FORCAST Imaging Pipeline Tutorial

This tutorial is designed to help guide users through the steps of processing FORCAST imaging data, from raw data files to the final, calibrated data product. The information in this tutorial can also be found in more detail FORCAST User's Manual. Additional detail about some of the data reduction modules can also be found in Herter et al. (2013; 10.1086/674144).

Retrieve the Data

For this sample reduction, we'll use FORCAST 11.2 μm observations of Europa. These data were obtained as calibration observations during a 2016 flight. 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 → 90_0073_17
  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=90_0073_17

On the search results page, click on the FORCAST tab. On the FORCAST tab, select all four 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 ~3MB in size). Save this file wherever you wish, unzip it, and navigate the subfolders to locate the four FORCAST FITS files. You may either leave these files in the directory or move them to another location of your choice; the folder containing the four FITS files will be referred to as the 'input' directory for the remainder of the tutorial.
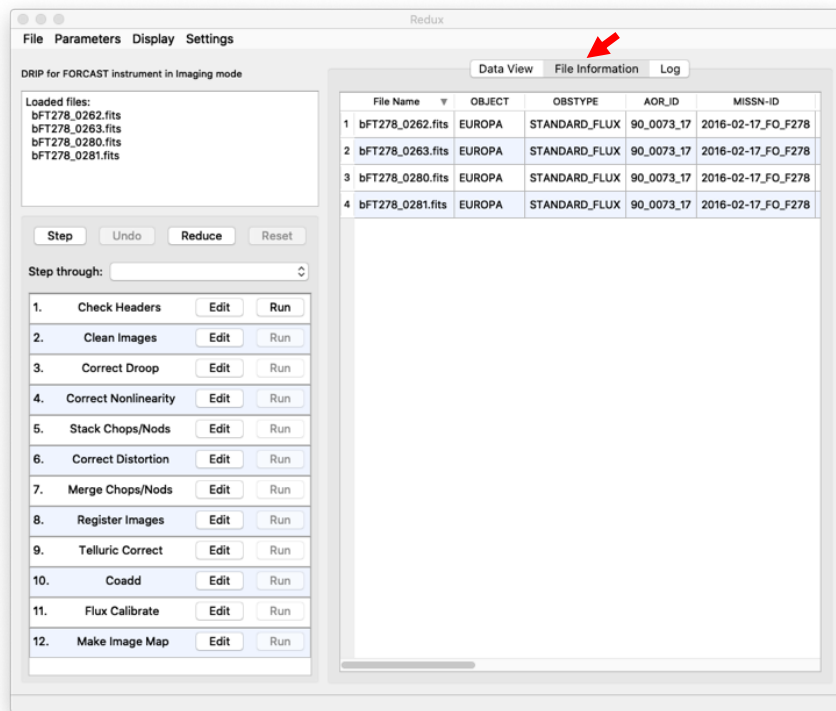
Download and Install the Pipeline

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 Europa data by selecting File → Open New Reduction, navigate to the input directory where you saved the data, select all four 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 'DRIP for FORCAST instrument 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.

