FLITECAM Imaging Pipeline Tutorial

This tutorial is designed to help guide users through the steps of processing FLITECAM imaging data, from raw data files to the final, calibrated data product. The information in this tutorial can also be found in more detail in the FLITECAM User's Manual.

Retrieve the Data

For this sample reduction, we'll use FLITECAM 3.3 μm observations of NGC 2023. These data were obtained in 2016 as part of project 04_0058 (PI: Tielens), and are published in [Knight et al. (2021)](). To retrieve the data from the SOFIA Science Archive at IRSA, enter the following criteria in the main SOFIA search page (https://irsa.ipac.caltech.edu/applications/sofia):

- Spatial Constraints → All-Sky
- Observation Constraints → AOR ID → 04_0058_5
- Data Product Constraints → Select Level 1 only (de-select Level 3 and Level 4)

or follow this link:

https://irsa.ipac.caltech.edu/applications/sofia/?api=search&spatialConstraints=allsky&execute=true&processingLevel=LEVEL_1&aorId=04_0058_5

On the search results page, click on the FLITECAM tab. On the FLITECAM tab, select all 48 data files, either individually or by selecting the box next to the AOR ID column header.

Click on Prepare Download to open a download dialog box, and then select Prepare Download within the dialog box. After a few moments, you will be asked to save a zip file to disk (it is ~106MB in size). Save this file wherever you wish, unzip it, and navigate the subfolders to locate the 48 FLITECAM FITS files. You may either leave these files in the directory or move them to another location of your choice; the folder containing the FITS files will be referred to as the 'input' directory for the remainder of the tutorial.
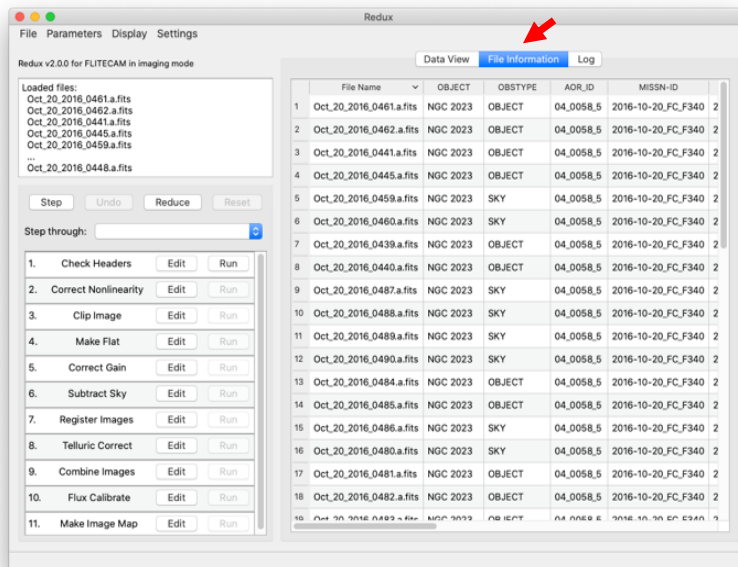
Download and Install the Pipeline

Instructions on how to download and install the *sofia_redux* pipeline package can be found at https://github.com/SOFIA-USRA/sofia_redux. If you need assistance, you can contact us through GitHub or the SOFIA Helpdesk (sofia_help@sofia.usra.edu).

Start the GUI

The pipeline can be executed in either Automatic Mode (on the command line) or in Manual Mode (through a GUI). In this tutorial, we will focus on running the pipeline through the GUI. To begin, launch the GUI by opening a terminal and typing:

> redux

In the Redux GUI, load the NGC 2023 data by selecting File → Open New Reduction, navigate to the input directory where you saved the data, select all 48 FITS files by clicking on the first file and shift-clicking on the last file, and then click Open. After clicking Open, the software reads the FITS headers and extracts relevant information, such as the instrument name for determining which pipeline the software will call (note that 'Redux v2.0.0 for FLITECAM in imaging mode' is now displayed above the list of loaded files). Some additional FITS header information is shown on the File Information on the right side of the GUI. You may notice (by scrolling to the right), that file 0439 was taken using a different filter from the others (FLT_K instead of FLT_PAH_329). To exclude this file from processing, go to File → Remove files, select Oct_20_2016_0439.a.fits, then click OK.

