An Introduction to *SCUBA-2* Data Reduction

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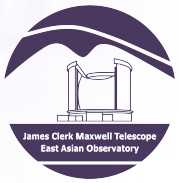
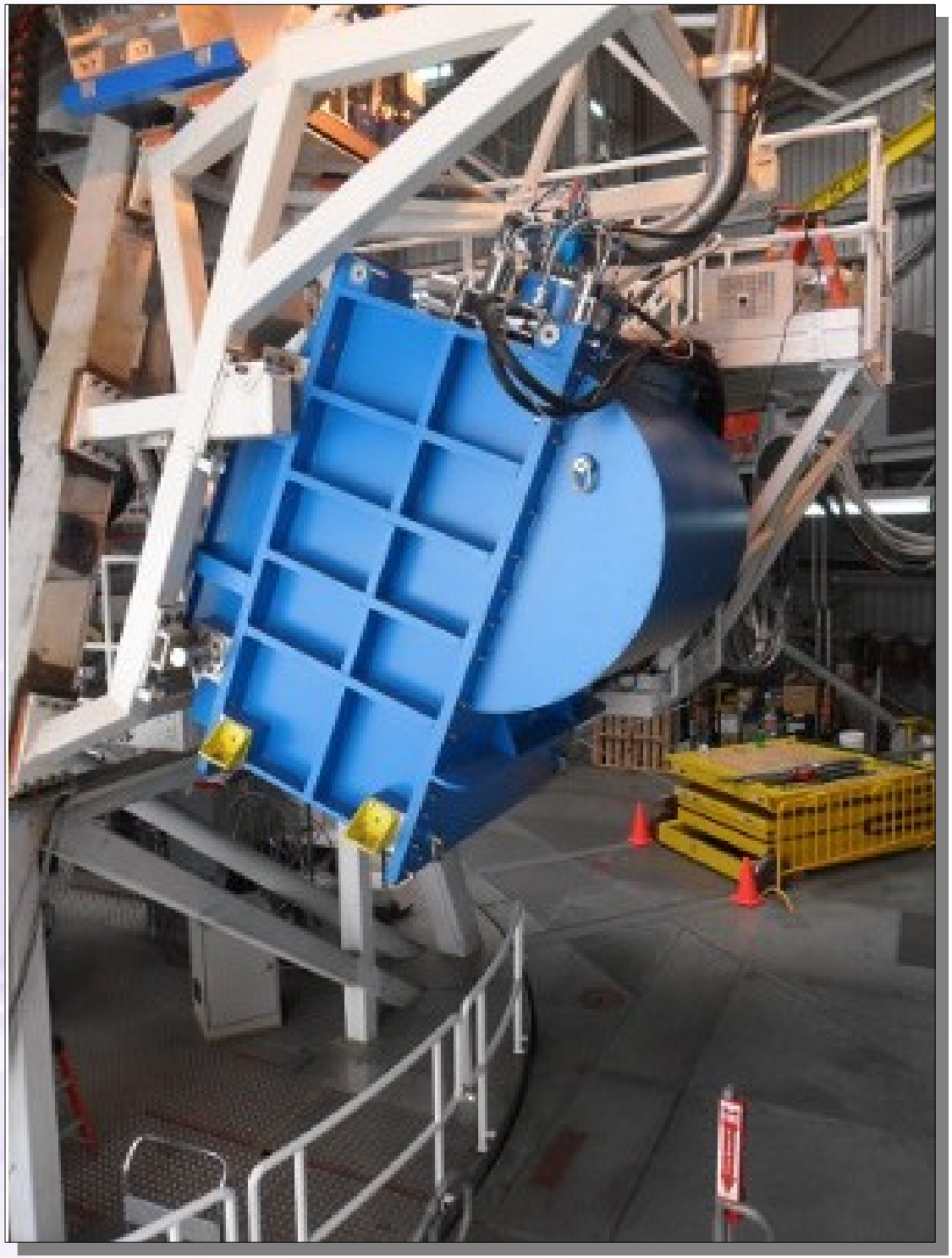


SCUBA-2 Overview

- Instrumental Overview
- Observing Modes
  - Basic dataset characteristics
  - *Daisy & Pong*
- Data Reduction Pipeline (*ORAC-DR*)
  - Running *ORAC-DR* for *SCUBA-2* data
  - Output summary: reduced data files
- Map Maker
  - What it is, what it does
  - Recipes: Standard & Customized
- Example Outputs
- Additional Help

SCUBA-2

- Commissioned in 2011
- Ancillary Instruments:
  - FTS-2
    - Commissioning ongoing
  - POL-2
    - First public mode recently commissioned & available for use



SCUBA-2 - Technical

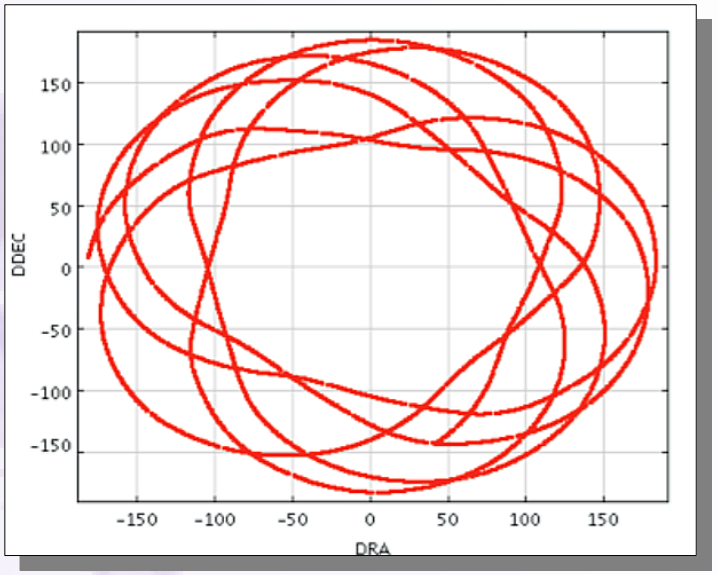
- 10240-pixel bolometer camera: 450 & 850 μm simultaneously
- Transition Edge Sensors (TES) on silicon wafers
  - Each wafer has an array of 32×40 TES bolometers
  - Read out by Superconducting Quantum Interference Devices (SQUID) multiplexer
  - 8 TES arrays, 4 for each wavelength. Each array: 32 × 40 = 1280 bolometers, i.e. 5120 bolometers per wavelength
  - No feed horns or cavities used
- Instrumental field of view = 45 arcmin^2 ≈ JCMT field of view
- Main beam sizes: 7.9” at 450 μm; 13.0” at 850 μm

