



SOFIA Redux:

Intro to the Data Reduction Pipeline Package

Melanie Clarke
for the SOFIA Data Processing System
(DPS) team
4/26/22



SOFIA Redux

SOFIA data reduction software is published as a single Python package, containing all code, configuration, and reference data needed to:

- read raw data
- remove instrument and background artifacts
- calibrate to physical units
- combine separate observations

for FORCAST, FIFI-LS, FLITECAM, and HAWC+ data.

EXES data is not yet supported, but hopefully will be within the next year.



Package information

SOFIA Redux is developed internally by the DPS team, then pushed to a public repository:

https://github.com/SOFIA-USRA/sofia_redux

The screenshot shows the GitHub repository page for SOFIA-USRA/sofia_redux. The repository is public and has 6 stars and 2 watchers. The main branch is 'main'. The repository contains several files and folders, including 'docs', 'licenses', 'sofia_redux', '.gitignore', '.gitlab-ci.yml', '.travis.yml', 'CHANGES.rst', 'CITATION', and 'MANIFEST.in'. The most recent commit is a patch to the 'sofia_redux' folder by melanieclarke, made 11 days ago. The repository also has 7 releases, with the latest being v1.2.3, released 11 days ago.

File/Folder	Commit Message	Commit Date
docs	Update scan docs	14 days ago
licenses	Initial commit	10 months ago
sofia_redux	Patch Windows tests	11 days ago
.gitignore	Initial commit	10 months ago
.gitlab-ci.yml	Test miniconda runner	8 months ago
.travis.yml	Configuration updates for v1.2.3	17 days ago
CHANGES.rst	Add date for v1.2.3	12 days ago
CITATION	Update docs and metadata	9 months ago
MANIFEST.in	Exclude large FLITECAM files from build	8 months ago



Package information

SOFIA Redux is open source,
licensed under BSD 3-clause.

Contributions are welcome!

Feel free to fork, modify,
experiment, and improve.

powered by **AstroPy** DOI [10.5281/zenodo.6423298](https://doi.org/10.5281/zenodo.6423298)

SOFIA Redux (`sofia_redux`) contains data processing pipelines and algorithms for instruments on the Stratospheric Observatory for Infrared Astronomy (SOFIA).

Currently, the SOFIA instruments supported by this package are the FORCAST and FLITECAM imaging and spectroscopic instruments, the FIFI-LS integral field spectrometer, and the HAWC+ imaging and polarimetric instrument.

SOFIA raw and processed data can be accessed from the [SOFIA archive](#). Archived data may not match the results of data processed with this pipeline software. Questions specific to particular data sets should be directed to the [SOFIA helpdesk](#).

SOFIA pipelines are developed internally by the USRA/SOFIA data processing software team, then are published publicly at the [SOFIA Redux GitHub project](#). Contributions and feedback are welcome via the GitHub project, but merge requests cannot be directly accepted. They will be internally reviewed, and pushed to the public site as needed.

For more information about installing and using this package, see the [online documentation](#), or `docs/install.rst` in the source distribution.

github-pages **Active**

Languages

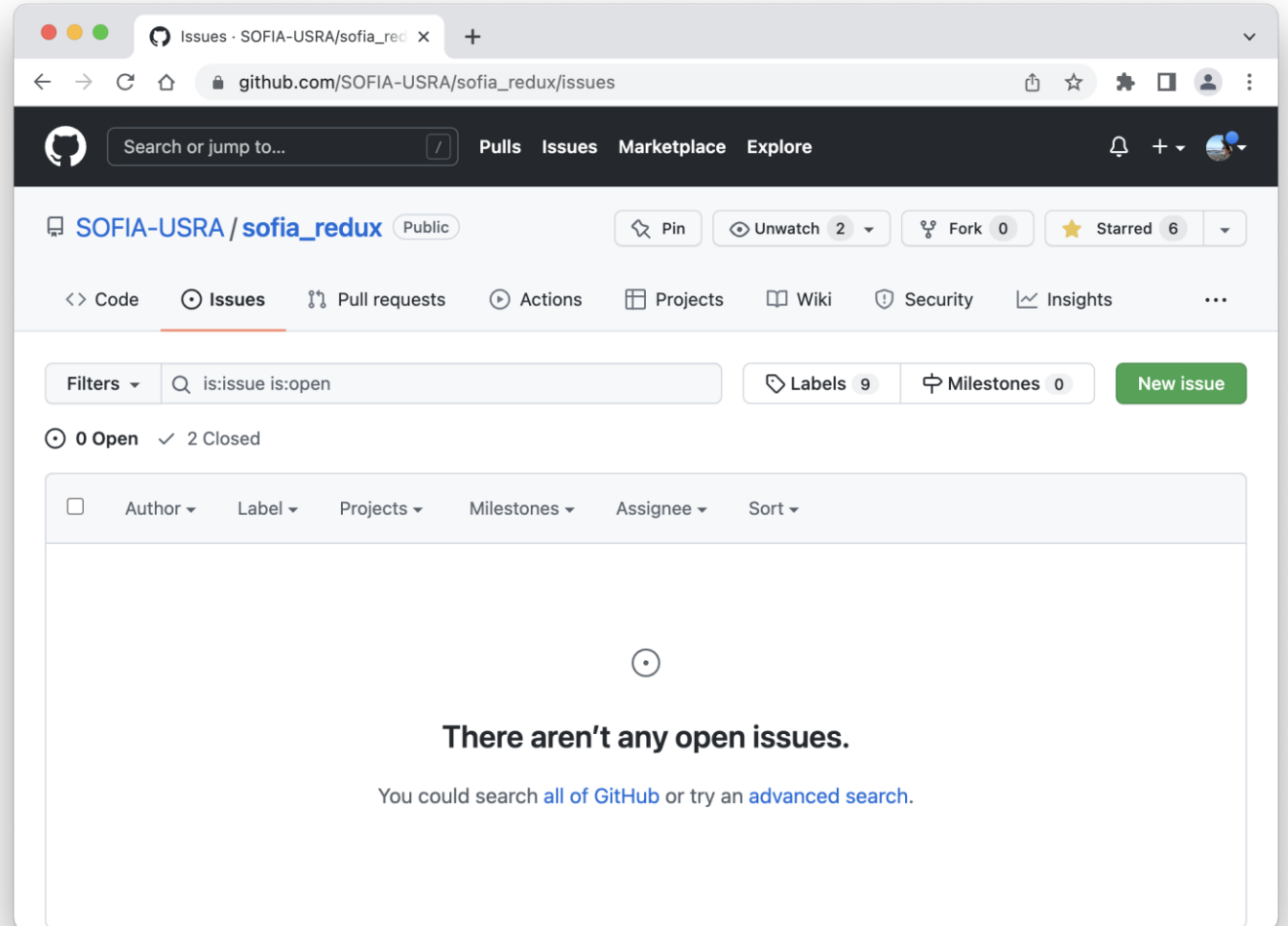
- Python 80.9%
- Jupyter Notebook 19.1%

Package information



Feedback or contributions:

- File an issue on GitHub
- Send a request to the SOFIA helpdesk:
sofia_help@sofia.usra.edu





Installation

Install `sofia_redux` with standard tools

Via pip:

```
pip install sofia_redux
```

Via conda:

```
conda install -c sofia-usra -c astropy sofia_redux
```

Online documentation: https://sofia-usra.github.io/sofia_redux

The screenshot shows a web browser window displaying the 'Getting Started' page for the SOFIA Redux package. The page is titled 'Getting Started' and contains the following sections:

- Installation**
 - Stable release**: The `sofia_redux` package is available via anaconda or pip:

```
conda install -c sofia-usra -c astropy sofia_redux
```

or:

```
pip install sofia_redux
```
 - From source**: Obtain the source code for this package from the [SOFIA Redux GitHub project](#), then install via one of the two methods below.
 - Via Anaconda**: We recommend Anaconda for managing your Python environment. A conda environment specification is included with this package, as [environment.yml](#). To install a `sofia_redux` environment with Anaconda:

```
conda env create -f environment.yml
```

Activate the environment:

```
conda activate sofia_redux
```

Install the `sofia_redux` package:

```
pip install .
```



Installation

Install `sofia_redux` from source

Recommended:

```
git clone https://github.com/SOFIA-USRA/sofia_redux.git
```

```
conda env create -f sofia_redux/environment.yml
```

```
conda activate sofia_redux
```

```
pip install -e sofia_redux
```

The screenshot shows a web browser window displaying the 'Getting Started' page for the SOFIA Redux project. The page is titled 'Getting Started' and contains the following sections:

- Installation**
 - Stable release**: The `sofia_redux` package is available via anaconda or pip:

```
conda install -c sofia-usra -c astropy sofia_redux
```

or:

```
pip install sofia_redux
```
 - From source**: Obtain the source code for this package from the [SOFIA Redux GitHub project](#), then install via one of the two methods below.
 - Via Anaconda**: We recommend Anaconda for managing your Python environment. A conda environment specification is included with this package, as `environment.yml`. To install a `sofia_redux` environment with Anaconda:

```
conda env create -f environment.yml
```

Activate the environment:

```
conda activate sofia_redux
```

Install the `sofia_redux` package:

```
pip install .
```

Online documentation: https://sofia-usra.github.io/sofia_redux



Installation

Download additional reference data

- ATRAN libraries for optimal telluric correction
- Standard flux models for spectroscopic calibration (pip, conda only)
- Auxiliary data for FLITECAM reductions (pip, conda only)

See the [Getting Started](#) documentation for more information.



