously by COADD for UKT14 [7].

The data set is split into subsamples that are specified by the user. The size of these subsamples clearly depends on the total number of photometric points and some experimentation is required

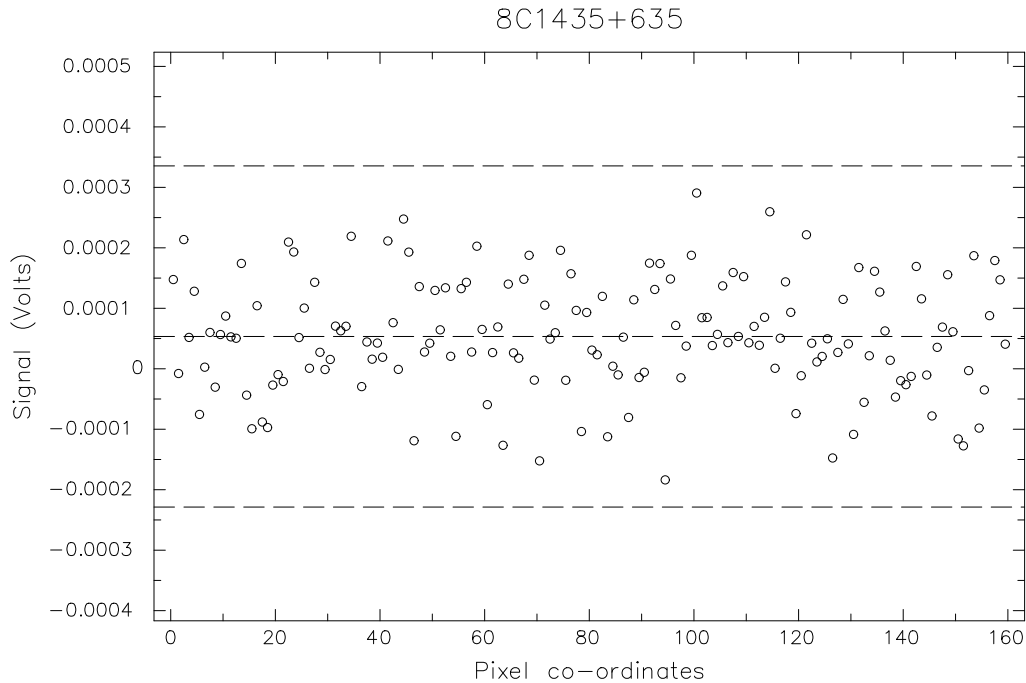


Figure 4: A 48 minute ($160 \times 9/2.0$ jiggle patterns) integration on 8C1435+635. The sigclip command has been used to produce a dataset despiked at the 3σ level.

but, for example, if the data set consists of 100 points then subsamples of 20 would be a sensible choice. The first subsample is compared with the second and is ‘rejected’ if the probability that the two are statistically different is lower than a user specified tolerance. If the KS test returns 0.1 then this indicates that there is a 90% probability that the two samples are different. If the first two subsamples are consistent then they are concatenated and compared with the third etc, otherwise the first subsample is compared with the third and so on. A problem arises if, for some reason, the first subsample is different from each of the others since in this case most of the data set will be rejected. If this happens it is necessary to repeat the process but this time select a different subsample against which the others are to be compared. In general, it is good practice to change the order and repeat the test.

The best way to illustrate the whole process is with an example using real data.

7.1 An example

For the example I’ll use the 8C1435+635 measurement at $850\mu\text{m}$ that was discussed in §4.2. Here the whole data set has been reduced with sky removal, concatenated and despiked using sigclip (see Figure 4). Note that sigclip must be used rather than drawsig because it produces an output file devoid of spikes. I renamed this file 8c_clip for brevity.

The kstest command is part of the Starlink KAPPA package and takes a variety of parameters. In this document I’ll just discuss those relevant to the basic KS test as applicable to photometry data. A full description of the routine can be found in the KAPPA manual (SUN/95).