When the pipeline runs, it is possible to automatically display the intermediate data using SAO DS9 if it is set up properly (see http://ds9.si.edu/ for download and installation instructions; the ds9 executable must be available in the PATH environment variable for the pyds9 interface to be able to find and control it). Alternatively, the automatic display can be disabled (each pipeline module can optionally produce FITS file output in case a different FITS viewer is preferred). Options for displaying images in DS9 are found under Display Settings on the Data View tab.
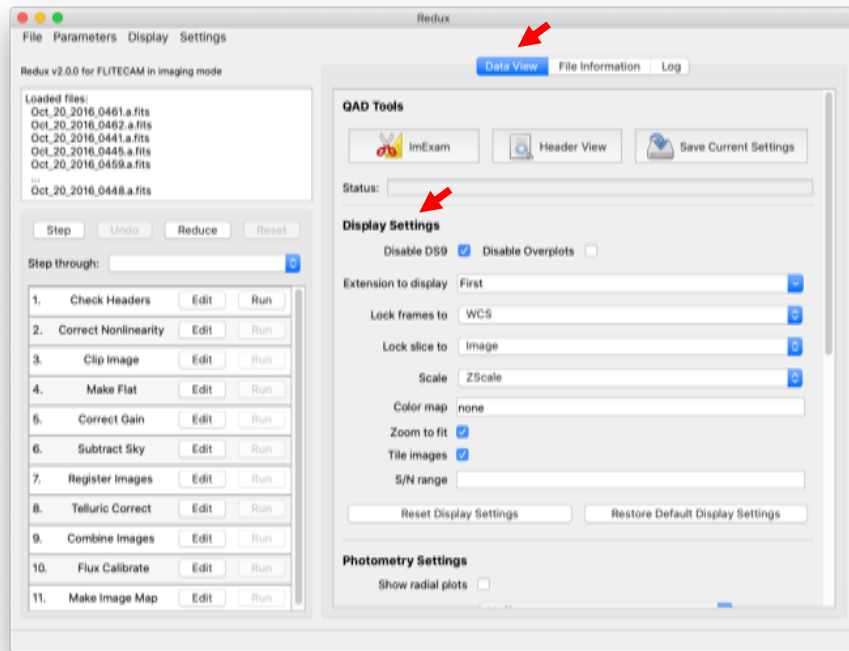
Run the Pipeline

There are 11 modules in the FLITECAM imaging pipeline, shown in the bottom-left panel of the GUI. Each pipeline module can be configured by clicking the 'Edit' button for that module. The entire pipeline can be executed by clicking the 'Reduce' button. Alternatively, the modules can be run individually by clicking on the 'Run' button for that module, or in a small group by selecting an end point in the 'Step Through' dropdown menu, then clicking 'Step.' In this tutorial, we'll run the modules one by one and examine their output.

1. Check Headers: This module examines the fits headers to make sure that they have the keywords required by the pipeline.

Options: Click on the Edit button next to Check Header module. A popup window for Edit Parameters for Check Headers will open up. In the popup window if the 'Abort reduction for invalid headers' option is not selected, the pipeline may fail in unexpected ways (as always: garbage in, garbage out!).
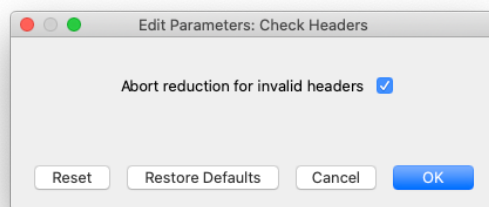
Output: This module creates no output; it allows the data set to pass through to the next modules in the reduction. For comparison with the output of the next module, we show the input file Oct_20_2016_0455.a.fits before any pipeline modules have been applied.
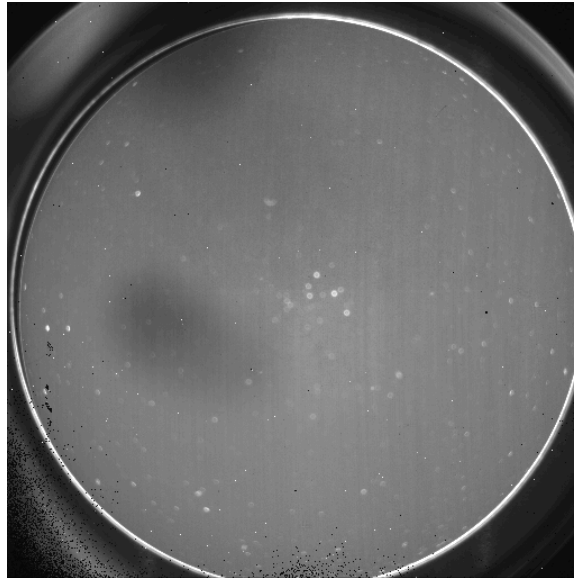

Oct_20_2016_0466.a.fits

2. Correct Nonlinearity: This module corrects the data for detector nonlinearity using the method described in Vacca et al. (2004). It also creates a bad pixel mask that is associated with the data, which initially contains the locations of saturated pixels.