Audience

SOFIA provides science-ready data products via the IRSA archive.

Why install the pipeline software?

- To understand your SOFIA data better
- To improve archival data products
- To customize your data reduction
- To develop your own astronomical software



Audience

SOFIA provides science-ready data products via the IRSA archive.

Why install the pipeline software?

- To understand your SOFIA data better
- To improve archival data products
- To customize your data reduction
- To develop your own astronomical software



Understand your data

- Extensive documentation posted online, including user and developer [manuals](#) for all instruments
- Intermediate data products illustrate each step of the reduction process
- Visualization tools packaged with the pipeline can help you access and understand your data products more quickly

SOFIA Redux:docs

sofia_redux v1.2.3 » next »

SOFIA Redux Documentation

User and Developer Documentation

- SOFIA Redux
 - Introduction
 - Getting Started
 - Tutorials
 - Manuals
 - Submodules
- Manuals
 - User's Manuals
 - Developer's Manuals

Project Details

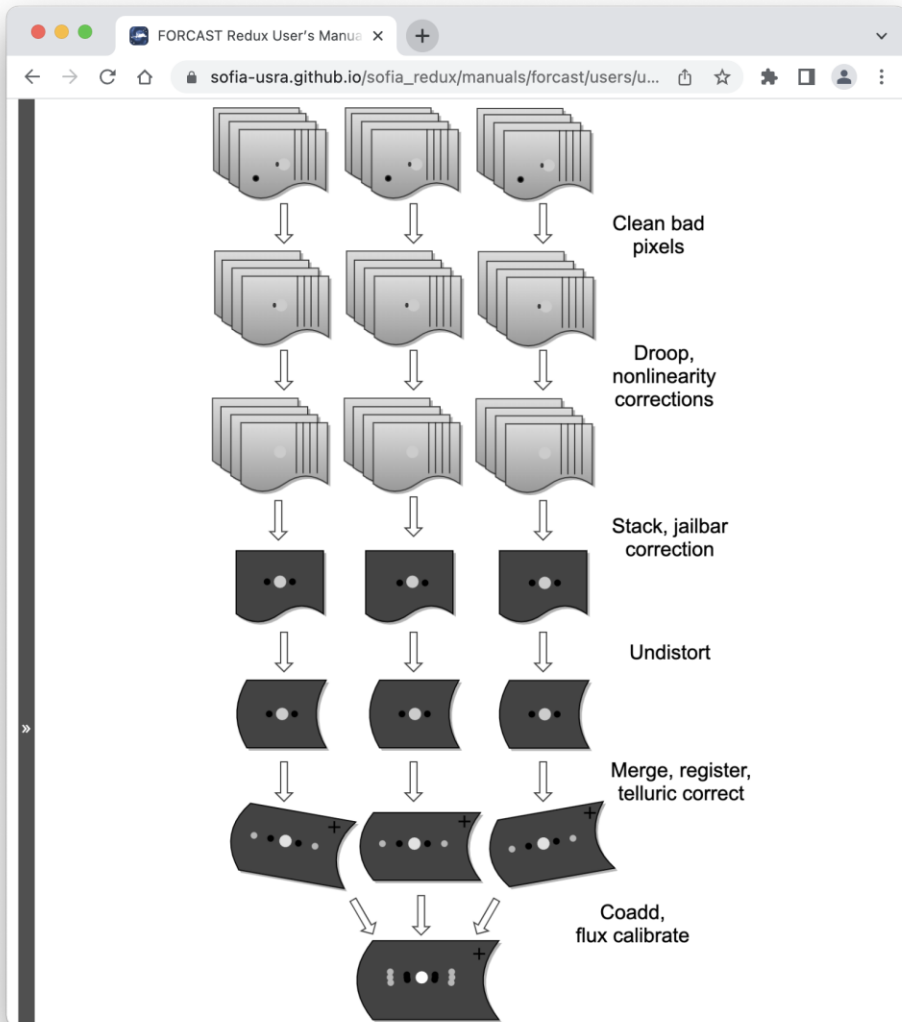
- Full Changelog
- Authors and Credits
- License

© Copyright 2022, SOFIA-USRA.
Created using Sphinx 4.4.0. Last built 07 Apr 2022.

[Page Source](#) [Back to Top](#)

Online documentation: https://sofia-usra.github.io/sofia_redux

Manuals



Pipeline Products

The following tables list all intermediate products generated by the pipeline for imaging and grism modes, in the order in which they are produced. [7] By default, for imaging, the *undistorted*, *merged*, *telluric_corrected*, *coadded*, *calibrated*, and *mosaic* products are saved; for grism, the *stacked*, *rectified_image*, *merged_spectrum*, *calibrated_spectrum*, *coadded_spectrum*, and *combined_spectrum* products are saved.

The final grism mode output product from the Combine Spectra or Combine Response steps are dependent on the input data: for INSTMODE=SLITSCAN, a *spectral_cube* product is produced instead of a *coadded_spectrum* and *combined_spectrum*; for OBSTYPE=STANDARD_TELLURIC, the *instrument_response* is produced instead.

For most observation modes, the pipeline additionally produces an image in PNG format, intended to provide a quick-look preview of the data contained in the final product. These auxiliary products may be distributed to observers separately from the FITS file products.

[7] Earlier versions of this pipeline (before v2.0.0) produced different sets of default products. Refer to earlier revisions of this manual for complete information.

Table 11 Intermediate data products for imaging reductions

Step	Data type	PRODTYPE	PROCSTAT	Code	Saved	Extensions
Clean Images	2D image	cleaned	LEVEL_2	CLN	N	FLUX, ERROR
Correct Droop	2D image	drooped	LEVEL_2	DRP	N	FLUX, ERROR
Correct Nonlinearity	2D image	linearized	LEVEL_2	LNZ	N	FLUX, ERROR
Stack Chops/Nods	2D image	stacked	LEVEL_2	STK	N	FLUX, ERROR
Undistort	2D image	undistorted	LEVEL_2	UND	Y	FLUX, ERROR
Merge	2D image	merged	LEVEL_2	MRG	Y	FLUX, ERROR, EXPOSURE
Register	2D image	registered	LEVEL_2	REG	N	FLUX, ERROR, EXPOSURE
Telluric Correct	2D image	telluric_corrected	LEVEL_2	TEL	Y	FLUX, ERROR, EXPOSURE
Coadd	2D image	coadded	LEVEL_2	COA	Y	FLUX, ERROR, EXPOSURE
Flux Calibrate	2D image	calibrated	LEVEL_3	CAL	Y	FLUX, ERROR, EXPOSURE
Mosaic	2D image	mosaic	LEVEL_4	MOS	Y	FLUX, ERROR, EXPOSURE

User manuals contain useful information about data processing steps and output data products.



Intermediate processing

Loading SOFIA FITS files into the pipeline interface automatically selects the correct pipeline steps and default parameters.

Step through to see the effects of each step on the data.

The screenshot displays the Redux software interface. The main window is titled "Redux" and has a menu bar with "File", "Parameters", "Display", and "Settings". Below the menu bar, it says "DRIP v2.3.1.dev0 for FORCAST in Spectroscopy mode".

On the left side, there is a "Loaded files:" list containing several FITS files: rFT432_0101.fits, rFT432_0102.fits, rFT432_0106.fits, rFT432_0107.fits, rFT432_0108.fits, and rFT432_0121.fits. Below this list are buttons for "Step", "Undo", "Reduce", and "Reset".

In the center, there is a "Step through:" dropdown menu currently set to "9. Trace Continuum". Below this is a list of 11 pipeline steps, each with an "Edit" and "Run" button:

1. Check Headers
2. Clean Images
3. Correct Droop
4. Correct Nonlinearity
5. Stack Chops/Nods
6. Stack Dithers
7. Make Profiles
8. Locate Apertures
9. Trace Continuum
10. Set Apertures
11. Subtract Background

On the right side, there is a "Data View" tab selected, showing the output of the "Locate Apertures" step. The output text is as follows:

```
Locate Apertures
-----
2021-08-03 17:33:30.072920

Parameters:
save = False
method = auto
num_aps = 1
input_position =
fwhm = 3.0
-----

Finding aperture positions from Gaussian fits.

Apertures found:|
F0432_FO_GRI_05006326_FORG227_LOC_0101-0121.fits
122.290 arcsec (sign: 1, fit FWHM: 18.458)

Mean fit FWHM: 18.46 +/- 0.00 arcsec
-----

Trace Continuum
-----
2021-08-03 17:33:30.179547

Parameters:
save = False
method = fit to continuum
fit_order = 2
fit_thresh = 4.0
step_size = 3
-----

Fitting trace to continuum.
Wrote region file /Users/mjclarke/pipeline/proc/tutorials/forcast_spec/F0432_
== Pipeline step complete. ==
```

The "Edit Parameters: Set Apertures" dialog box is shown in the foreground. It contains the following options:

- Save output
- Extract the full slit
- Refit apertures for FWHM
- Aperture sign
- Aperture radius
- PSF radius
- Background regions

At the bottom of the dialog are buttons for "Reset", "Restore Defaults", "Cancel", and "OK".