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.
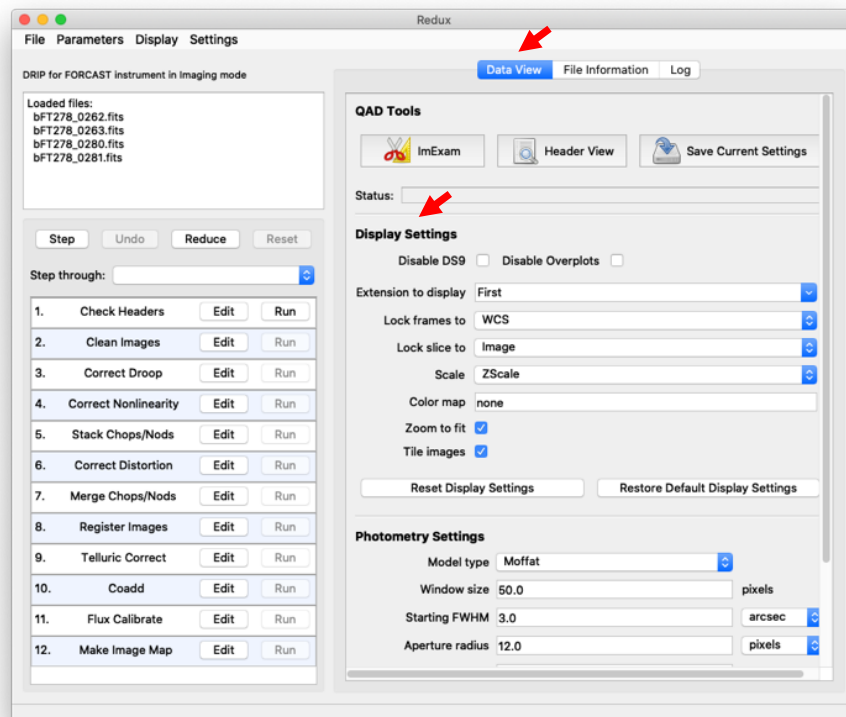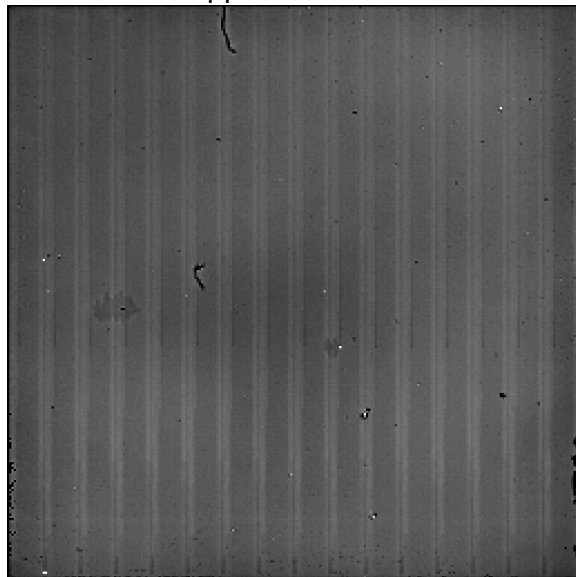
Run the Pipeline

There are 12 modules in the FORCAST 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!).
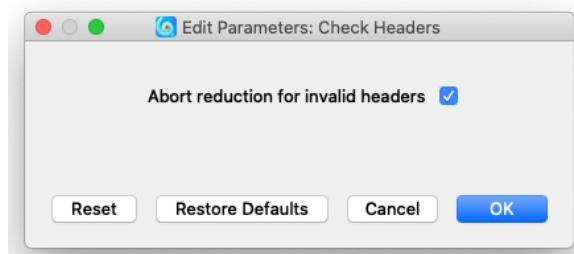
Output: This module creates no output; it allows the data set to pass through to the next modules in the reduction. For comparison with the output of the next module, we show the first plane (each raw data file in C2N mode has four frames, 2 nod and 2 chop) of file bFT278_0262.fits before any pipeline modules have been applied.


First plane of file bFT278_0262.fits

2. Clean Images: This module will apply a bad pixel mask to the data (as NaN values), and search for (and correct) a FORCAST-specific issue in which the data are shifted by 16 pixels.

Options: The pipeline automatically loads the bad pixel map appropriate for the data that will be processed (based on the FITS header information). In most cases, users will want to use the default values in this module.
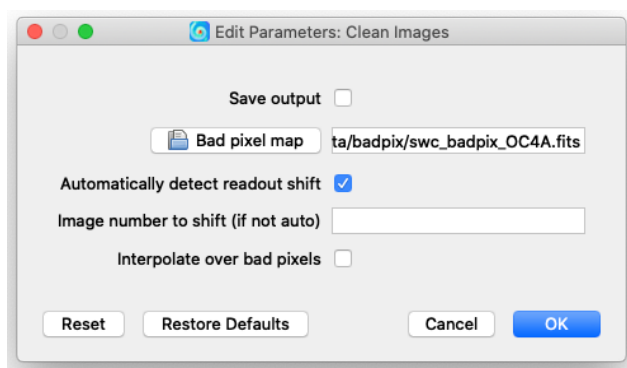