Options: You may notice an unusual (and non-local) file name in the 'Linearity correction file' field. If you installed the pipeline using pip or conda, the default file used in this step has not yet been installed. It will be automatically downloaded from cloud storage (which requires an internet connection) the first time this module is run and cached locally for future running of the pipeline. You can expect similar behavior for other pipeline modules that use reference data. (Note that if you installed from source, then these reference data files are download during the install) The 'Saturation level' value species the threshold used to flag saturated pixels that are then included in the bad pixel mask. If no saturation clipping is desired, no number should be entered in this field. By default, the output FITS file for this step is not saved.
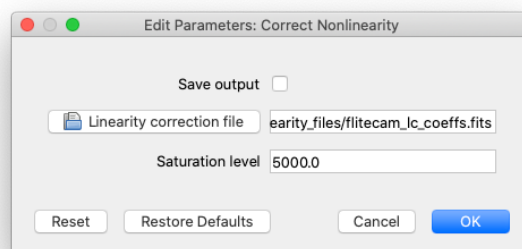

Output: The output from this step is shown below.
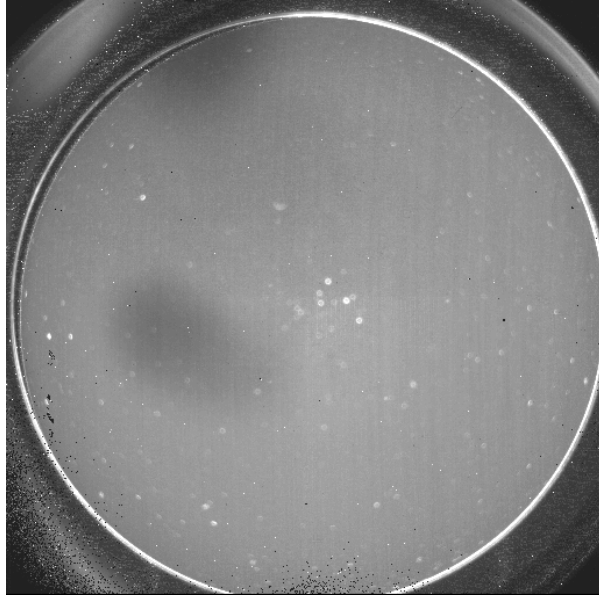
First extension of F0340_FC_IMA_0400585_FLTPAH329_LNZ_0466.fits.

3. Clip Image: This module selects the useable part of the image. The regions of the image nearer the edges display too much coma for accurate measurements. The module also identifies outlier (hot and cold) pixels and adds them to the bad pixel mask.

Options: The size of the cropped region can be controlled using the 'Data section to clip to' option. The default values should work in most cases, but there may be some data sets for which a larger or smaller image is desired. In those cases, the values are entered as [xmin,xmax,ymin,ymax], with the pixel counting starting at zero. The 'Skip clean' option, if selected, will retain hot and cold pixels instead of adding them to the bad pixel mask.
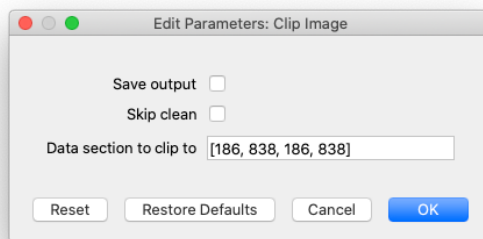

Output: The output of this step is the cropped image:
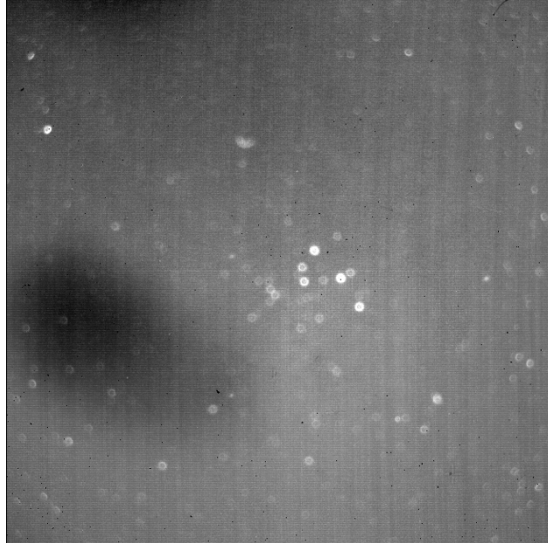
First extension of F0340_FC_IMA_0400585_FLTPAH329_CLP_0466.fits.

4 and 5. Make Flat and Correct Gain: Together, these modules correct the FLITECAM pixel-to-pixel gain variations. A flat is generated in step 4 based on sky images, and then it is applied to the data in step 5.