I'll split the dataset into subsamples of 20 integrations (the second subsample will contain only 19 points because sigclip removed one spike). In this example, the input and output file names are specified on the command line but this need not be the case. Note that it is, however, necessary to give the number of samples and the probability in the same way, otherwise the default values of 3 and 0.05 are assumed respectively. A maximum number of 20 subsamples is allowed by kstest.

```
% kstest in=8c_clip out=8c_ks nsample=8 limit=0.05
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 19 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
```

	Probability	Max. Sep.	
cf. with 2 :	0.288655E+00	0.300000E+00	(Accepted)
cf. with 3 :	0.244933E+00	0.270513E+00	(Accepted)
cf. with 4 :	0.981682E+00	0.116102E+00	(Accepted)
cf. with 5 :	0.924850E+00	0.132279E+00	(Accepted)
cf. with 6 :	0.288812E-01	0.344444E+00	(Rejected)
cf. with 7 :	0.380108E+00	0.215151E+00	(Accepted)
cf. with 8 :	0.583820E+00	0.181092E+00	(Accepted)

```
Number of subsamples rejected: 1
Coadded result is 4.8022197E-5 +/- 8.0190266E-6
```

Subsample 6 which contains many more points with a signal greater than zero compared to the other subsamples is rejected (see Figure 4). If you wish to view the truncated dataset then 8c_ks.sdf can be displayed with qdraw in the usual way.

If the first sample is anomalous then we can repeat the test in reverse order by applying the KAPPA command flip to the original dataset, 8c_clip;

```
% flip 8c_clip 8c_flip
```

More generally, any subsample can be specified with a NDF section [8]. In the above example, subsample 7 is 8c_clip(121:140). The kstest command can then read in an ascii file containing a list of NDF sections, such as,

```
% cat kstest.dat
8c_clip(121:140)
8c_clip(1:20)
8c_clip(61:80)
8c_clip(81:100)
8c_clip(21:40)
8c_clip(101:120)
8c_clip(141:160)
8c_clip(41:60)
%
```

The following command then performs the KS test using this file;

```
% kstest '^kstest.dat' out=8c_ks limit=0.05
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 19 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.
Data for "8C1435+635" contain 20 points, of which 20 are good.

-----
                Probability           Max. Sep.
-----
cf. with 2 : 0.497342E+00           0.250000E+00 (Accepted)
cf. with 3 : 0.767976E+00           0.175000E+00 (Accepted)
cf. with 4 : 0.860007E+00           0.150000E+00 (Accepted)
cf. with 5 : 0.444130E+00           0.212500E+00 (Accepted)
cf. with 6 : 0.100815E-01           0.384849E+00 (Rejected)
cf. with 7 : 0.835178E+00           0.146970E+00 (Accepted)
cf. with 8 : 0.189298E+00           0.253361E+00 (Accepted)

Number of subsamples rejected: 1
Coadded result is 4.8022197E-5 +/- 8.0190266E-6

%
```

Note that the NSAMPLE parameter is now redundant and also that single quotes must surround the input file name. The final result in this case is unchanged, of course.

8 A note on calibration

To get the final calibrated flux in Jy we need to multiply by a conversion factor or responsivity that is calculated by making observations of a compact planet such as Mars or Uranus; the planetary fluxes, corrected for the SCUBA beamsizes, are available from the Starlink package FLUXES (SUN/213) [9]. Note that the secondary sources used for the calibration of UKT14 photometry [10] will probably have different fluxes in the SCUBA wavebands, mainly due to the different beam sizes, i.e. these sources are extended at some level. This is certainly the case for the one source, N2071IR, that has been calibrated against a planet so far and the whole list may have to be re-observed.

A Getting ASCII output

ASCII output can be produced for any bolometer using the `ndf2ascii` command which is part of the Starlink package, `CONVERT`. Note that if you intend to compare the bolometer signals then the flatfielded or extinction corrected data must be used. Here's observation #52 of 8C1435+635 again,

```
% convert

    CONVERT commands are now available -- (Version 0.6-2, 1996 September)

    Defaults for automatic NDF conversion are set.

    Type conhelp for help on CONVERT commands.

% ndf2ascii prompt
IN - Input NDF data structure /@red52_phot/ > red52_ext(19,,2)
COMP - Array component to copy to the ASCII file /'Data'/ >
FITS - Write a FITS header in the ASCII file? /NO/ >
FIXED - Fixed format of the array values? /NO/ > y
NOPEREC - Number of data values per ASCII record /1/ >
OUT - ASCII file /@h14_52/ > h7_52
%
```

The output file `h7_52` contains a single column of numbers each corresponding to 2 seconds of integration time (corrected for the beam-switching). The input NDF, `red52_ext(19,,2)` is thus the output of extinction but using a section to select the central pixel of the long-wave array, i.e. bolometer 19. The '2' just selects the central beam position. Similarly the sky bolometer, `h14`, is referred to as `red52(26,,2)`. Further information on the data structure can be found in the SURF documentation (SUN/216).

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