Intermediate processing



The screenshot displays the Redux software interface, which is used for processing astronomical data. The main window is titled "Redux" and shows a list of loaded files on the left, a central panel with a "Log" tab, and a right panel with a "Data View" tab. The "Log" tab shows the following text:

```
Locate Apertures
-----
2021-08-03 17:33:30.072920

Parameters:
save = False
method = auto
num_aps = 1
input_position =
fwhm = 3.0

-----
Finding aperture positions from Gaussian fits.
Apertures found:|
F0432_FO_GRI_05006326_FORG227_LOC_0101-0121.fit
122.290 arcsec (sign: 1, fit FWHM: 18.458)

Mean fit FWHM: 18.46 +/- 0.00 arcsec

-----
Trace Continuum
-----
2021-08-03 17:33:30.179547

Parameters:
save = False
method = fit to continuum
fit_order = 2
fit_thresh = 4.0
step_size = 3

-----
Fitting trace to continuum.
Wrote region file /Users/mjclarke/pipeline/proc/t
== Pipeline step complete. ==
```

The right panel shows a "SAOImage ds9" window with a table of coordinates and a spectral plot. The table contains the following data:

Object	Value
NGC 7009	3.5685
LINEAR-LINEAR-A x	25.82292
Physical x	199.552
Image x	199.552
Frame 1 x	3.44166
y	116.71459
Physical y	149.472
Image y	149.472
z	1
°	0

The spectral plot shows "Spectral_flux [Jy]" on the y-axis (0 to 100) and "Wavepos [um]" on the x-axis (18 to 26). A sharp peak is visible at approximately 25.5 micrometers. The plot also shows "Transmission" on the right y-axis (0.86 to 1.00). The plot is titled "The Eye of SOFIA".



Data reduction example
from the FORCAST
imaging tutorial

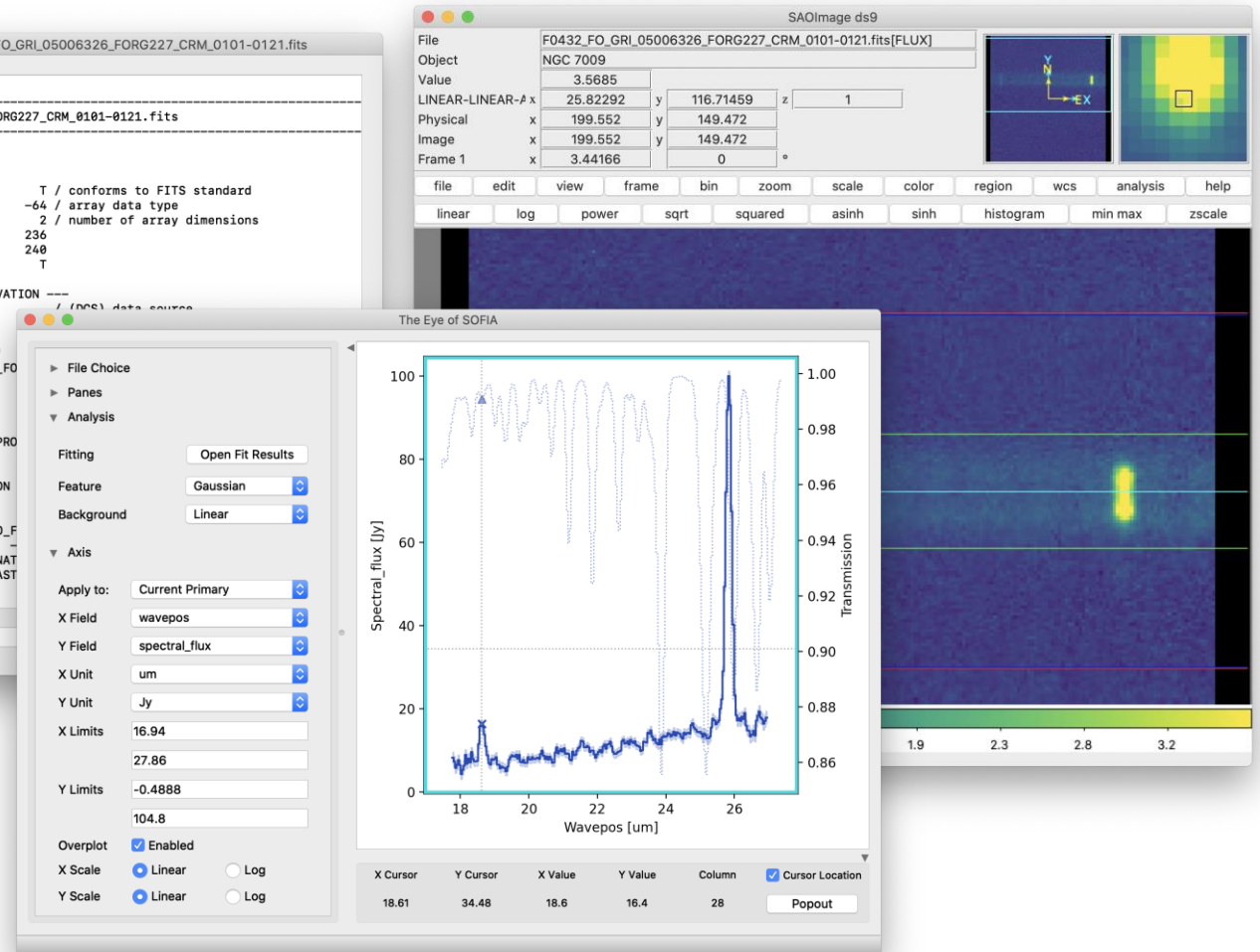
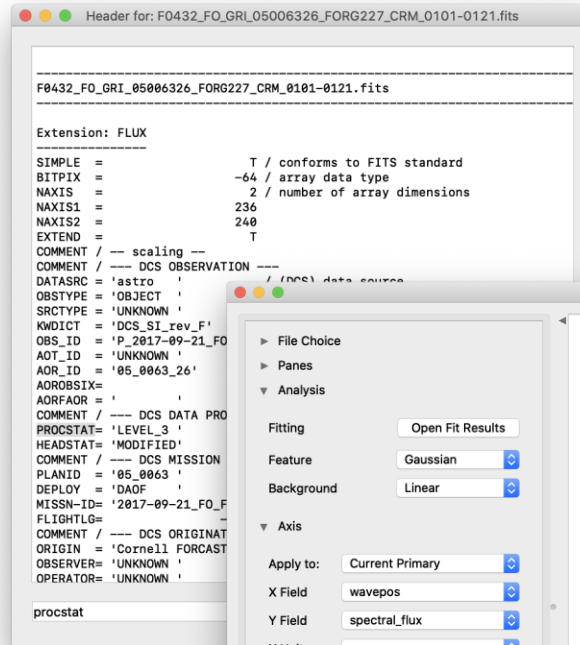
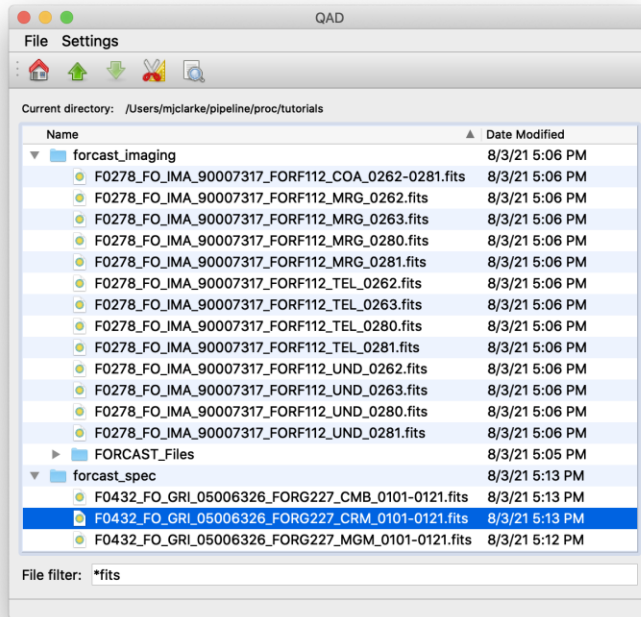
```
forcast_imaging --zsh -- 112x24
(sofia_redux) mjclarke@ARSDA18100178 forcast_imaging %
```

I

Visualization tools



The pipeline package also includes standalone visualization tools.





Standalone QA
tools

qad:
Quality Analysis and
Display tool

eospec:
The Eye of SOFIA
spectral viewer

```
tutorials -- zsh -- 134x24
(sofia_redux) mjclarke@ARSDA18100178 tutorials %
```



Audience

SOFIA provides science-ready data products via the IRSA archive.

Why install the pipeline software?

- To understand your SOFIA data better
- To improve archival data products
- To customize your data reduction
- To develop your own astronomical software



Archival data reprocessing

Archived data from recent flights are likely good as is, but older data might benefit from re-reduction.