Options: Output FITS files are saved by default for step 4. Rather than having the pipeline generate a flat file from sky data, it's possible to provide a FITS file containing a flat field that can be used instead. Applying the gain correction is recommended, but it can be skipped by selecting the 'Skip gain correction' box. In this tutorial, we will apply the gain correction.
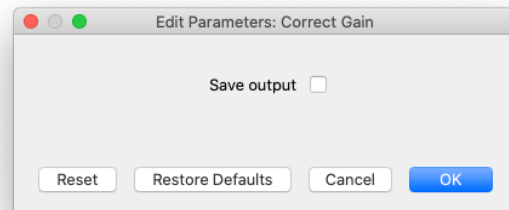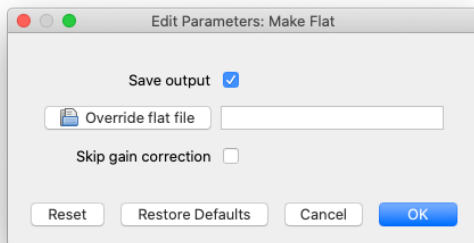

Output: The 'Make Flat' creates a 'FLAT' extension in the FITS file that is then used in the 'Correct Gain' module. Example output of both modules are shown below.
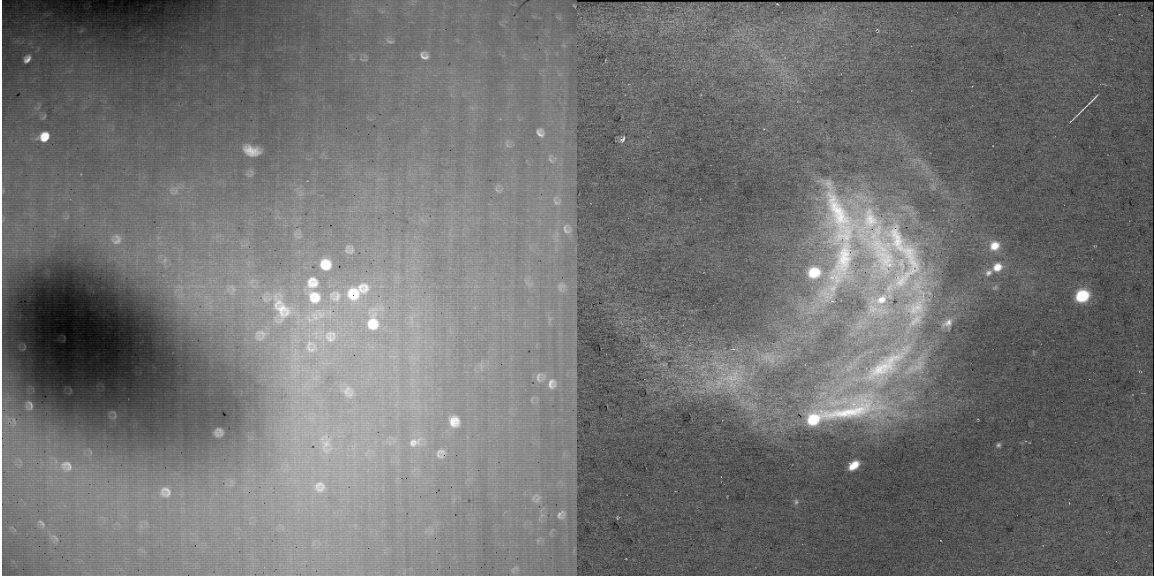
Left: The FLAT extension of F0340_FC_IMA_0400585_FLTPAH329_FLT_0466.fits Right: First extension of F0340_FC_IMA_0400585_FLTPAH329_GCR_0466.fits. With the gain correction applied, we can now clearly see the nebular emission from NGC 2023.

6. Subtract Sky: This module subtracts the background sky value for each image.

Options: The main two options for which background value to subtract are the normalization value from the 'Make Flat' module or the median of the image. For very large extended sources that fill a most of the image, like NGC 2023, the flat normalization value may yield better results. There is also an option to use an input FITS file that can be used to calculate the background value, but we will not use that here. In this tutorial, we will use the image median as the background value.
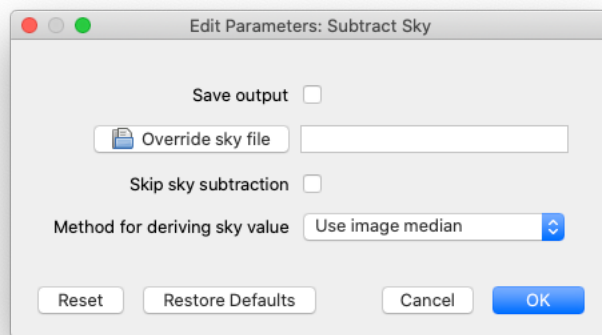

Output: In the image below, the background subtraction has been performed.