Output: A careful comparison of this image with the prior image shows that the 'hot' pixels are now blanked, along with another elongated region near the center of the array (examples marked with red arrows).
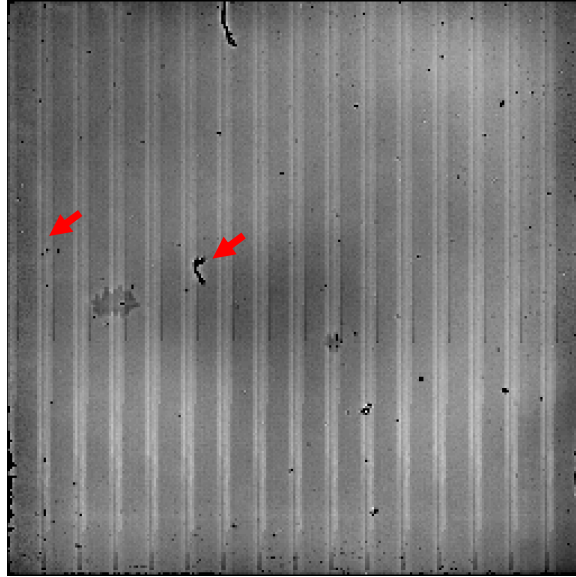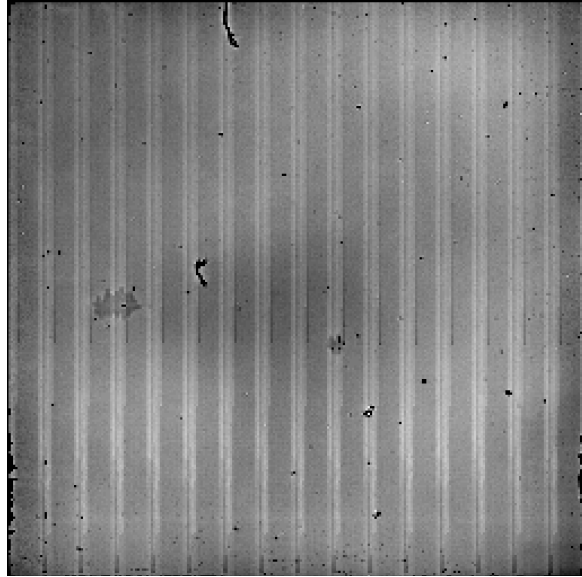
First plane of F0278_FO_IMA_90007317_FORF112_CLN_0262.fits.

3. and 4. Correct Droop and Correct Nonlinearity: These modules correct a few issues specific to the FORCAST arrays and readout electronics (see the User's Manual for more details; see also Fig. 4 of the Herter et al. (2013) for additional examples of how these data issues are corrected).

Options: The default values used in these two modules have been determined by scientists at the SOFIA Science center. You will probably not want to change them without a very good reason.
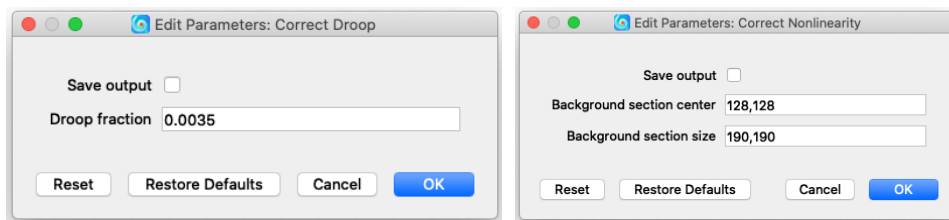

Output: The effects of these two pipeline modules are relatively subtle for this data set.

First plane of F0278_FO_IMA_90007317_FORF112_LNZ_0262.fits.

5. Stack Chops/Nods: This module combines the 4 chop/nod frames into a single image. It also by default removes the 'jailbar' features seen in the prior modules.