For example:

- New FIFI-LS measured water vapor values may improve telluric correction
- New FORCAST data product formats easier to understand and use
- FLITECAM imaging pipeline improvements

Archival data reprocessing

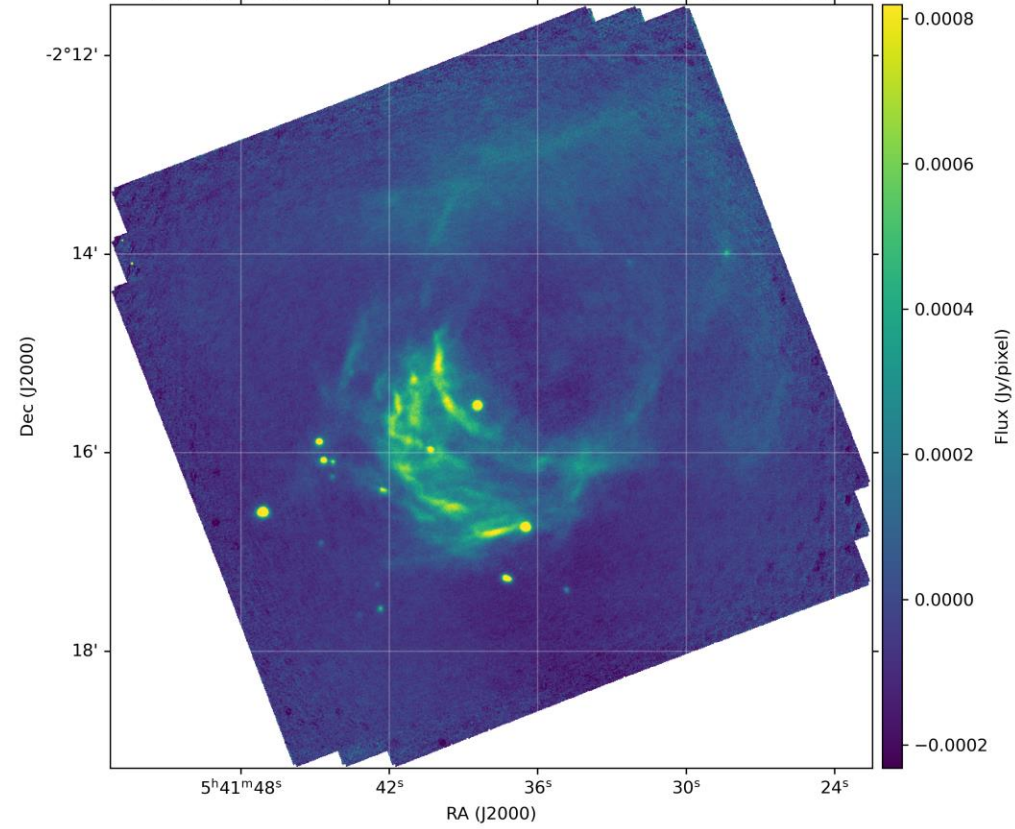
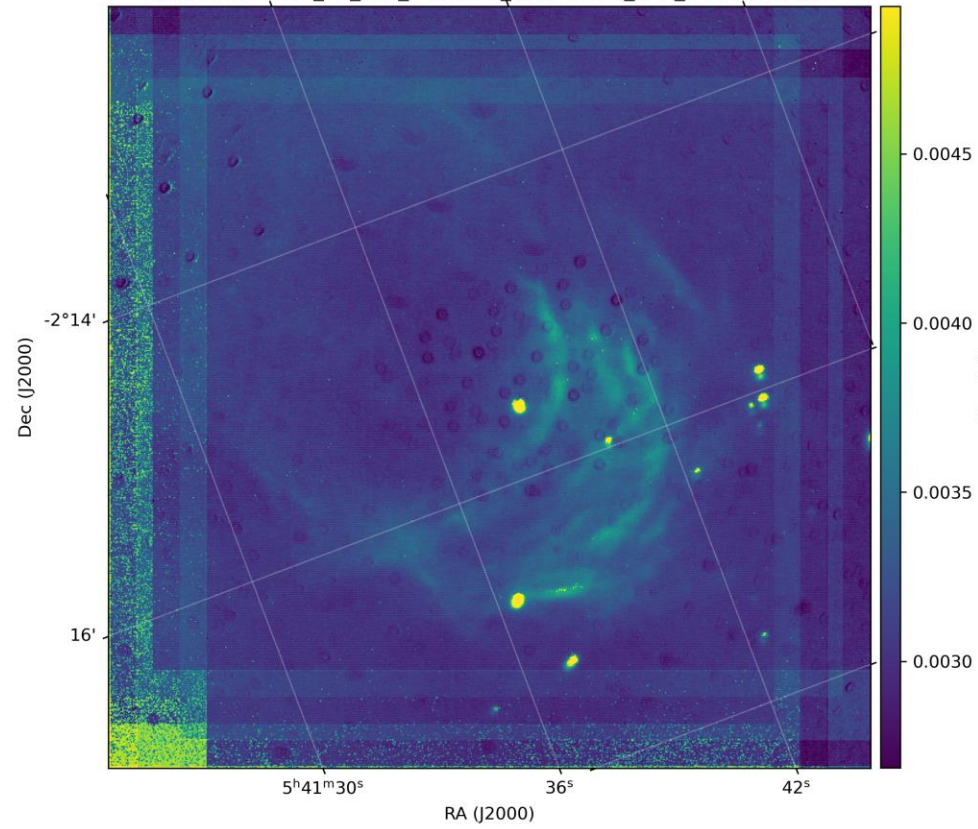


Object: NGC 2023, Filter: FLT_PAH_329

Object: NGC 2023, Filter: FLT_PAH_329

Filename: F0340_FC_IMA_0400585_FLTPAH329_CAL_0446-0485.fits

Filename: F0340_FC_IMA_0400585_FLTPAH329_CAL_0446-0485.fits



Improvements to:

- background correction
- edge effects
- registration
- final image rotation

Archived: FLITECAM Redux v1.2.0

Reprocessed: sofia_redux v1.1.0



Audience

SOFIA provides science-ready data products via the IRSA archive.

Why install the pipeline software?

- To understand your SOFIA data better
- To improve archival data products
- **To customize your data reduction**
- To develop your own astronomical software



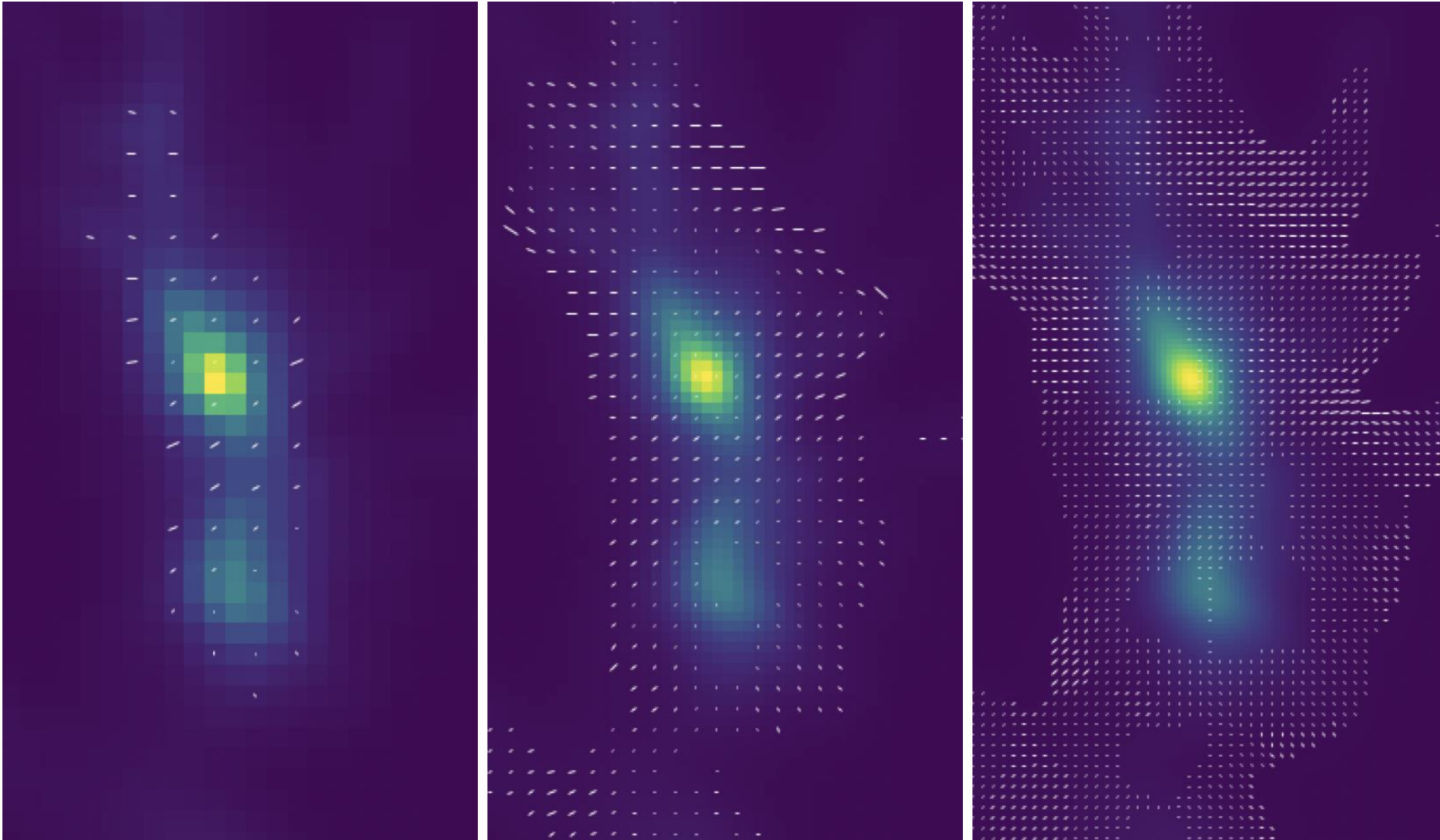
Custom data reduction

Archived data is usually reduced with default pipeline parameters. Your science may benefit from alternate settings.

