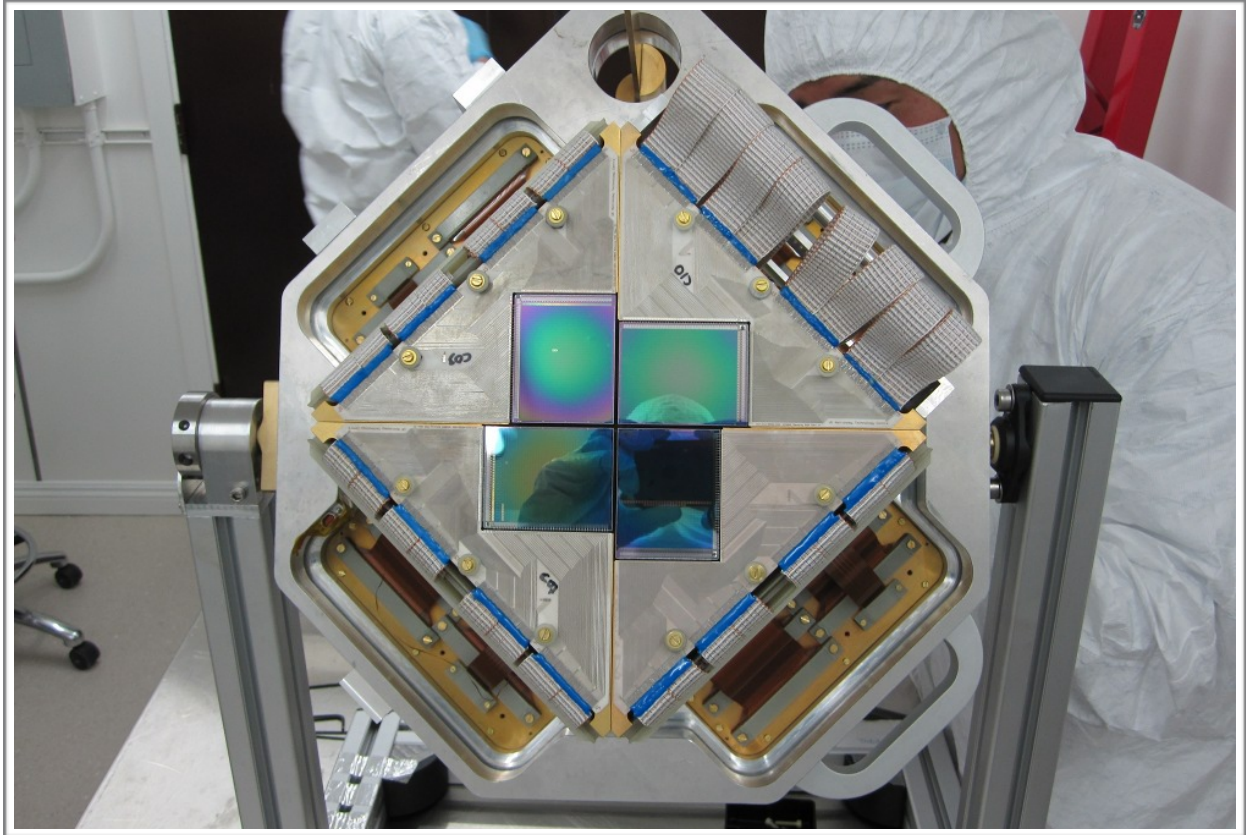


Assignment 1

SCUBA-2 Data Reduction



ASTR 351L

Spring 2019

Let's Remove the Atmosphere

And a bunch of other stuff

Link to Introductory Slides:

https://www.eaobservatory.org/~s.mairs/ASTR351/slides/ASTR351L_SCUBA2DR.pdf

Procedure:

Part I

1. Download the file (650 MB):

http://ftp.eao.hawaii.edu/jcmt/usersmeetings/JCMT_SCUBA-2_tutorial1_2016.tar.gz

This is a compressed file containing raw SCUBA-2 (850 micron, continuum) data of the compact star-forming region known, affectionately, as G34.3+0.2 (G34, for short).