Options: As with the earlier modules, the default options are usually best for most data sets.
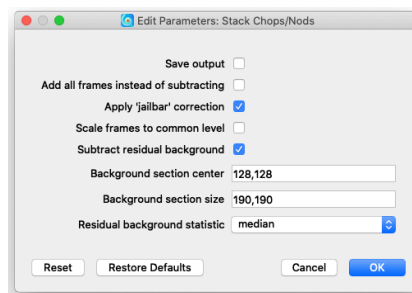
Output: Because these observations were designed with on-chip chopping and nodding, the resulting file contains three images of Europa—one positive, and two negatives.
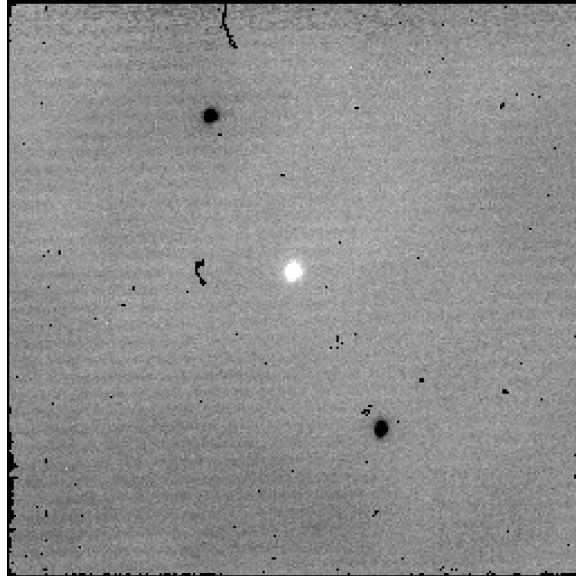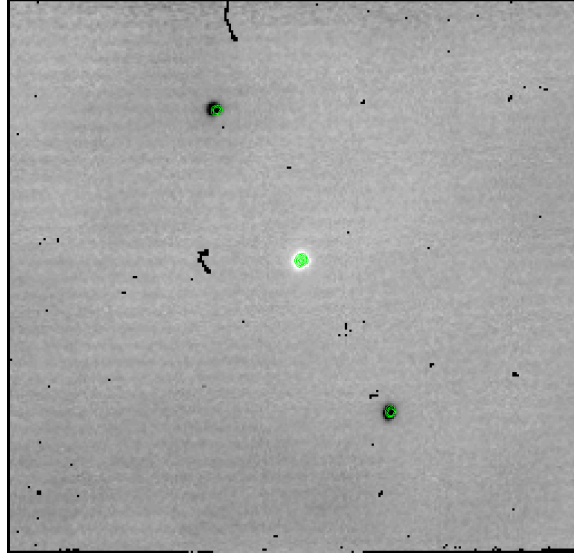
F0278_FO_IMA_90007317_FORF112_STK_0262.fits.

6. Correct Distortion: The FORCAST optics introduce some distortion, which is fixed in this module using a lab-imaged grid of pinholes.

Options: Again, default options here are best for most data sets.
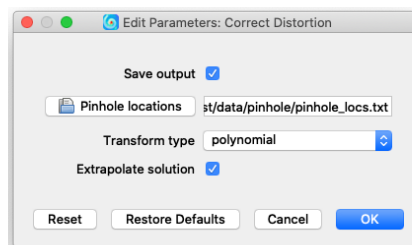
Output: In the image below, you can see that the distortion correction has shifted the negative images of Europa.
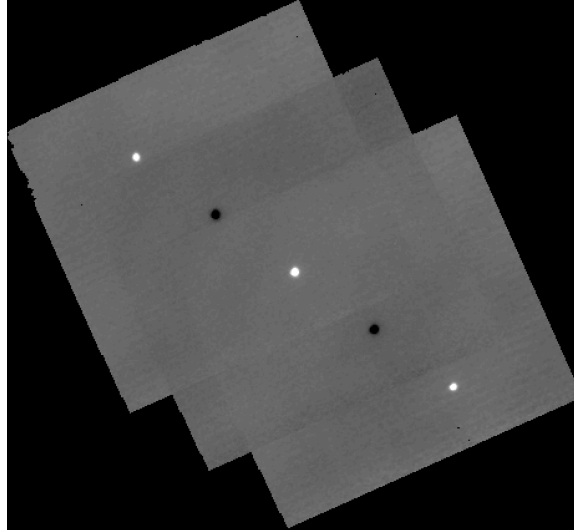
F0278_FO_IMA_90007317_FORF112_UND_0262.fits (result of module 6), overlaid with green contours from F0278_FO_IMA_90007317_FORF112_STK_0262.fits (result of module 5).

7. Merge Chops/Nods: In the previous modules, we saw one positive image of Europa and two negative ones. Each of these measurements is independent and can be combined to improve the signal-to-noise ratio (SNR) of the final image. This is done in this pipeline module.