For example:

- Subtract a background region to correct for negative fluxes in HAWC+ scans.
- Rebin HAWC+ polarimetry data for decreased resolution, increased S/N.
- Tweak the wavelength calibration, improve telluric correction, or recalibrate spectroscopic data with an alternate flux standard for FORCAST or FLITECAM spectroscopy.
- Generate FIFI-LS spectral cubes with adaptive smoothing kernels for better peak flux recovery.

Custom data reduction

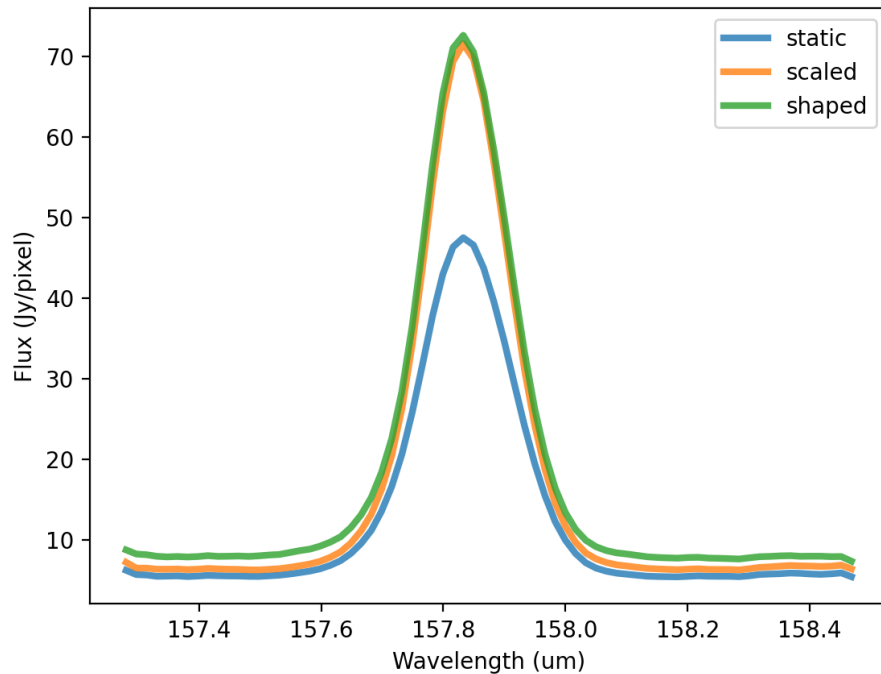
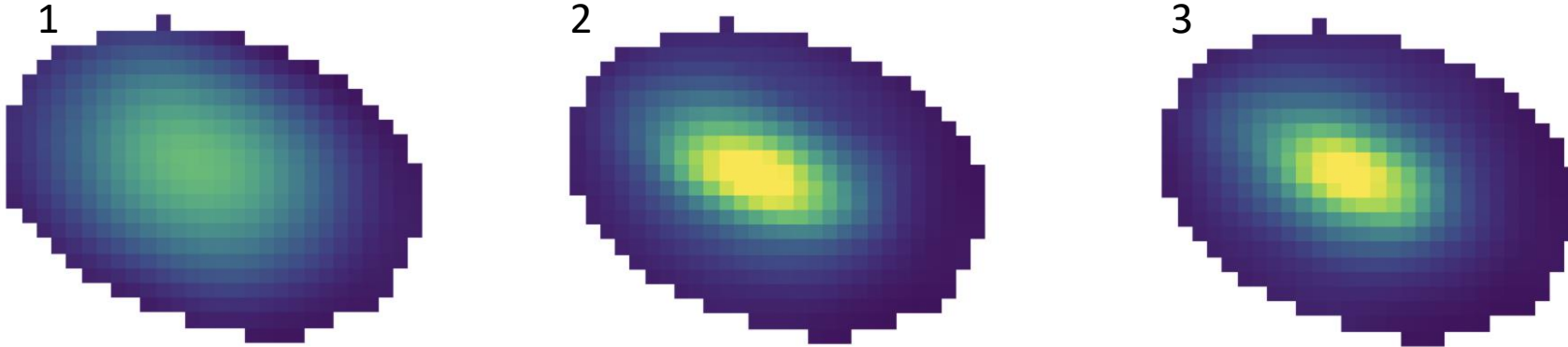


Example:
Rebin HAWC+
polarimetry data.

Center image is binned
to default resolution.



Custom data reduction



Example:

Resample a bright, compact FIFI-LS source with adaptive smoothing.

Shown:

1. Static kernel (default): left image, blue spectrum
2. Adaptively scaled kernel: middle image, orange spectrum
3. Adaptively shaped and scaled kernel: right image, green spectrum



Audience

SOFIA provides science-ready data products via the IRSA archive.

Why install the pipeline software?

- To understand your SOFIA data better
- To improve archival data products
- To customize your data reduction
- To develop your own astronomical software

Python solutions for astronomy problems



The primary purpose of the pipeline package is to reduce SOFIA data, but along the way, we've developed extensive libraries of highly performant scientific Python algorithms.

```
sofia_redux
├── calibration
├── instruments
│   ├── fifi_ls
│   ├── flitecam
│   ├── forcast
│   └── hawc
├── pipeline
├── scan
├── spectroscopy
├── toolkit
└── visualization
```

We have solutions for a variety of common problems in mid- and far-infrared astronomy.

They might serve your needs, too.



Software solutions: imaging calibration

```
sofia_redux
├── calibration
├── instruments
│   ├── fifi_ls
│   ├── flitecam
│   ├── forcast
│   └── hawc
├── pipeline
├── scan
├── spectroscopy
├── toolkit
└── visualization
```

sofia_redux.calibration:

General purpose imaging flux calibration
and photometry routines.



After calibration:

Source Flux: 205.54 +/- 0.89 Jy

Model Flux: 197.329 +/- 9.866 Jy

Percent difference from model: 4.2%



Software solutions: instrument artifacts

```
sofia_redux
├── calibration
├── instruments
│   ├── fifi_ls
│   ├── flitecam
│   ├── forcast
│   └── hawc
├── pipeline
├── scan
├── spectroscopy
├── toolkit
└── visualization
```

sofia_redux.instruments:

Instrument-specific handling;
detailed working examples of how to use
all our other tools.

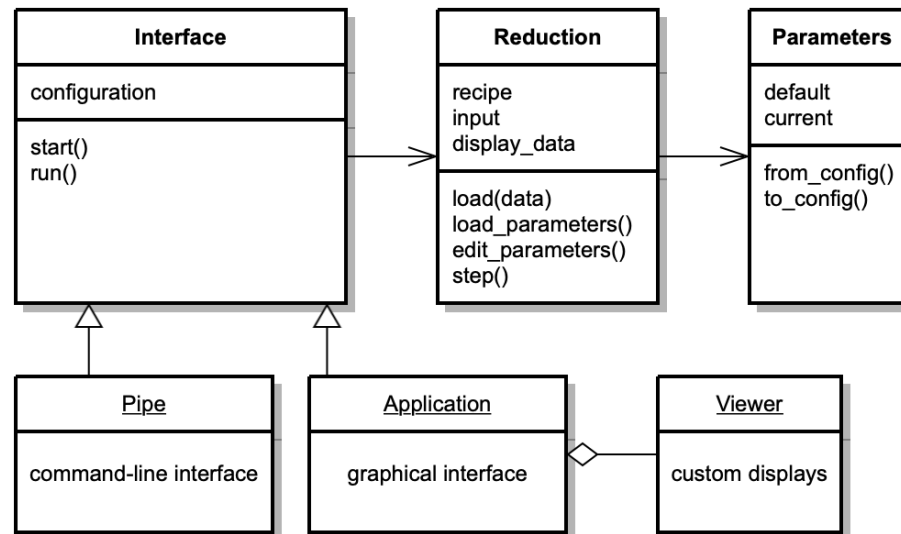


Software solutions: pipelines

```
sofia_redux
├── calibration
├── instruments
│   ├── fifi_ls
│   ├── flitecam
│   ├── forcast
│   └── hawc
├── pipeline
├── scan
├── spectroscopy
├── toolkit
└── visualization
```

sofia_redux.pipeline:

Extensible pipeline interfaces for batch mode and GUI processing, as well as intermediate file display.