2. Copy this file to a suitable directory to work in (e.g. your local home directory, ~/ , in the following example):

```
%cp JCMT_SCUBA-2_tutorial_2016.tar.gz ~/
```

3. Switch to the working directory, open the tarball and change to the newly-created directory containing the raw data:

```
%cd ~/
%tar -xvzf JCMT_SCUBA-2_tutorial_2016.tar.gz
%cd tutorial/raw/
```

This directory should contain a number of *.sdf* files and a *README* document. This can be checked by listing the contents of the directory by typing: `%ls`

4. Create an index file (called *mylist*) listing all of the input files, with explicit pathnames, and move it to the reduced directory, and switch to that as the current working directory (*ORAC-DR* will be run from there later on):

```
%ls -d -1 $PWD/*.sdf > mylist
%mv mylist ../reduced/
%cd ../reduced/
```

5. Initialise the Starlink software and load the necessary packages for analysis. This is a good thing to do every time you use Starlink:

```
%export STARLINK_DIR=/opt/star-2018A
%source $STARLINK_DIR/etc/profile
%kappa
%smurf
```

6. Set up *ORAC-DR* for *SCUBA-2* 850-micron data processing, and specify that the reduced files will be written to the current working directory:

```
%oracdr_scuba2_850 -cwd
```

The *-cwd* option specifies that the current working directory should be used.

By default, *ORAC-DR* will issue a warning that the default input data directory does not exist. It is therefore necessary to manually set the *ORAC_DATA_IN* and *ORAC_DATA_OUT* environment variables.

In a Bash shell, type:

```
%export ORAC_DATA_IN=./
%export ORAC_DATA_OUT=./
```

Or, in the TC-shell or C-shell, type:

```
%setenv ORAC_DATA_IN ./
%setenv ORAC_DATA_OUT ./
```

It should now be possible to run *ORAC-DR* by typing the following:

```
%oracdr -nodisplay -log sf -loop file -files mylist
```

This should start printing messages to the screen (and save those messages to a file) showing the progress of the data reduction. It will also indicate any problems encountered, and report as files are created and/or deleted.

7. Once the reduction process has completed, press the *Exit ORAC-DR* button to close the window. A number of files should have been produced as a result of the reduction process, including various logs, NDF and PNG preview image files.
8. It is also possible to examine the reduced group dataset in *Gaia*. This can be done by typing:

```
%gaia gs20120501_68_850_reduced.sdf &
```