First extension of F0340_FC_IMA_0400585_FLTPAH329_BGS_0466.fits. This is similar to the output of the previous module, but it now has been background-subtracted.

7. Register Images: This module prepares the data to be combined in a later module by registering all images to a common frame.

Options: The default registration algorithm for combining data is 'Use WCS as is.' For data that have reliable WCS information, this is often the best option. If the WCS is suspect for some reason, we can either look at individual frames now to search for offsets, or we can examine the coadded image after module 9 to see if sources appear to be extended. If there is a WCS mismatch or if point sources are extended in the coadded image, one of the other options (centroid, cross-correlation, or no shift) can be used to try and align the images. For NGC 2023, we'll use the WCS as-is.
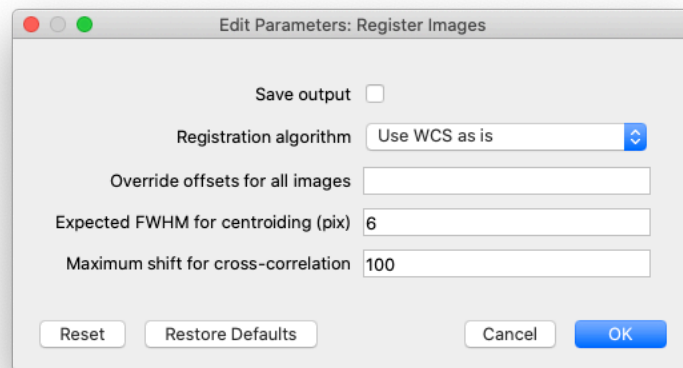

Output: Because we selected to use WCS as-is, there is little difference in the output image in modules 6 and 7.

First extension of F0340_FC_IMA_0400585_FLTPAH329_REG_0466.fits.

8. Telluric Correct: This module corrects for the opacity of the atmosphere. The correction is based on the flight altitude and telescope zenith angle at the time of the observation, and ATRAN (courtesy of Steve Lord) as its atmospheric model.

Options: Saving the output files is the only option for this module.
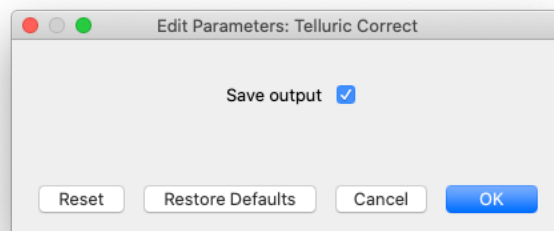
Output: This image looks similar to the output from module 7, but the scale of the image has changed based on the optical depth of the atmosphere.
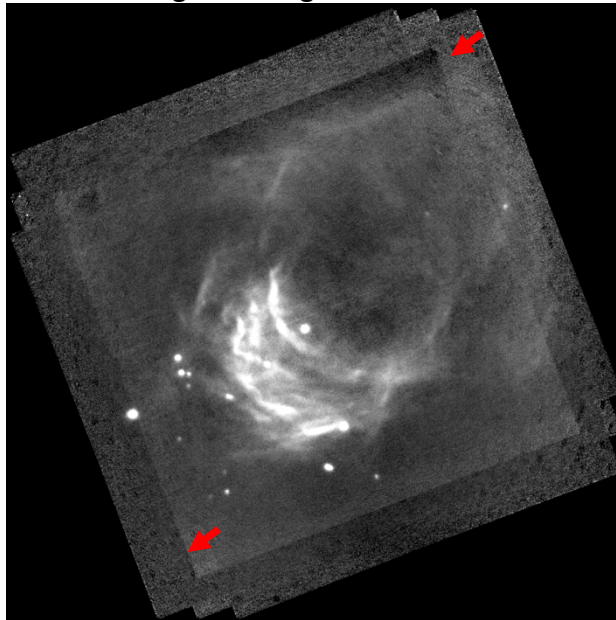
First extension of F0340_FC_IMA_0400585_FLTPAH329_TEL_0466.fits.

9. Combine Images: Up until this module, the input files have been processed individually. Based on the image registration in module 7, the files are now combined into a single data product.