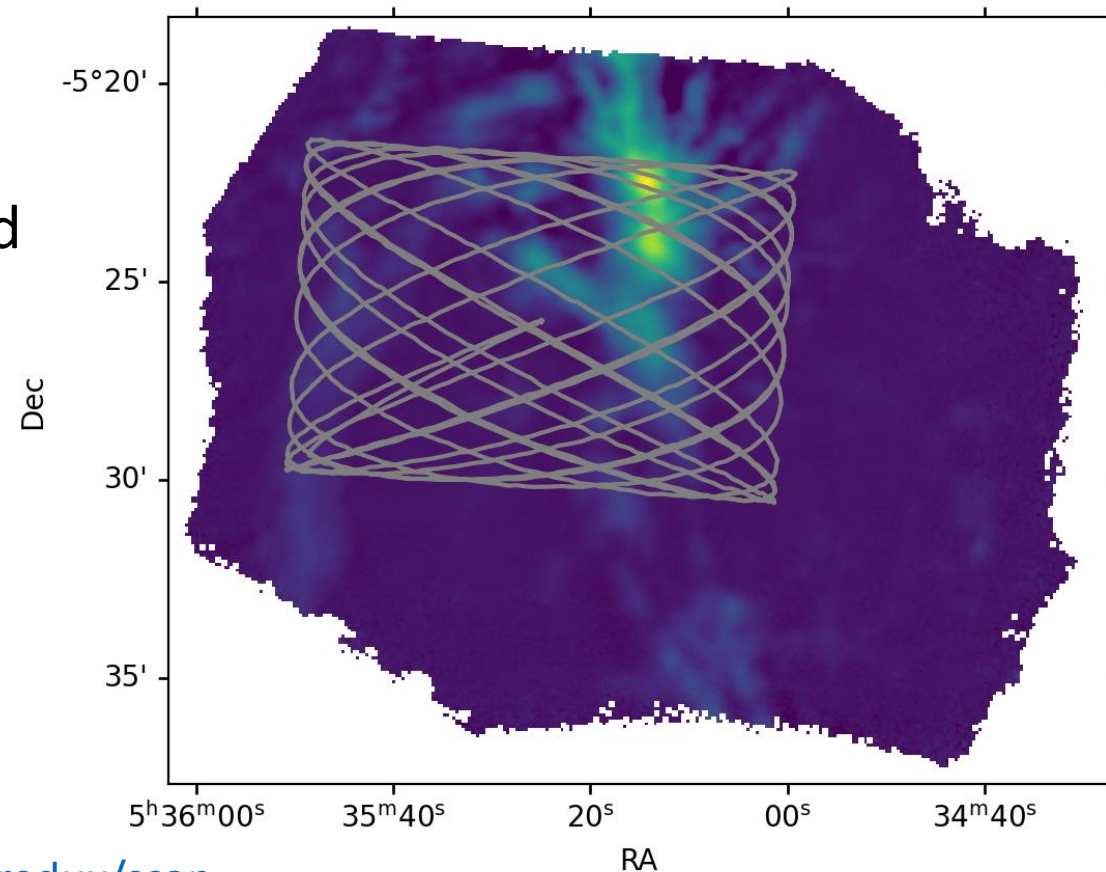


Software solutions: scan maps

```
sofia_redux
├── calibration
├── instruments
│   ├── fifi_ls
│   ├── flitecam
│   ├── forcast
│   └── hawc
├── pipeline
├── scan
├── spectroscopy
├── toolkit
└── visualization
```

sofia_redux.scan:

Algorithms to derive source flux from continuously scanned far-infrared data.



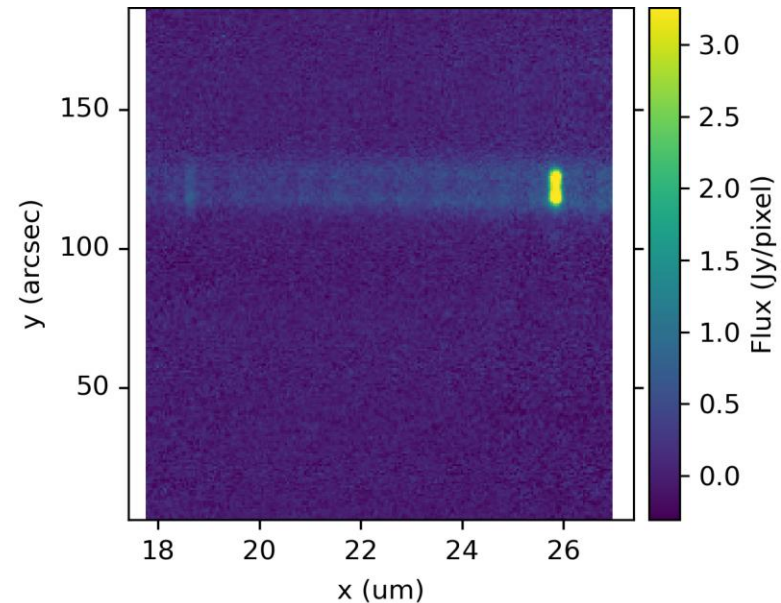
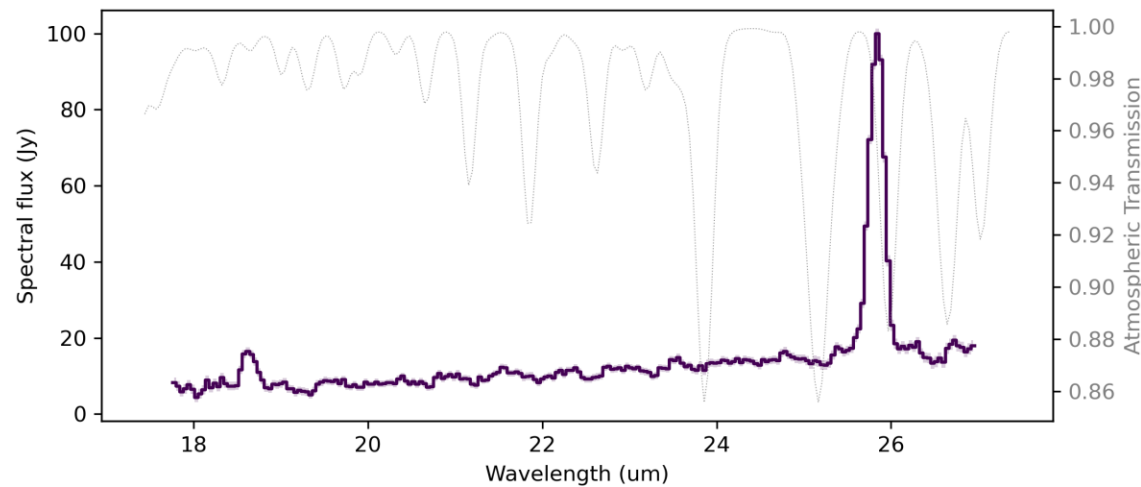


Software solutions: spectroscopy

```
sofia_redux
├── calibration
├── instruments
│   ├── fifi_ls
│   ├── flitecam
│   ├── forcast
│   └── hawc
├── pipeline
├── scan
├── spectroscopy
├── toolkit
└── visualization
```

sofia_redux.spectroscopy:

Algorithms for spectroscopic rectification, calibration, and extraction.





Software solutions: image processing

```
sofia_redux
├── calibration
├── instruments
│   ├── fifi_ls
│   ├── flitecam
│   ├── forcast
│   └── hawc
├── pipeline
├── scan
├── spectroscopy
├── toolkit
└── visualization
```

sofia_redux.toolkit:

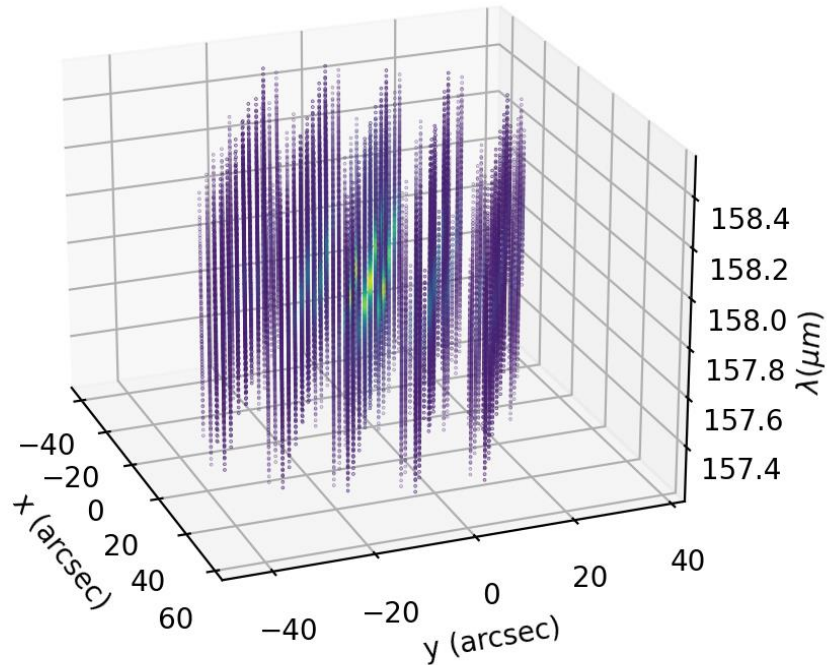
Scientific and numerical processing algorithms

- image processing and manipulation
- convolution, fitting, and interpolation
- resampling and mosaicking routines for irregularly sampled N-dimensional data with associated errors