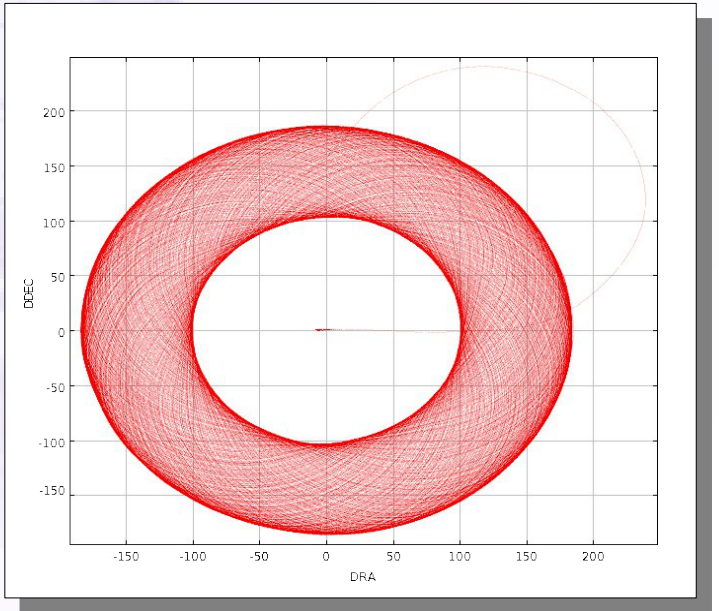
SCUBA-2 Datasets

- Obtainable from JCMT data archive at CADC
- 2D continuum imaging data at 450 and 850 μm
- Four arrays of bolometers labelled ***a***, ***b***, ***c*** & ***d*** for each wavelength (8 total)
- *Starlink* NDF files with specific naming convention
  - For example: **s8a20160322_00013_0004.sdf** means:
    - **S8a** – indicates data from ***S****CUBA-2* **8**50μm "***a***" array
    - **20160322** – observation UT date (this case: **22**nd **March**, **2016**)
    - **00013** – index that uniquely identifies observation for that UT date (in this example, **13**th observation)
    - **0004** – sub-scan index that identifies each specific block of 30 seconds of data within a single observation
    - **.sdf** – indicates that file follows *Starlink* NDF format

SCUBA-2 Observing Modes: *CV Daisy* Scan Pattern

- "CV" = Constant Velocity
- Modulates sky spatially & temporally
- Covers same positions at different angles & cross-links scans
- Maximizes central exposure time but less-uniform depth
- Good for (e.g.) point sources





Telescope track from 30-sec (upper) & 30-min (lower) observations

SCUBA-2 Observing Modes: *Daisy* Field Coverage

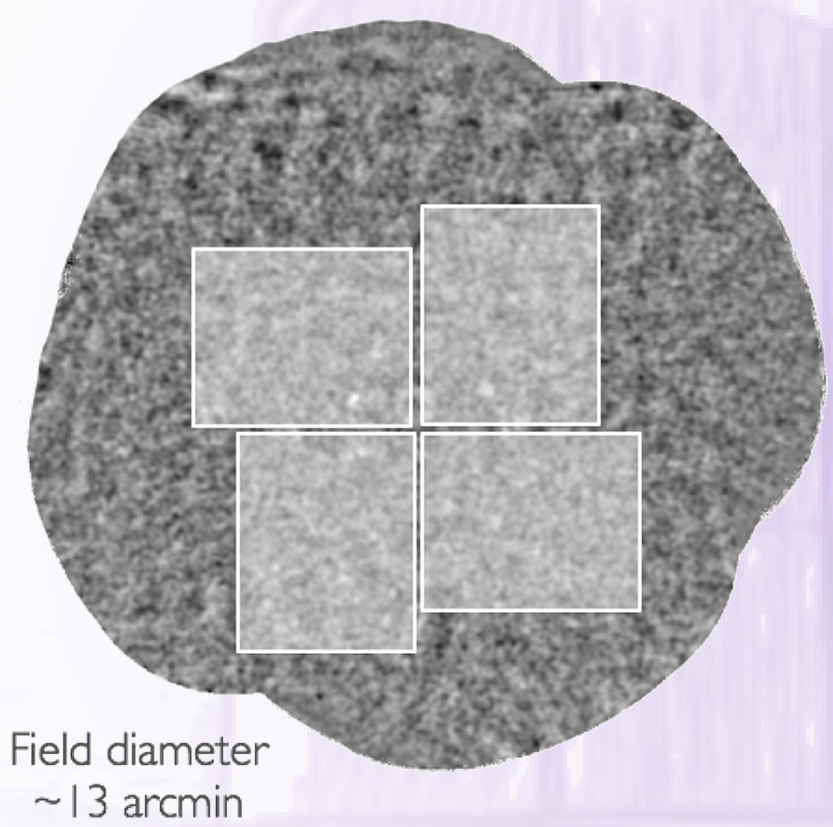
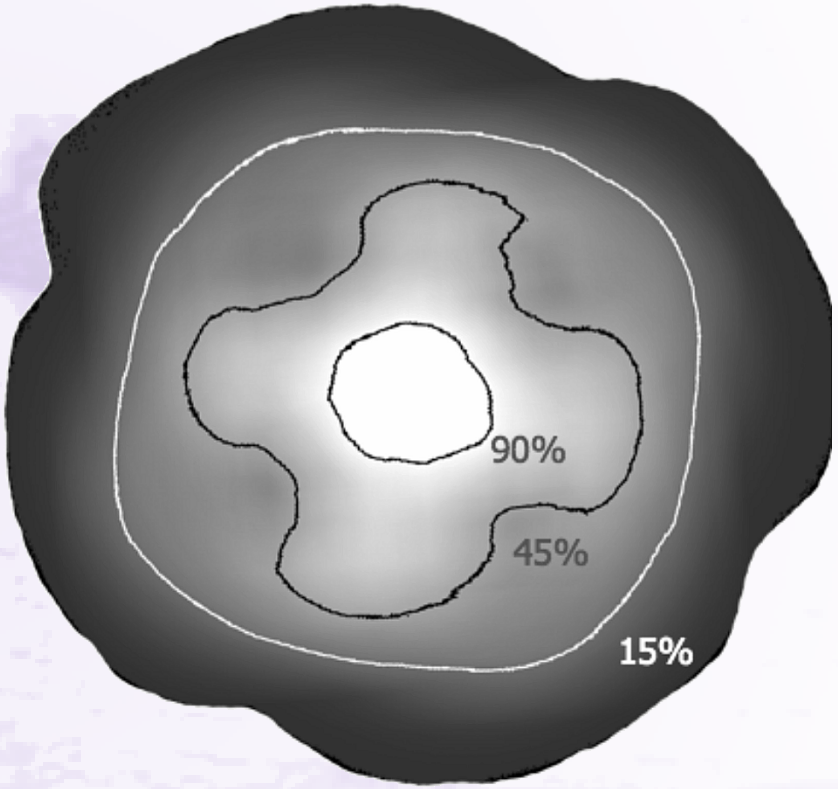