Options: There are three ways to combine multiple images—median, mean, and resample. The default option of 'median' typically works well, and is what we will use in this tutorial. The 'Use weighted mean' option is ignored when using the 'median' option. 'Robust combination' uses a sigma-clipping to reject outlier data points when combining the images, controlled by the values in the 'Outlier rejection threshold' and 'Maximum sigma-clipping iterations' fields. The 'Gaussian width for smoothing' parameter is used when the combination method is set to 'resample.'
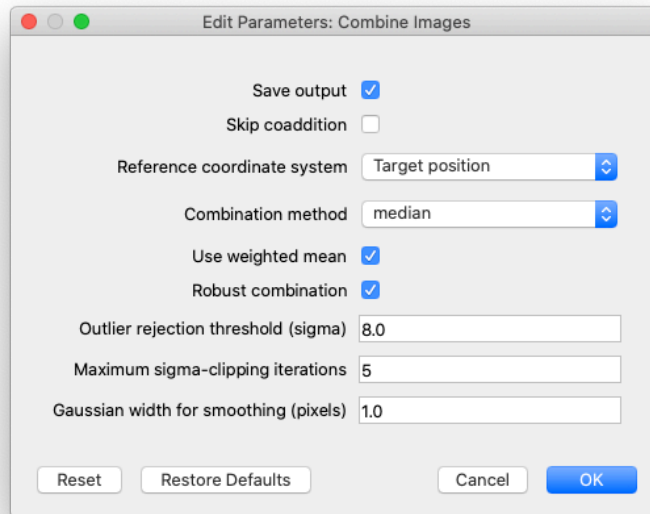
Output: The combined image is rotated to align its axes with the J2000 coordinate system, with north up and east to the left. The image clearly shows artifacts along the edges of the input images, as well as some uneven background regions.

First extension of F0340_FC_IMA_0400585_FLTPAH329_COA_0440-0485.fits.

Often image artifacts such as the ones shown above can be traced back to bad input data. There are several ways to try and identify bad data, such as visually inspecting the input files (or the individual files produced after each pipeline module) or examining the FITS headers. In the *redux* GUI, we can quickly look at some FITS header parameters to search for potential problems by clicking on the 'File Information' tab. After some inspection of the table, it shows that 5 files have

unusually short exposure times of 1 second or less, compared to the nominal 20 seconds of exposure time for the rest of the files.
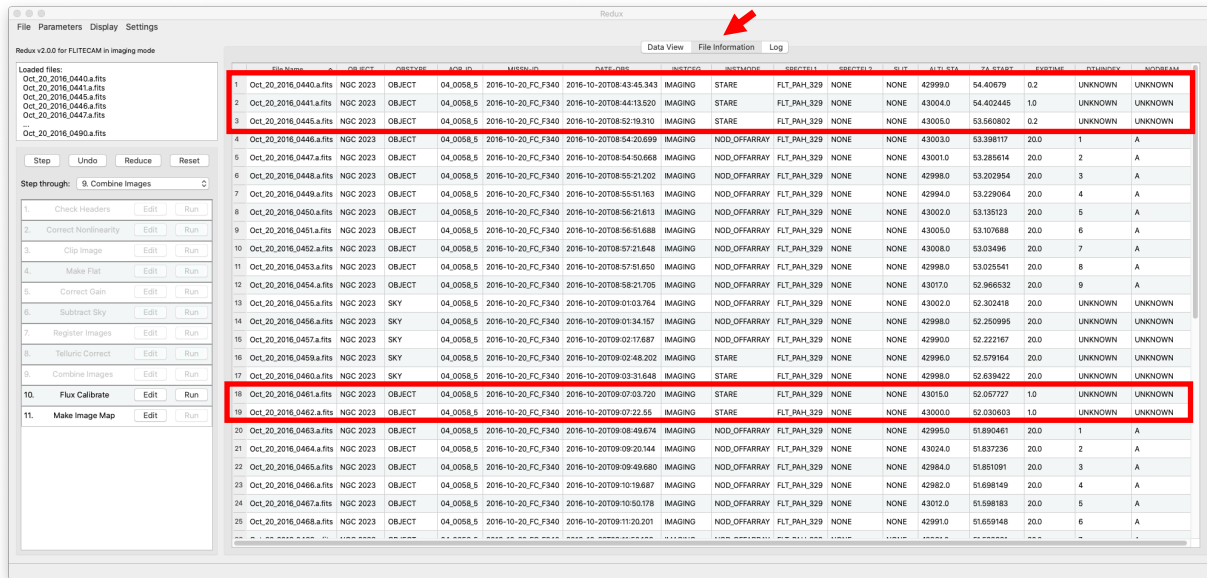

The 'File Information' tab of the *redux* GUI. The red arrow shows where to click in the GUI to get to the 'File Information' tab, and the red boxes show the 5 files with short exposure times.