Options: The default mode to combine the multiple sources in images is 'centroid'—this is best used for bright, compact sources. Other methods, such as 'header shifts' or 'cross-correlation' may work better for sources that have different structure.
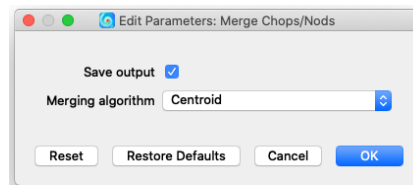

Output: The result of this module has 5 images of Europa. Only the central image, which has the highest SNR, should be used for science.
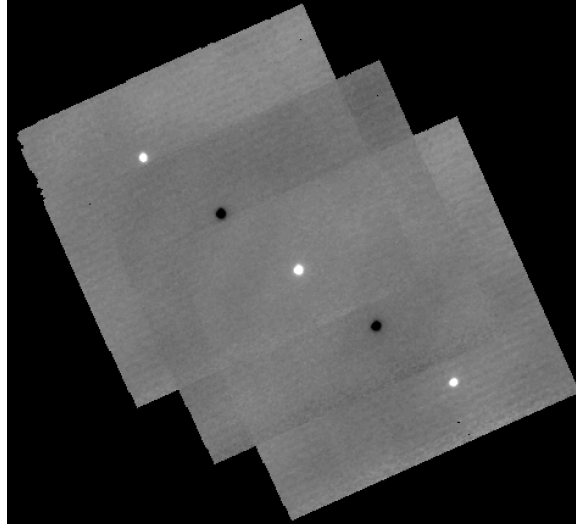
F0278_FO_IMA_90007317_FORF112_STK_0262.fits

8. Register Images: This module is done to prepare for the combination of multiple input files. In our example, we have 4 independent observations of Europa that we want to combine. This module ensures that the combination will be done correctly.

Options: The default registration algorithm for combining data is 'Use WCS as is.' For recent FORCAST data that have reliable WCS information, this is often the best option. Because Europa is a non-sidereal target, and because we have observations that span about 10 minutes of clock time (see the 'DATE-OBS' column on the 'File Information' tab describe above), the better option is to select 'centroid' for image registration (see the Output section of module 10 below).
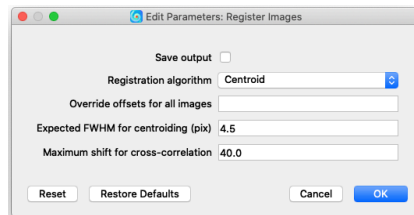

Output: Because the main change in this module is to the WCS in the fits header, there is little difference in the output image in modules 7 and 8.
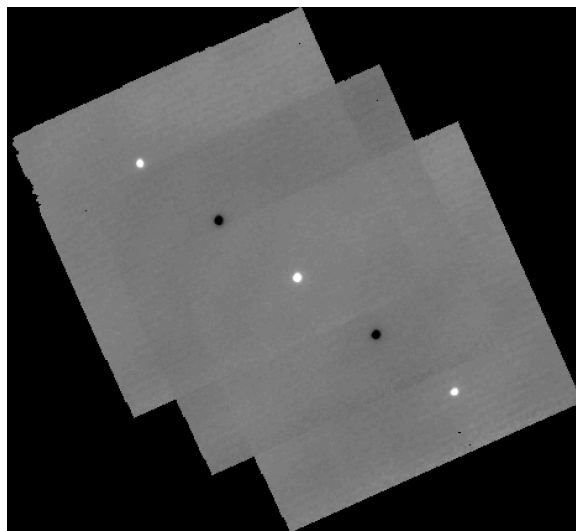
F0278_FO_IMA_90007317_FORF112_REG_0262.fits

9. 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.
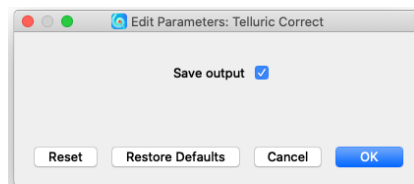
Output: This image looks similar to the output from module 8, but the scale of the image has changed based on the optical depth of the atmosphere.

10. Coadd: Up until this module, the 4 input files have been processed individually. Based on the image registration in module 8, the files are now combined into a single data product.