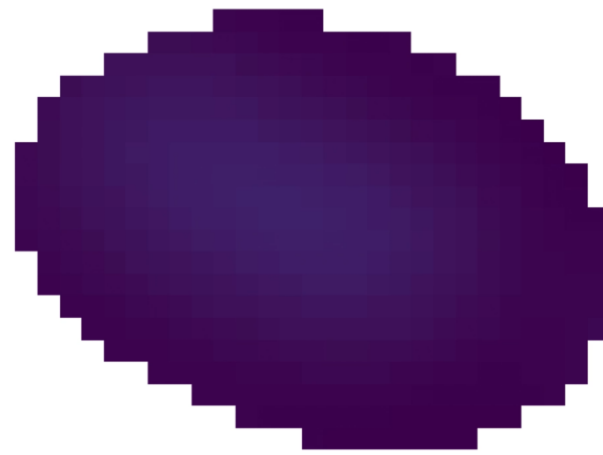


Software solutions: data resampling

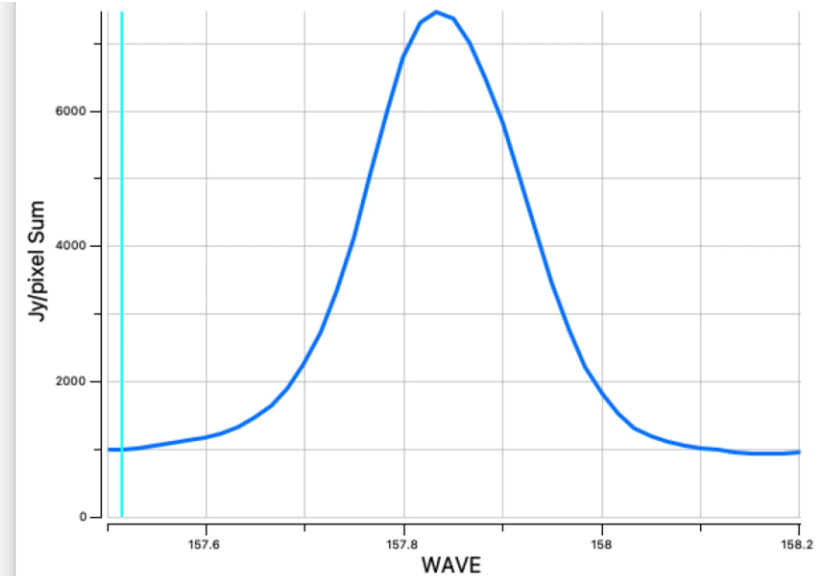
Pipeline use case: resample FIFI-LS data points into a smooth flux cube



Sample distribution (x, y, wavelength)



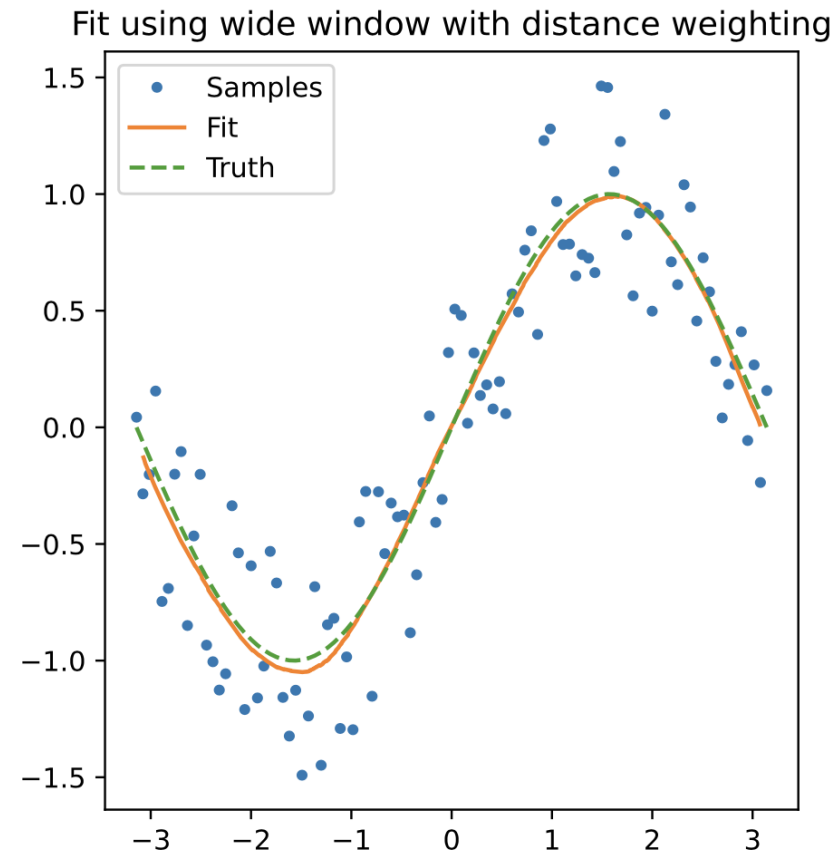
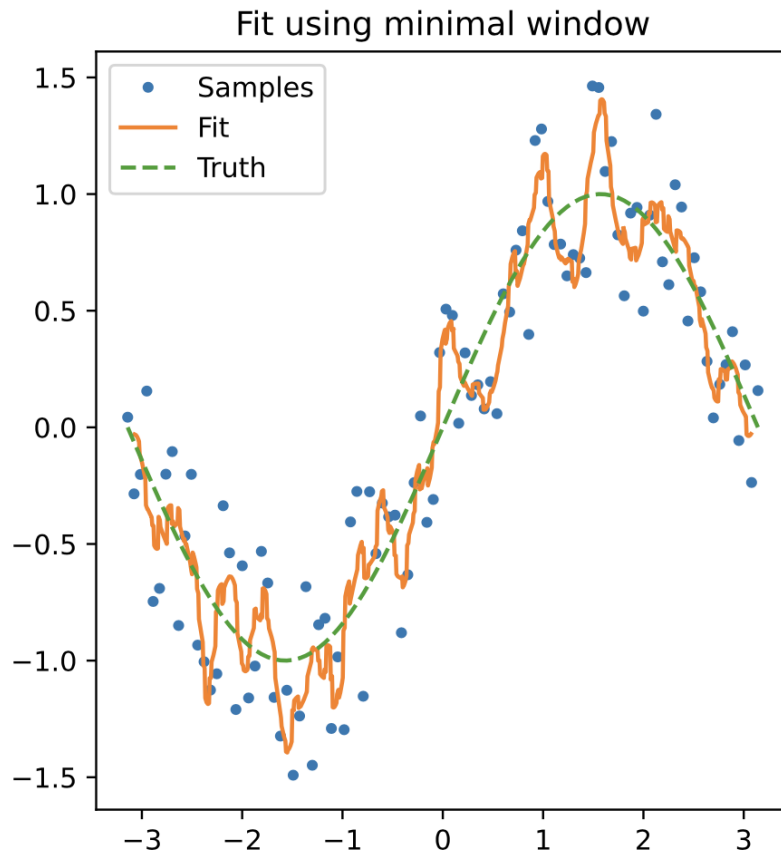
Resampled spectral flux cube





Software solutions: data resampling

Other use cases in image and signal processing:



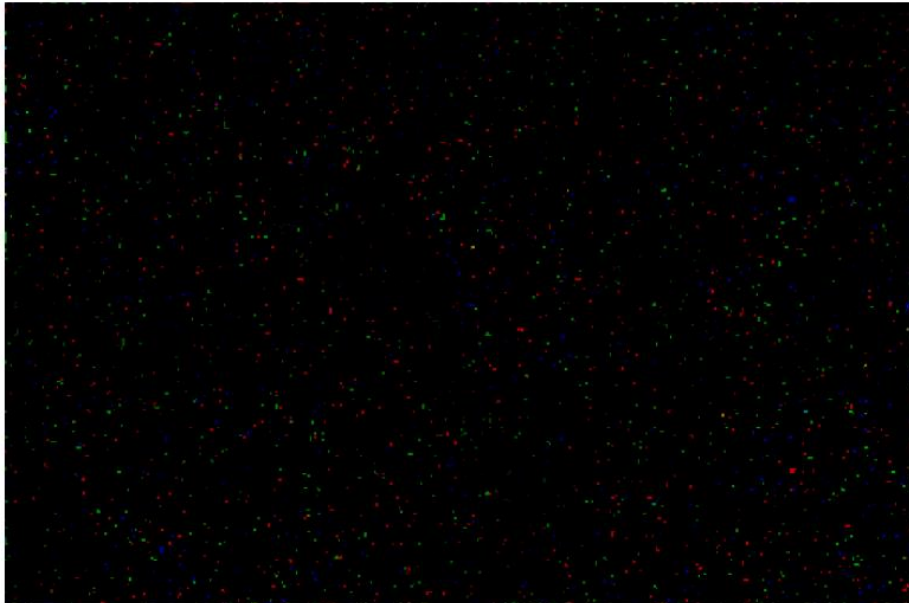
Fit noisy data



Software solutions: data resampling

Other use cases in image and signal processing:

Corrupted image (70% NaN)