To see if these 5 files are causing the issues in the combined data product, we can remove them from the reduction and re-generate the combined file. To do this, click on 'File'→'Remove Files', then removing file numbers 440, 441, 445, 461, and 462. This action resets the pipeline back to module 1, which is exactly what we want. Any parameters in modules 1 through 9 that were changed from the default values have been retained, so there is no need to re-do any editing of parameters. To run all the way through 'Combine Images' (module 9), you can either click 'Run' for each step, or select '9. Combine Images' in the 'Step through:' drop-down menu and then click 'Step.'

Now we can examine the resulting combined file after excluding the 5 potentially bad input files. Note that the filename has changed from our first attempt, from:
F0340_FC_IMA_0400585_FLTPAH329_COA_0440-0485.fits
to
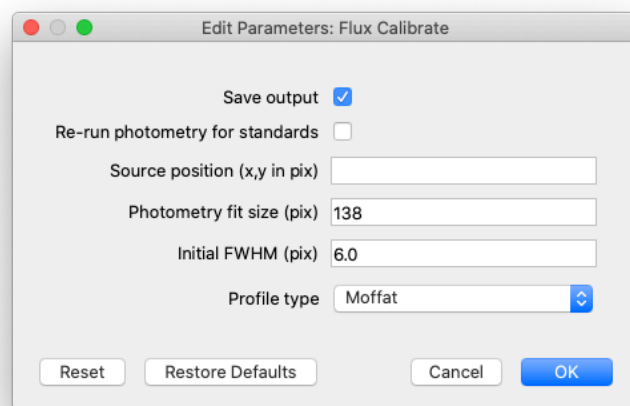F0340_FC_IMA_0400585_FLTPAH329_COA_0446-0485.fits.

The new coadded image is shown below.
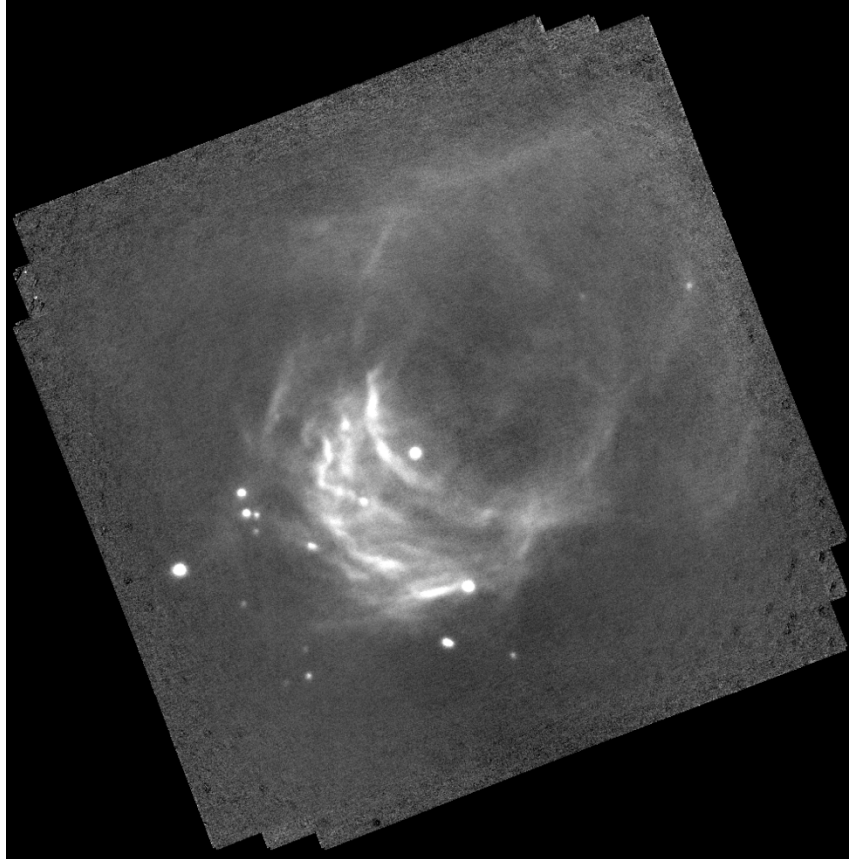
First extension of F0340_FC_IMA_0400585_FLTPAH329_COA_0446-0485.fits. The artifacts seen in the prior coadd are now largely removed.