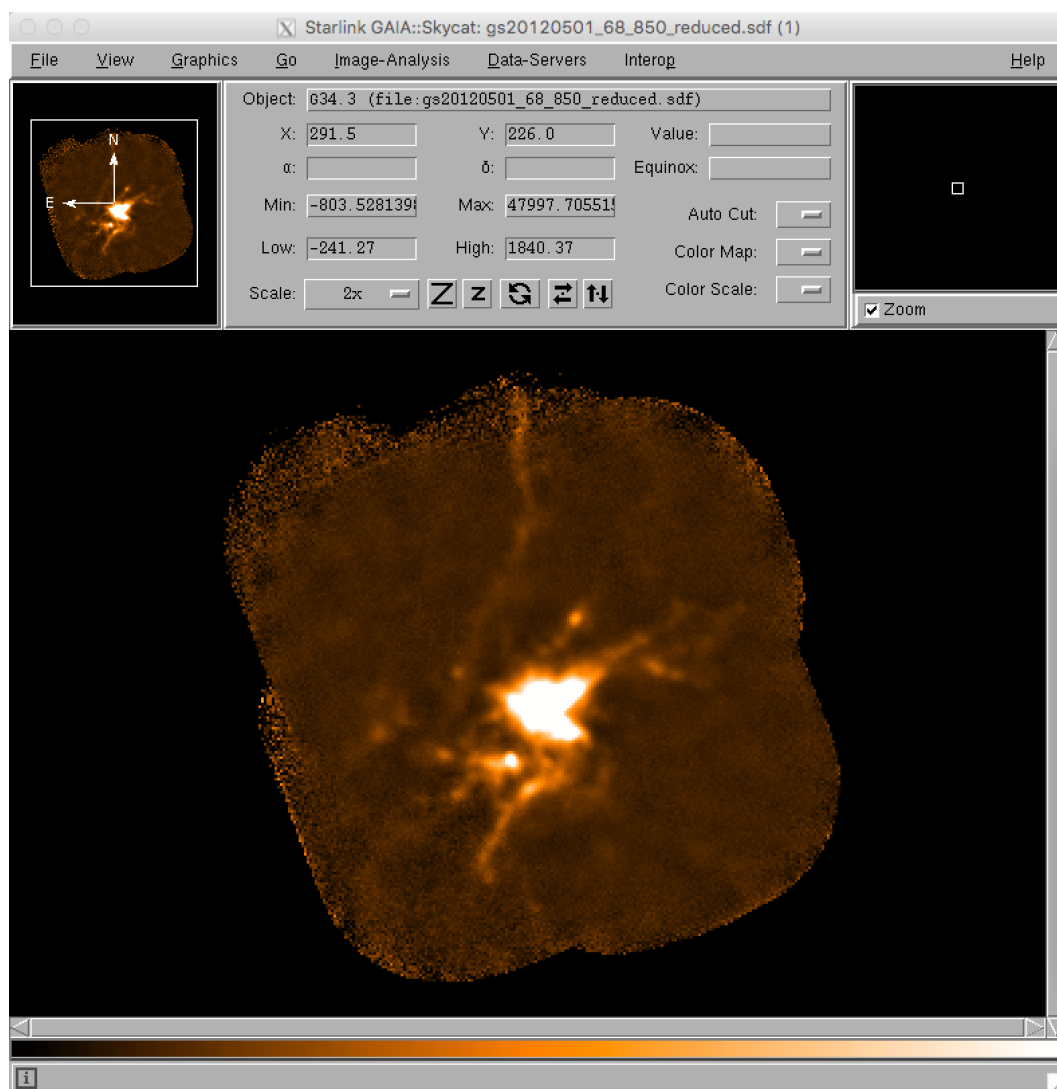


Fig 1. G34.3+0.2 at 850 μ m: a compact star forming region displayed with GAIA.

This should launch a main *Gaia* window with the reduced image in it. To get a better sense of the more extended structure in the source, use the *View* drop-down menu, select *Cut Levels* and use the *Auto Set* option of 98%. It is also trivial to zoom in and out of the image using the two *Z* buttons.

Gaia has many other features to aid in image analysis. Feel free to experiment!