Image plane

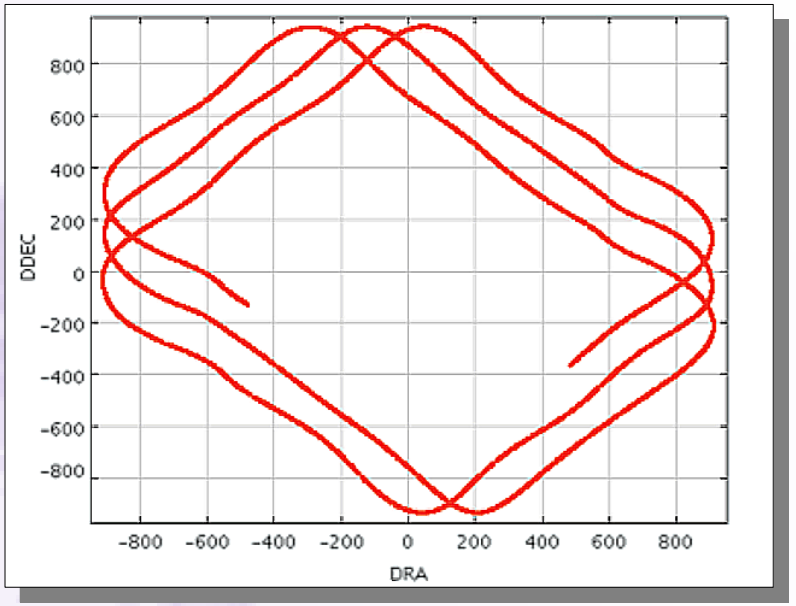


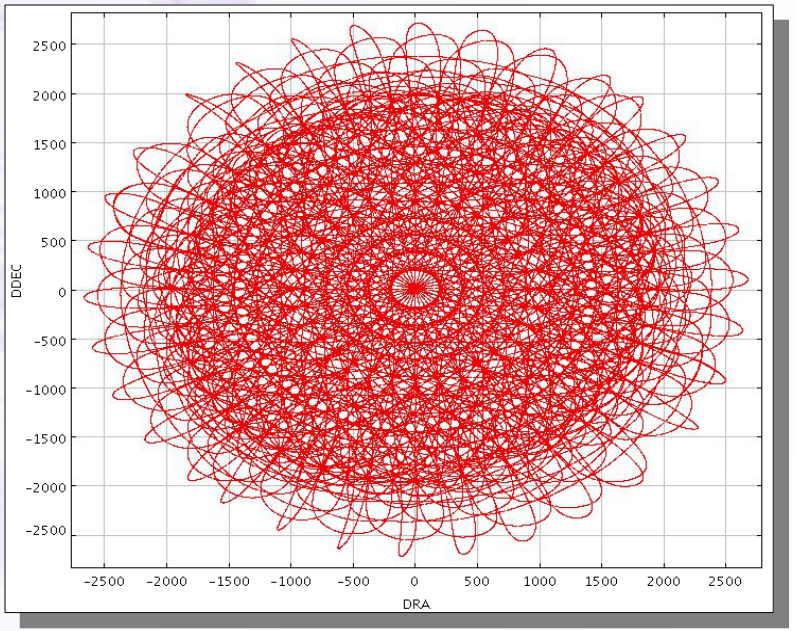
Exposure time

For a Nyquist-sampled output map, exposure time in central 3’ region ~0.25 × elapsed time

SCUBA-2 Observing Modes: *Pong* Scan Pattern

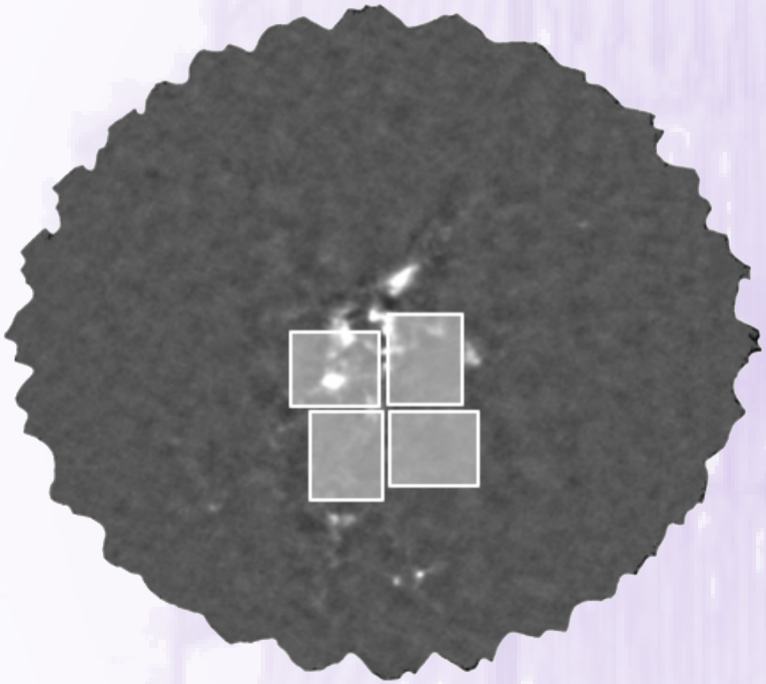
- Modulates sky spatially & temporally
- Covers same positions at different angles & cross-links scans
- Maximize field coverage & provides more uniform exposure time across field; less central depth
- Good for (e.g.) extended sources
- 900″, 1800″, 3600″ & 7200″