10. Flux Calibrate: In this module, the calibration factor determined by the FLITECAM calibration team is applied to the coadded image

Options: Aside from the 'Save output' option, the options in this module are used by the FLITECAM calibration team to determine calibration factors from standards.
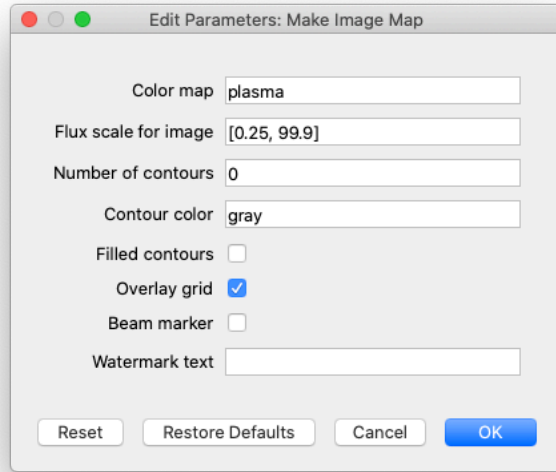
Output: This is now the final, calibrated image for the NGC 2023.
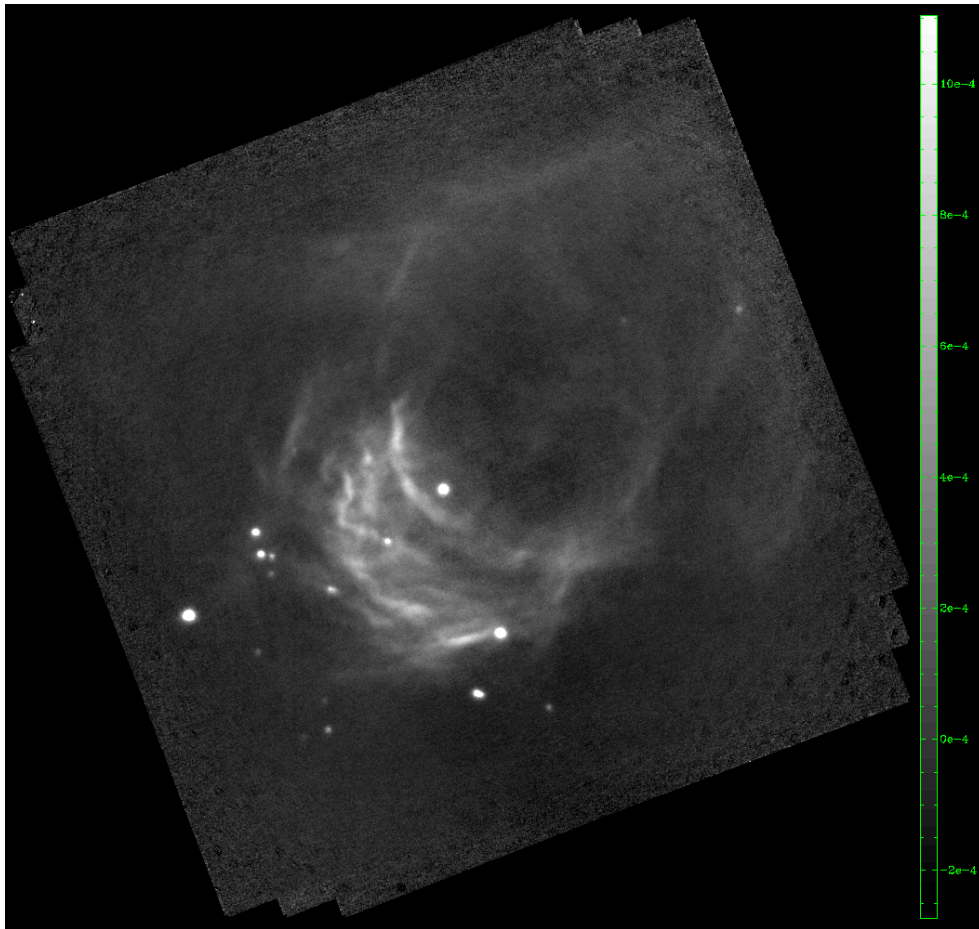
First extension of F0340_FC_IMA_0400585_FLTPAH329_CAL_0446-0485.fits

11. Make Image Map: This last module is used to generate a png file from the final data product.
Options: These options control the look of the final png image.

Edit Parameters: Make Image Map

Color map   plasma

Flux scale for image   [0.25, 99.9]

Number of contours   0

Contour color   gray

Filled contours   ☐

Overlay grid   ☑

Beam marker   ☐

Watermark text

Reset   Restore Defaults   Cancel   OK

Output:

Object: NGC 2023, Filter: FLT_PAH_329

Filename: F0340_FC_IMA_0400585_FLTPAH329_CAL_0446-0485.fits

-2°12'

14'

Dec (J2000)

16'

18'

5ʰ41ᵐ48ˢ   42ˢ   36ˢ   30ˢ   24ˢ

RA (J2000)

0.0008
0.0006
0.0004
0.0002
0.0000
-0.000