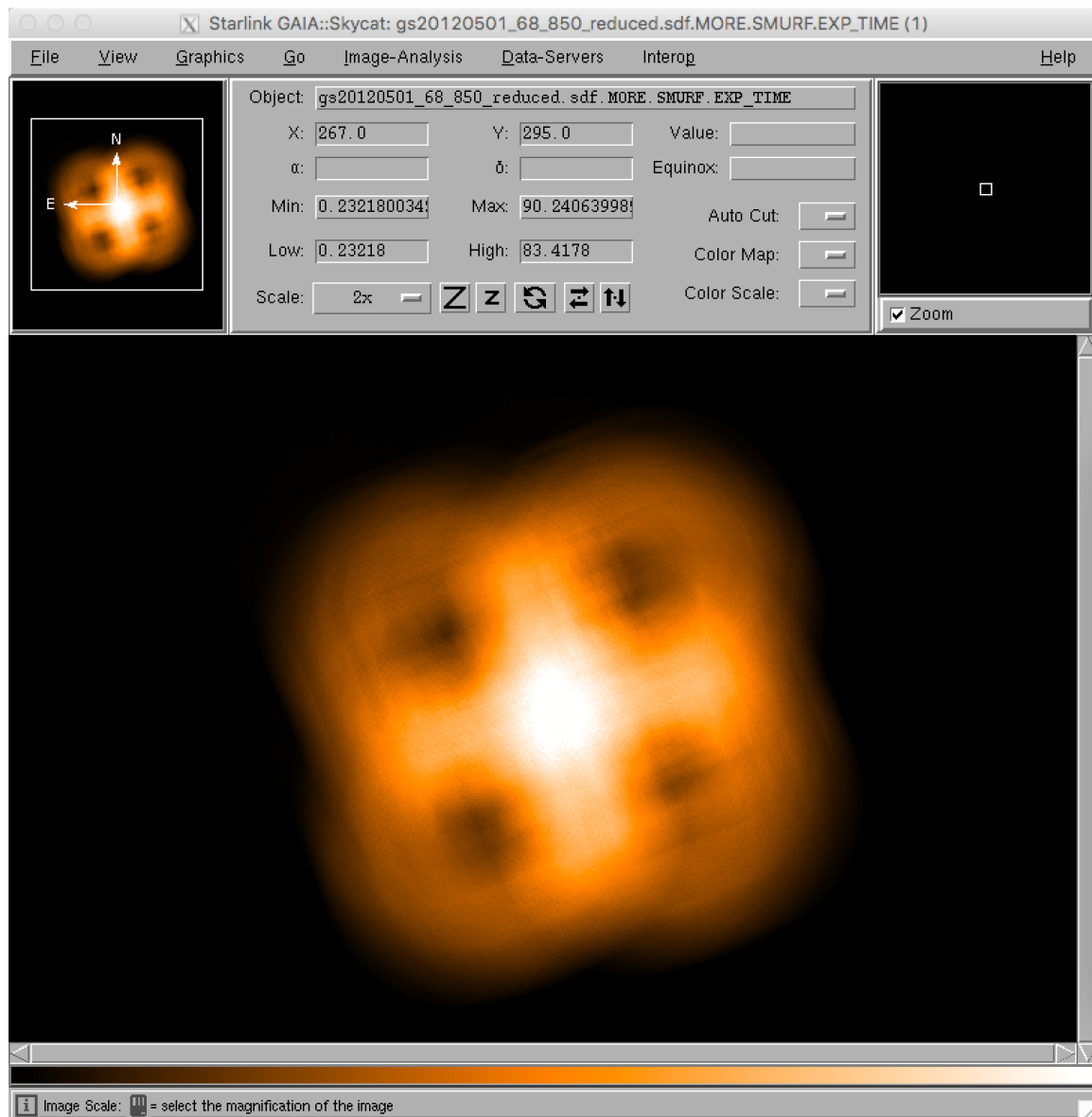


Fig 2. G34.3+0.2 exposure time: a typical “daisy” observation.

9. As well as examining the reduced image data in *Gaia*, it is also possible to view other components of the *NDF* file. For example, the dataset also includes maps of the weights used at each position, the exposure times, and so on. In order to view these, the general strategy is to locate the supplementary *Gaia* window with the title *Select NDF* in container file, then select the desired table entry, and finally select one of the buttons near the bottom of that window. For example, to view the variance map of the science data, click on the top row of the table (number 1) to choose the science dataset, and then press the *Variance* button to see the science data variance map in the main *Gaia* window. Similarly, to view the exposure time map for the field, select the third row of the table (number 3 / *EXP_TIME*) and click on the *data* button. It should be noted that the levels of each of these maps can be very different, so it may be necessary to modify the cut levels again, as in step 8.
10. Now, let's change the units of the map! One of the ways to see the units of the map is to select (with the map open in *Gaia*) "View..." (from the top drop-down menus) -> "Fits header". Look for the keyword "BUNIT".

We will convert this map into units of mJy/arcsec² (from its original mJy/beam). To do this, let's use PICARD (another starlink package):

```
%picard CALIBRATE_SCUBA2_DATA --nodisplay --log sf  
--recpars="USEFCF=True,FCF_CALTYPE=ARCSEC"  
gs20120501_68_850_reduced.sdf
```

"recpars" stands for "recipe parameters" and "FCF" stands for "Flux Conversion Factor". To signify we want the map in mJy/arcsec², we set the FCF_CALTYPE to ARCSEC.