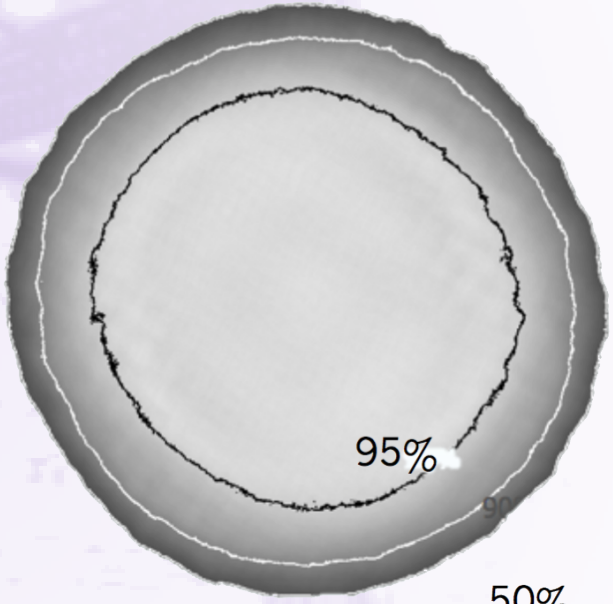
Rotating *Pong* for large fields. 30-sec subscan (upper) & ~40-min observation (lower)

SCUBA-2 Observing Modes: *Pong* Field Coverage



Field diameter
30 arcmin

Image plane



Exposure time

For a Nyquist sampled output map, exposure time in central 3’ region ~ 0.014 × elapsed time

Running the *SCUBA-2* Data Reduction Pipeline: *ORAC-DR*

- **Step 1:** Initialise *ORAC-DR* (for chosen *SCUBA-2* frequency)

```
% oracdr_scuba2_850 -cwd
```

- **Step 2:** Set environment variables

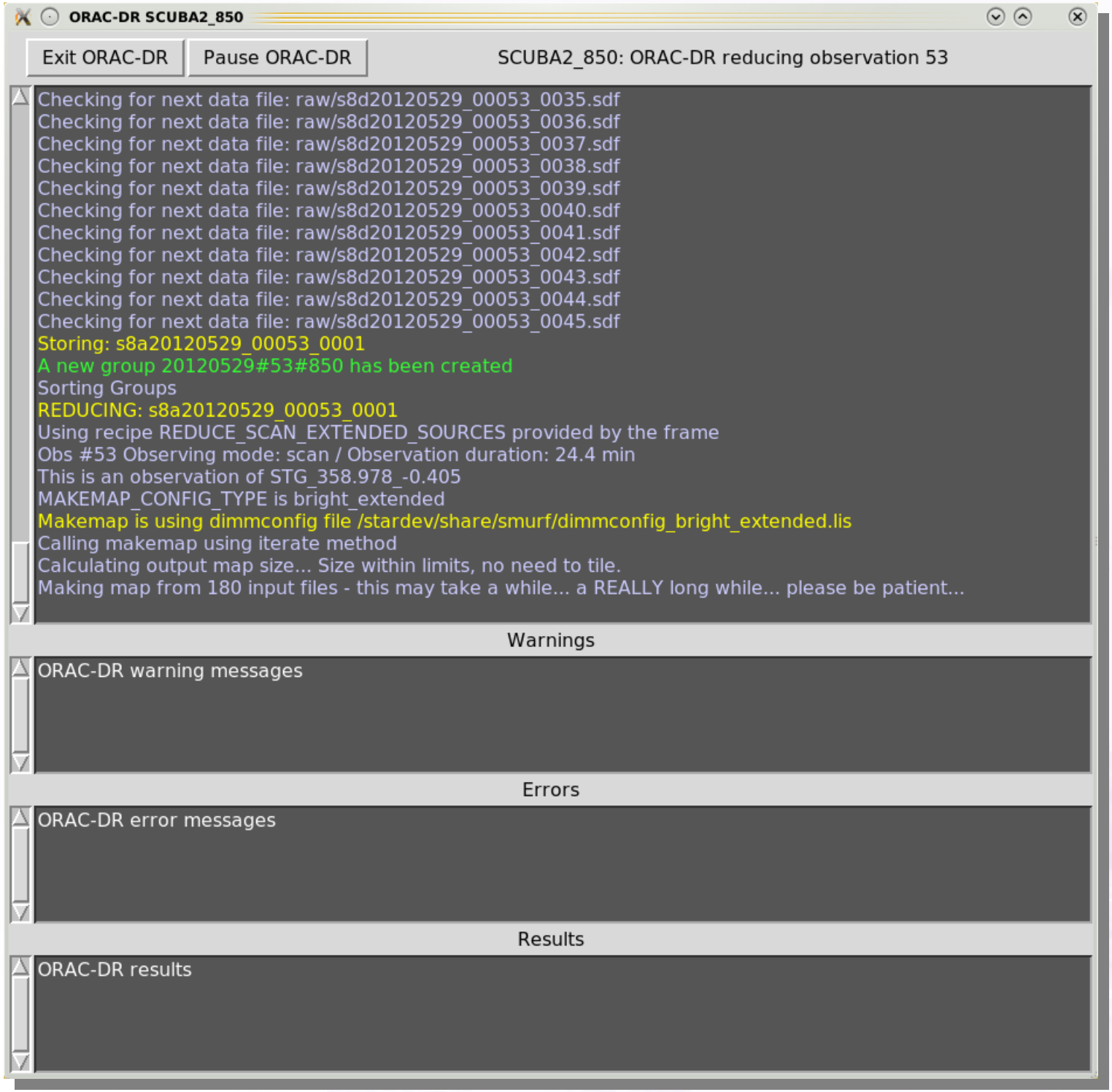
  These ensure data are read from & written to correct locations. Many set automatically when pipeline initialised, but others must be set manually (see *Starlink* document *SUN/264*).Three main ones:

  - ***STARLINK_DIR*** – Location of *Starlink* installation
  - ***ORAC_DATA_IN*** – Location from where data should be read. If supplying text file listing raw data, this should be that file's location
  - ***ORAC_DATA_OUT*** – Location where data products are to be written. Also used as the location for any user-specified configuration file

- **Step 3:** Run the pipeline

```
% oracdr -loop file -files <list_of_files>
```

  where ***<list_of_files>*** to be reduced can be one or more observations



Running *ORAC-DR* for *SCUBA-2*

***ORAC-DR* can:**

- **Run Map Maker (primary operation)**
- Apply FCF (to get mJy/beam; *see later*)
- Co-add observations of same source
- Apply matched-filtering
- Run source-finding algorithm

ORAC-DR Output

Output files (which have had standard peak Flux Conversion Factor applied):

- **log.group** – **File containing all raw data included in reduction**
- **s20141024_00033_850_reduced.sdf** – Reduced file from single observation
- **s20141024_00033_850_reduced_*.png** – Image files of individual reductions
- **log.mapstats** – File containing information on the individually reduced data
- **log.nefd** – File containing NEFD information from raw data
- **log.noise** – File containing noise information from reduced data
- **gs20141024_00033_850_reduced.sdf** – Group file, i.e. all reduced files co-added
- **gs20141024_00033_850_reduced_*.png** – Image files of co-added reductions
- **s20141024_00033_850_reduced.sdf.FIT** – FITS file containing sources of emission within map

Dynamic Iterative Map-Maker

- Invoked via *SMURF makemap* command or *ORAC-DR*
  - **Initialization:** Performs all pre-processing steps to clean data (concatenation, flat-fielding, down-sampling for scan speed & desired pixel size, initial cleaning & flagging). “Chunking” may also be performed for larger datasets
  - **Iteration:** Solves for multiple signal components using iterative algorithm
  - **Final Map:** Bins resulting time-series data to produce final science map
- Different recipes (see later) can be used to optimize results for different types of observations
  - ***Dimmconfig:*** Dynamic Iterative Map-Maker Configuration file. Specifies what map maker should do

Map-Maker Iteration

$$b(t) = f * [\, e(t)\, a(t) + n(t) \,]$$

b(t) = bolometer signal

f = responsivity / DAC constant

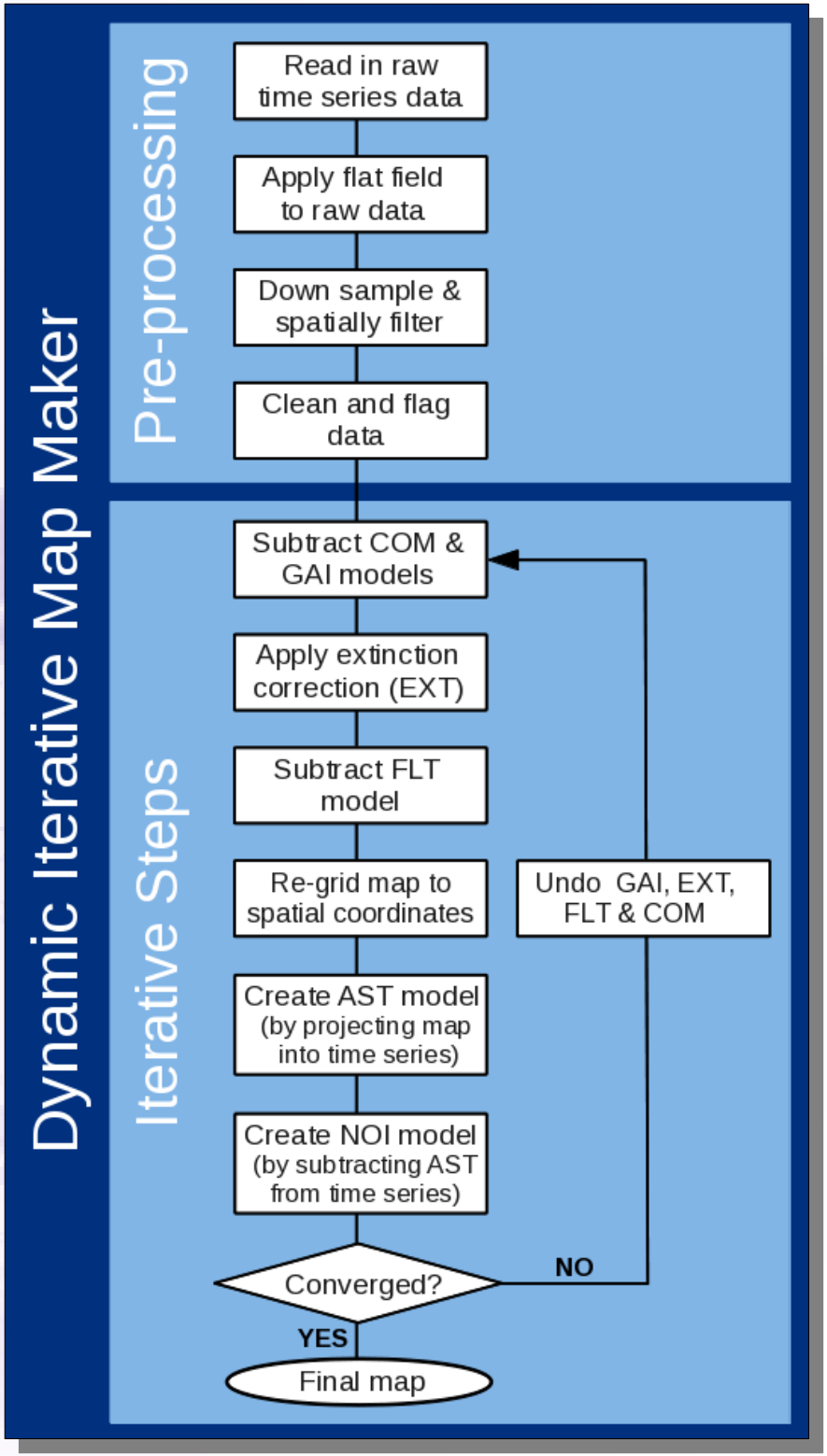
e(t) = time varying atmospheric extinction