Reconstructed image

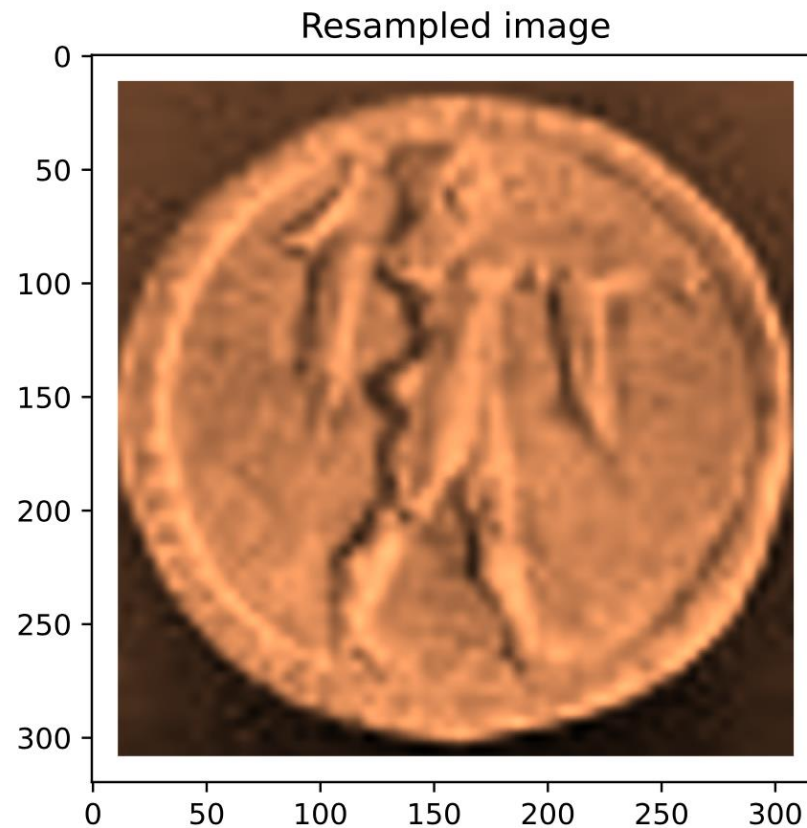
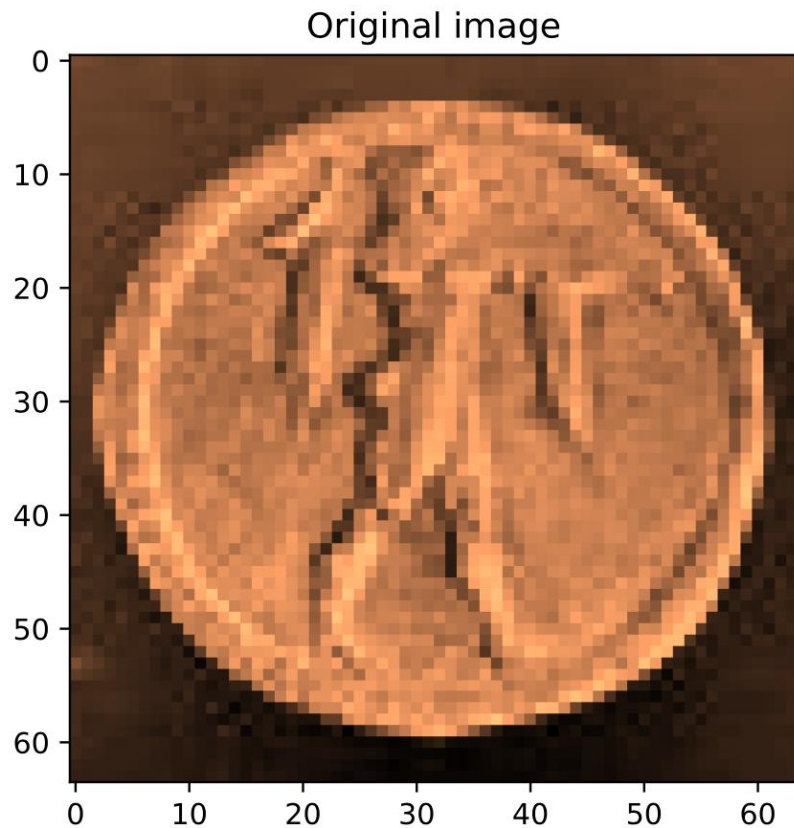


Reconstruct
corrupted data



Software solutions: data resampling

Other use cases in image and signal processing:



Enhance resolution

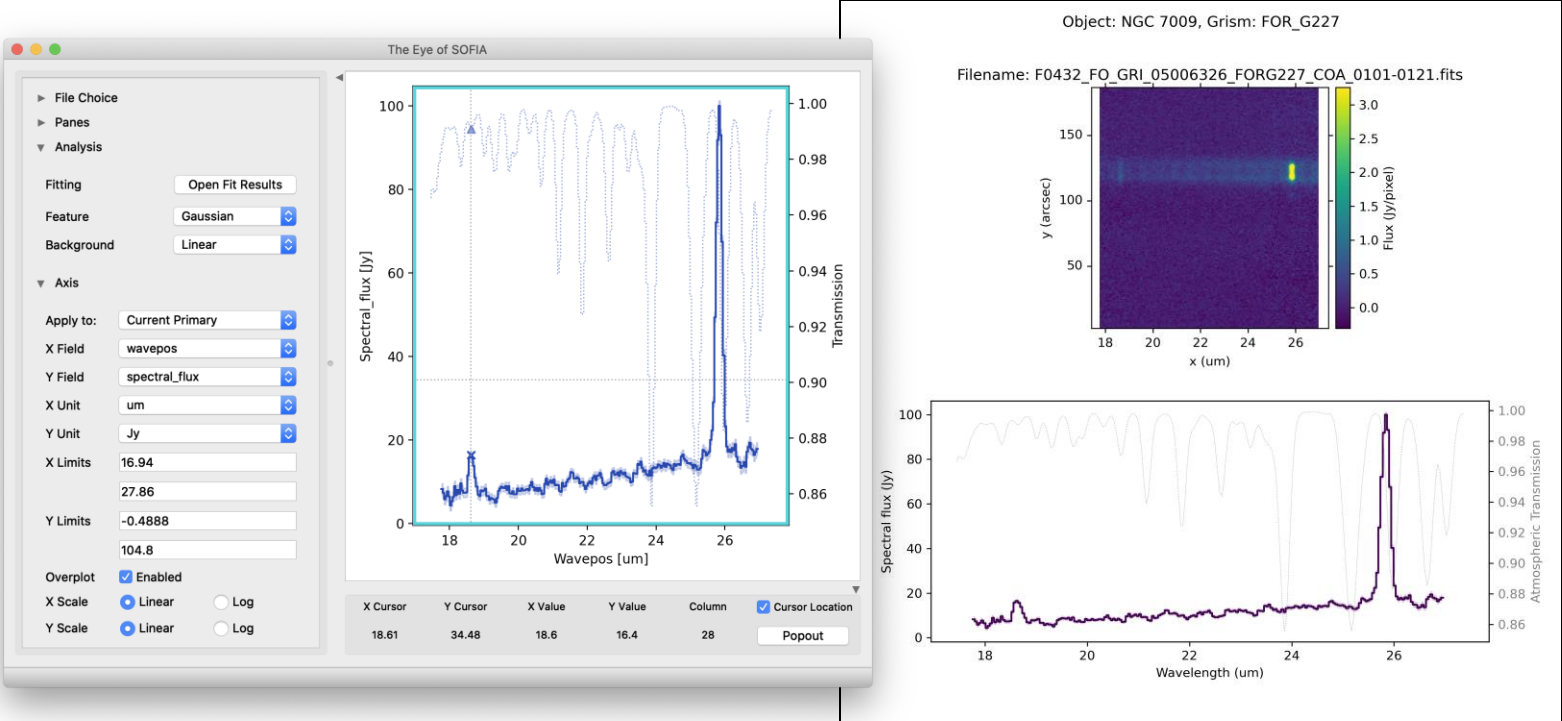


Develop new software: data visualization

- sofia_redux
 - calibration
 - instruments
 - fifi_ls
 - flitecam
 - forcast
 - hawc
 - pipeline
 - scan
 - spectroscopy
 - toolkit
 - visualization**

sofia_redux.visualization:

Interactive and static data visualization tools.





Contributors

SOFIA pipelines were made possible by the contributions of dozens of developers and scientists over SOFIA's lifetime.

Current SOFIA DPS team

Melanie Clarke, development lead
Ed Chambers, science lead
Dan Perera, developer
Rachel Vander Vliet, developer
Karishma Bansal, developer
Bruce Clarke, systems engineer
John Fenwick, systems administrator

Direct contributors to SOFIA Redux

Ryan Arneson	Enrique Lopez-Rodriguez
Karishma Bansal	Robert Minchin
Ed Chambers	Dan Perera
Melanie Clarke	Leslie Proudfit
Sebastian Colditz	James Radomski
Arpan Das	Sachin Shenoy
Dario Fadda	William Vacca
Christian Fischer	Rachel Vander Vliet
Nicole Karnath	
Mark Langer	

Contributors to earlier pipeline versions

Marc Berthoud	Luke Keller
Nicholas Chapman	Randolf Klein
Miguel Charcos-Llorens	Attila Kovacs
David Chuss	Kaori Nishikida
Michael Cushing	Giles Novak
Darren Dowell	Fabio Santos
Jordan Guerra	Klara Shabun
Ryan Hamilton	David Shupe
CJ Hansen	Ralph Shuping
Al Harper	John Vaillancourt
Terry Herter	Carrie Volpert
Jennifer Holt	





Acknowledgements

In addition, some of the core modules and structures were based significantly on several external packages:

astropy

packaging, documentation, coding style and standards



CRUSH

original work of authorship for the scan module



Spextool

original version of algorithms in the spectroscopy module

Spextool: A Spectral Extraction Package for SpeX, a 0.8-5.5 micron Cross-Dispersed Spectrograph
Michael C. Cushing, William D. Vacca and John T. Rayner
(2004, PASP 116, 362).

A Method of Correcting Near-Infrared Spectra for Telluric Absorption
William D. Vacca, Michael C. Cushing and John T. Rayner
(2003, PASP 115, 389).



SOFIA Redux

GitHub: https://github.com/SOFIA-USRA/sofia_redux

Documentation: https://sofia-usra.github.io/sofia_redux/

Questions? Feedback? Contributions?

- File an [issue](#) on GitHub
- Send a request to the SOFIA helpdesk: sofia_help@sofia.usra.edu