This will give you a new file called: gs20120501_68_850_reduced_uncal_cal.sdf, showing you that it uncalibrated, then recalibrated that map. We can rename this something more useful, like:

```
%mv gs20120501_68_850_reduced_uncal_cal.sdf  
gs20120501_68_850_reduced_mjya2.sdf
```

Part II

1. Each *SCUBA-2* science observation specifies a default data reduction recipe in the header information. This is originally set by selecting a recipe option in the *Observing Tool* during MSB preparation. To view the default recipe for a given dataset, switch to the raw data directory:

```
%cd ../raw/
```

And use either of the following to examine the relevant part of the FITS header component of the data:

```
%fitsval s8a20120501_00068_0001.sdf RECIPE
```

or

```
%fitslist s8a20120501_00068_0001.sdf | grep RECIPE
```

The default recipe for the example dataset is *REDUCE_SCAN*.

2. It is also possible to re-run the pipeline reduction process using a different recipe from the default specified in the FITS header by simply appending the name of the recipe to the command line instruction. To try this, switch to the reduced data directory and try re-running the pipeline reduction with a different recipe in a different folder:

```
%mkdir ~/tutorial/reduced_extended/  
%cd ~/tutorial/reduced_extended
```

Re-initialise the *oracdr* software and the *ORAC_DATA_IN* and *ORAC_DATA_OUT* environment variables.

```
%oracdr_scuba2_850 -cwd
```

In a Bash shell:

```
%export ORAC_DATA_IN=./  
%export ORAC_DATA_OUT=./
```

Or, in the TC-shell or C-shell, type:

```
%setenv ORAC_DATA_IN ~/tutorial/raw/  
%setenv ORAC_DATA_OUT ./
```

Then run the new reduction:

```
%oracdr -nodisplay -log sf -loop file -files mylist REDUCE_SCAN_EXTENDED_SOURCES
```

Note that when this is run, *ORAC-DR* will issue a warning about the suitability of the specified recipe for the *DAISY* mode data used in this tutorial. This demonstrates that care should be taken when manually specifying recipes.

3. Subtract the final images produced by the two recipes to see the differences in the structure recovered (make sure you are using maps with the same units!):

```
%sub ~/tutorial/reduced_extended/FinalMap ~/tutorial/reduced/FinalMap OutputName
```

This command subtracts the second map from the first and it stores the result in a file called *OutputName* (whatever name you choose). Use *Gaia* to look at this subtracted map.

Questions:

1. What are the main sources of signal that are fitted and removed from the raw data?
2. Attach an image of the first map with a reasonable dynamic range.
3. In what units are the data calibrated?
4. In what weather grade was the observation taken? (Hint: In the fits header... WVMTAUST and WVMTAU End stand for the opacity at 225 GHz at the start and end of the observation. [<https://www.eaobservatory.org/jcmt/observing/weather-bands/>])
5. Using the relationship $\text{Tau}_{225\text{GHz}} = 0.04 \text{ PWV} + 0.017$, where $\text{Tau}_{225\text{GHz}}$ is the opacity at 225 GHz and PWV stand for “Precipitable Water Vapour”, calculate the PWV in the atmosphere when the observations were being taken.
6. What is the area of one pixel? How many pixels fit within the SCUBA-2 (850 μm) beam? Assume the beam is Gaussian and has a FWHM of 15”.
7. What is the background RMS noise in the central region of the first map produced? What method did you use to perform a robust measurement?
8. How large is the region with the highest sensitivity in the map?
9. Describe the main differences between the first map produced (REDUCE_SCAN) and the second map (REDUCE_SCAN_EXTENDED_SOURCES).

References to use:

- ★ Slides from the lab:
https://www.eaobservatory.org/~s.mairs/ASTR351/slides/ASTR351L_SCUBA2DR.pdf
- ★ Chapin, E. et al. 2013, MNRAS, 430:2545: **Section 3.2 will be the most helpful**
<http://adsabs.harvard.edu/abs/2013MNRAS.430.2545C>
- ★ Dempsey, J. et al. 2013, MNRAS, 430:2534:
<http://adsabs.harvard.edu/abs/2013MNRAS.430.2534D>