a(t) = astronomical signal

n(t) = noise

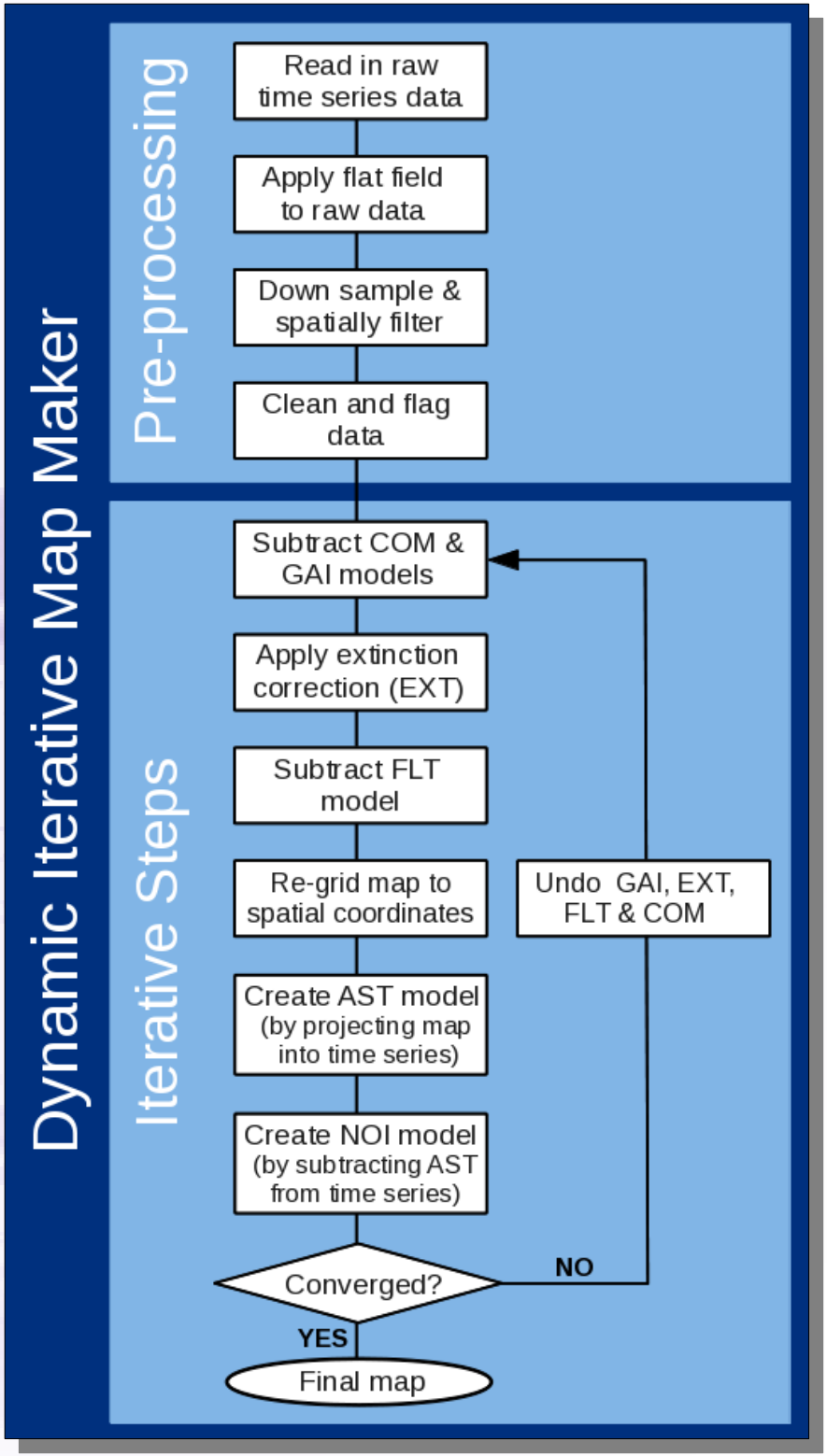
Procedure

- Divide b(t) by f (fixed quantity)
- Remove most of n(t) with common-mode subtraction
- Divide by e(t) (noisy measurement from WVM)
- Remove remainder of low-frequency noise in n(t) with high-pass filter
- Regrid what is left over (a(t) + ~ white noise) to estimate map & remove back-projected signal from time streams
- Astronomical sources cause ringing, so check for convergence & iterate again as necessary



Map-Maker Models

- **COM:** Common-mode signal
- **GAI:** Gains that scale each bolometer to common-mode
- **EXT:** Extinction correction
- **FLT:** Filter that removes low frequencies
- **AST:** Astronomical signal
- **NOI:** Residual noise



Map-Maker – Standard Recipes (I)

- ***REDUCE_SCAN*** – Usual configuration file: ***dimmconfig_jsa_generic.lis***
  - Uses configuration file ***dimmconfig_jsa_generic.lis*** **for *makemap*, unless source is identified as calibrator**. After all observations have been processed, data are co-added & calibrated in mJy / beam using the default FCF. Noise & NEFD properties for co-add are calculated & written to log files (*log.noise* & *log.nefd* respectively). Finally, *Cupid* task *findclumps* run using *FellWalker* (source finder algorithm) to create source catalogue
  - For calibrators, ***dimmconfig_bright_compact.lis*** is used & FCFs derived from map
- ***REDUCE_SCAN_EXTENDED_SOURCES*** - Configuration file: ***dimmconfig_bright_extended.lis***
  - For processing extended sources. Multiple observations are co-added & output map is calibrated in units of mJy / arcsec^2. Also executes source finder routine; results written as FITS catalogue (with file extension .FIT) which can be read as local catalogue into *Gaia*