Options: There are three ways to combine multiple images—median, mean, and resample. Because the similar data quality in each of our four images, the choice for this data set is not crucial.
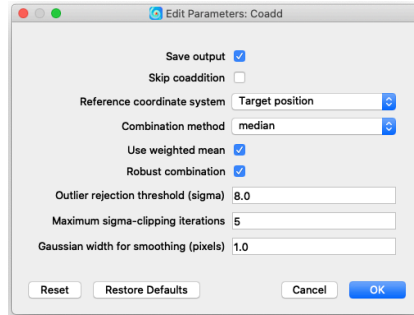

Output: Here are two example outputs from this module. On the left is the combination of the data when 'Centroid' is selected in module 8. On the right is the combination of the data when 'Use WCS as is' is selected in module 8.
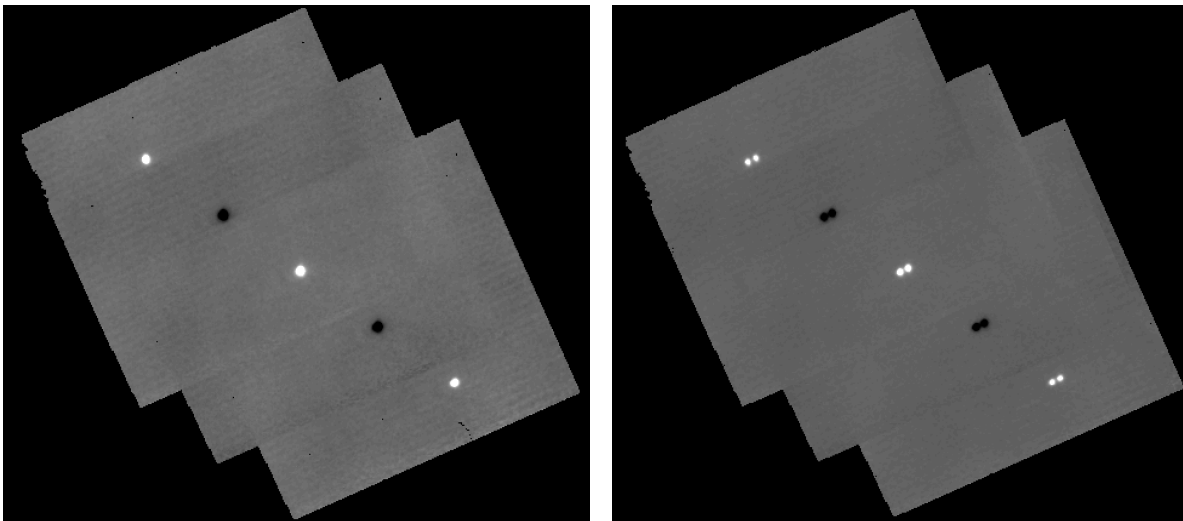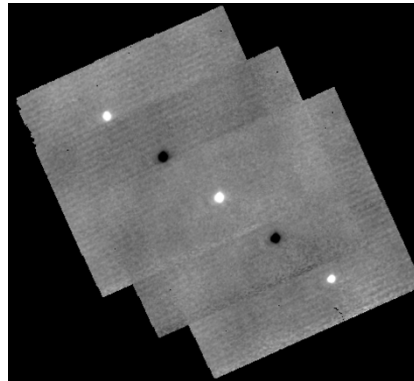

F0278_FO_IMA_90007317_FORF112_COA_0262.fits

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

Options: Aside from the 'Save output' option, the options in this module are used by the FORCAST calibration team to determine calibration factors from standards.
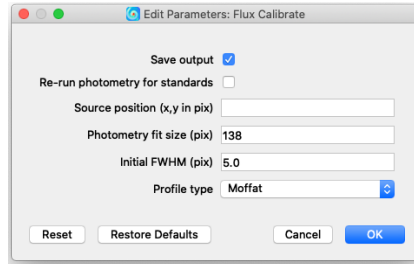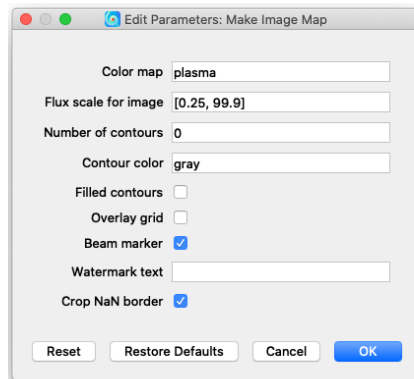
Output: This is now the final, calibrated image for the Europa.

F0278_FO_IMA_90007317_FORF112_CAL_0262.fits

12. 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.

Output:

Object: Europa, Filter: FOR_F112

Filename: F0278_FO_IMA_90007317_FORF112_CAL_0262-0263.fits