Map-Maker – Standard Recipes (II)

- ***REDUCE_SCAN_FAINT_POINT_SOURCES*** - Configuration file: ***dimmconfig_blank_field.lis***
  - For processing maps containing faint compact sources. Resultant map calibrated in mJy / beam. Output map further processed with matched filter, & S / N taken to enhance point sources. A map is written out at each step. Also performs source finder routine; results are written as FITS catalogue (with file extension .FIT) which can be read as local catalogue into *Gaia*
- ***REDUCE_SCAN_ISOLATED_SOURCE*** - Configuration file: ***dimmconfig_bright_compact.lis***
  - Used for processing calibrator data. Can also be used for any map of a single bright, isolated source at tracking position. Reduction constrains map to zero beyond radius of 1 arcmin from source centre. **Note: Assumes presence of a central source**

Science Program

Open | Cut | Copy | Paste | Save | Image | Prioritize | Validation

OR Folder
AND Folder
Survey Container
MSB Folder
Observation
Note
Library
Component
Iterator
Observe

- *Sample SCUBA-2 project*
  - *1 degree map with opt*
    - Note: Please read
    - Site Quality
    - DRRecipe
    - SCUBA-2
    - Target Information
    - Science Observation
      - Sequence
        - Offset
          - Scan

DR Recipe

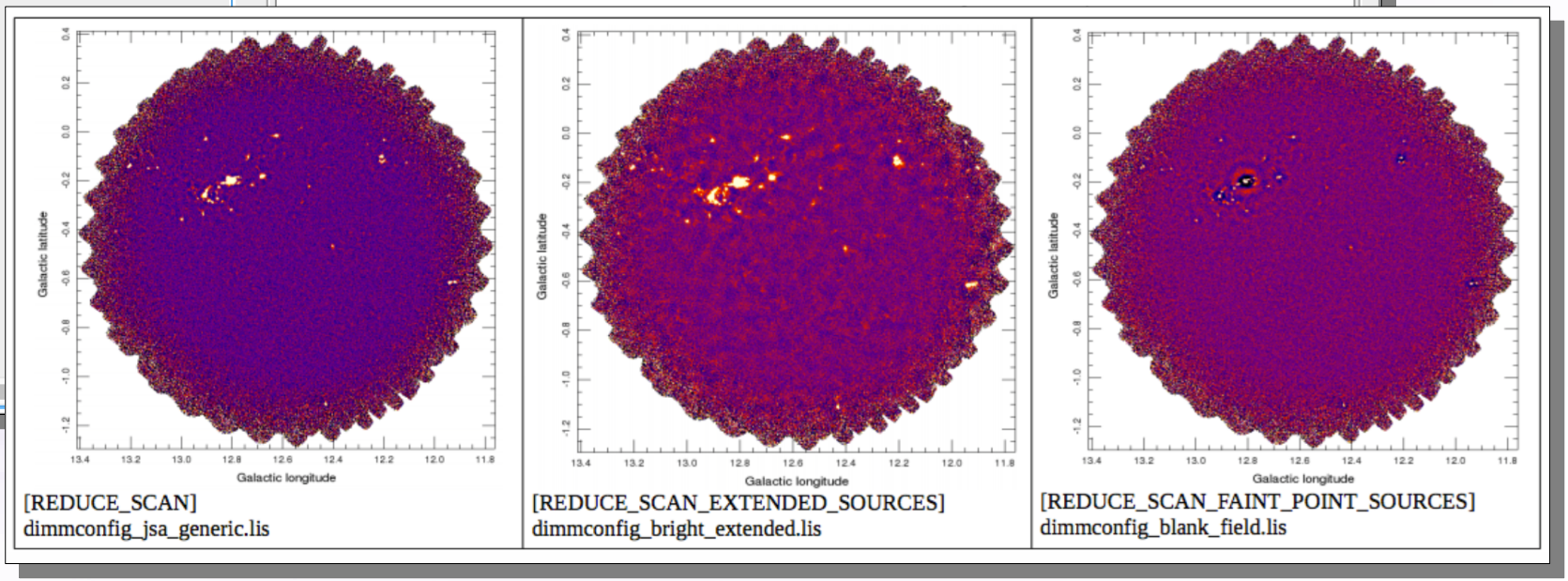
Enter the Data Reduction recipe to be used

Observation Type		Recipe Name
Scan	Set	
Jiggle	Set	
Stare	Set	
Pointing	Set	
Focus	Set	

DR Recipes Comparison

Default

Recipe Name	Description
REDUCE_SCAN	Basic scan reduction for SCUBA-2
REDUCE_SCAN_EXTENDED_SOURCES	Scan map processing optimized for extended...
REDUCE_SCAN_FAINT_POINT_SOURCES	Scan map processing optimized for faint poin...
REDUCE_SCAN_ISOLATED_SOURCE	Scan map processing for a single source at th...



ORAC-DR Customization

- Possible to re-run reduction with different recipe from default originally specified in *Observing Tool*
  - Useful if (e.g.) original recipe proves unsuitable
  - Simply append new recipe name when running *ORAC-DR*, e.g.

```
% oracdr -loop file -files <list_of_files> REDUCE_SCAN_EXTENDED_SOURCES
```

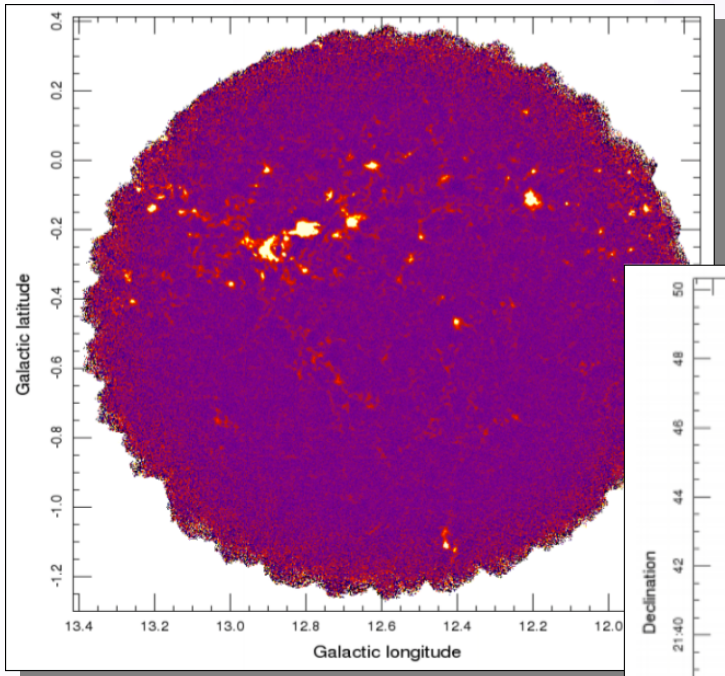
- Also possible to modify the parameters used by data reduction recipe using *recpars* (recipe parameters) file
  - Simple, plain-text file, allows (e.g.) specification of different map pixel size, dimmconfig file to be used. Invoked with *-recpars* option:

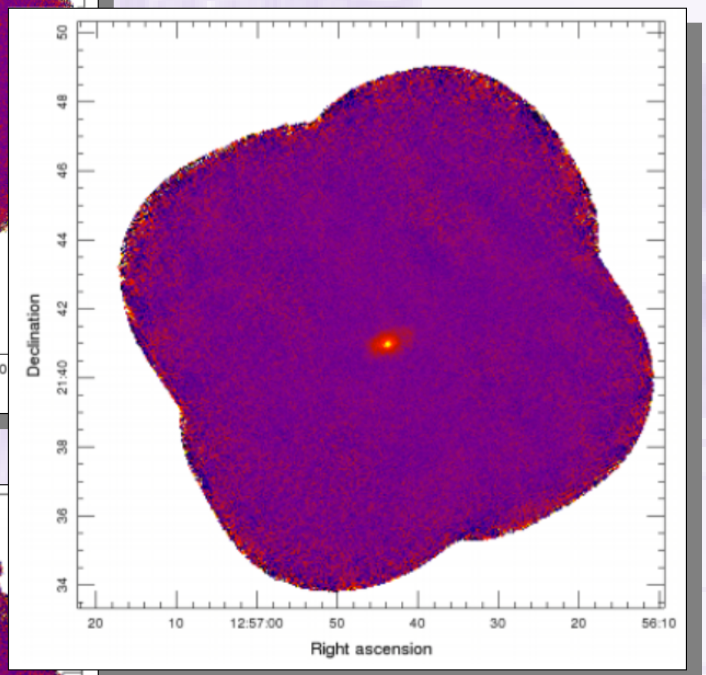
```
% oracdr -loop file -files <list_of_files> -recpars <recpars_file>
```

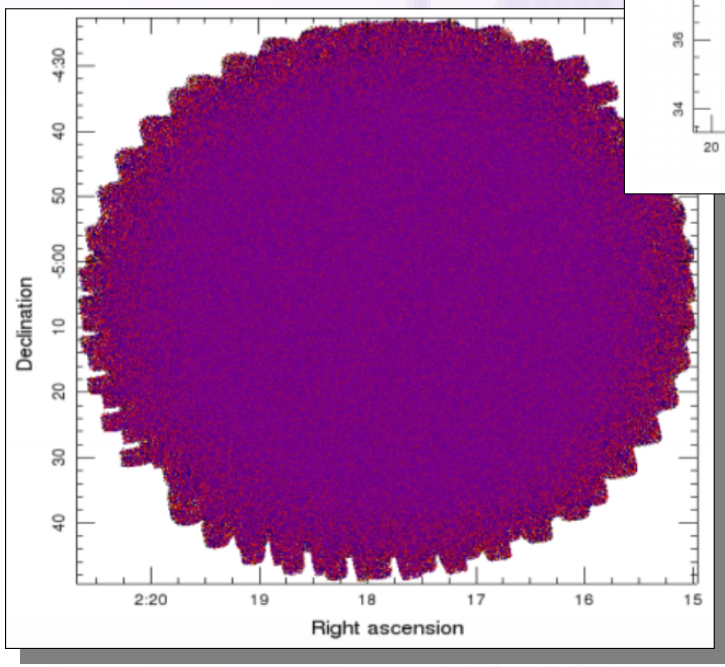
  - Can be provided to EAO by PIs for customizing nightly reductions, if needed

If customizing, calibrations should be carefully checked!

Examples







Upper:
Crowded Galactic Plane Field (JPS)

Middle:
Nearby Galaxy (NGLS)

Lower:
Cosmological Field (CLS)

Additional Help

- Chapin et al. 2013, MNRAS, 430, 2545 (for Map-Maker)
- Dempsey et al. 2013, MNRAS 430, 2534 (for Calibration)
- http://www.eaobservatory.org/jcmt/instrumentation/continuum/scuba-2/data-reduction/
  - Contains links to quick data reduction guide, *SCUBA-2 DR Cookbook*, *Starlink* download site & CADC archive
- http://www.eaobservatory.org/jcmt/instrumentation/continuum/scuba-2/
  - Summary of instrument characteristics, sensitivity, etc. Also, details on *POL-2* polarimetry
- *Starlink* document *SUN/265: SCUBA-2* mosaics with PICARD
- Helpdesk link: help@eaobservatory.org
- Can e-mail designated Friend of Project (if you have one)

SCUBA-2 Data Reduction Tutorials

- Requirements
  - Computer with 2015B *Starlink* installed
  - Tutorial Dataset (Size ~650 MB)
    - Short observation of HII region complex G34.3+0.2
      - Often used as JCMT pointing source
    - Available from website or USB stick
    - From public calibration project M12AEC05
    - *scuba2_00068_20120501T164451* in JCMT Archive at CADC
    - 850 μm dataset only, but same procedures should work for 450 μm datasets

http://www.eaobservatory.org/jcmt/science/reductionanalysis-tutorials/