SOFIA Redux:

Intro to the Data Reduction Pipeline Package

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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

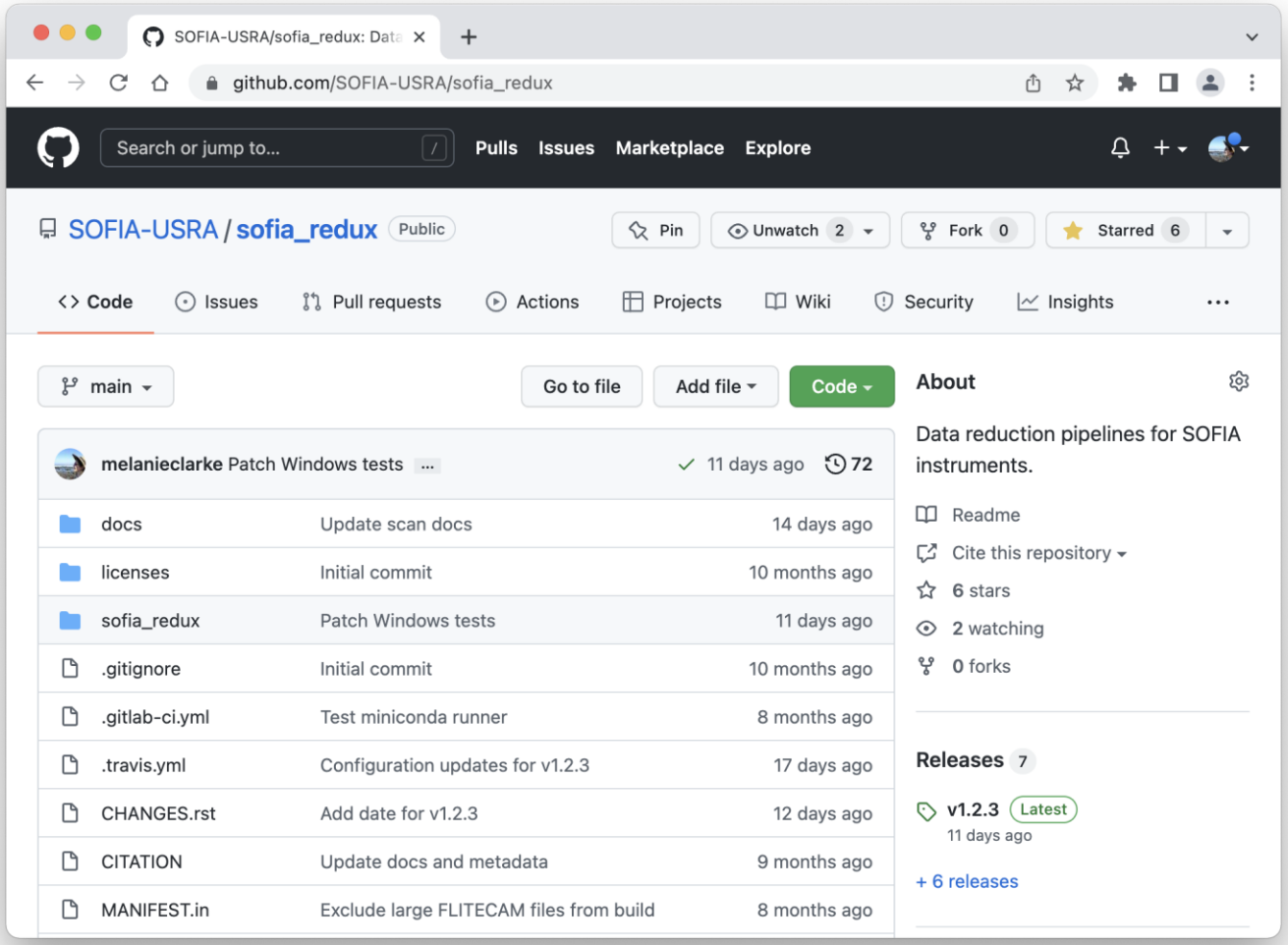
for FORCAST, FIFI-LS, FLITECAM, and HAWC+ data.

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

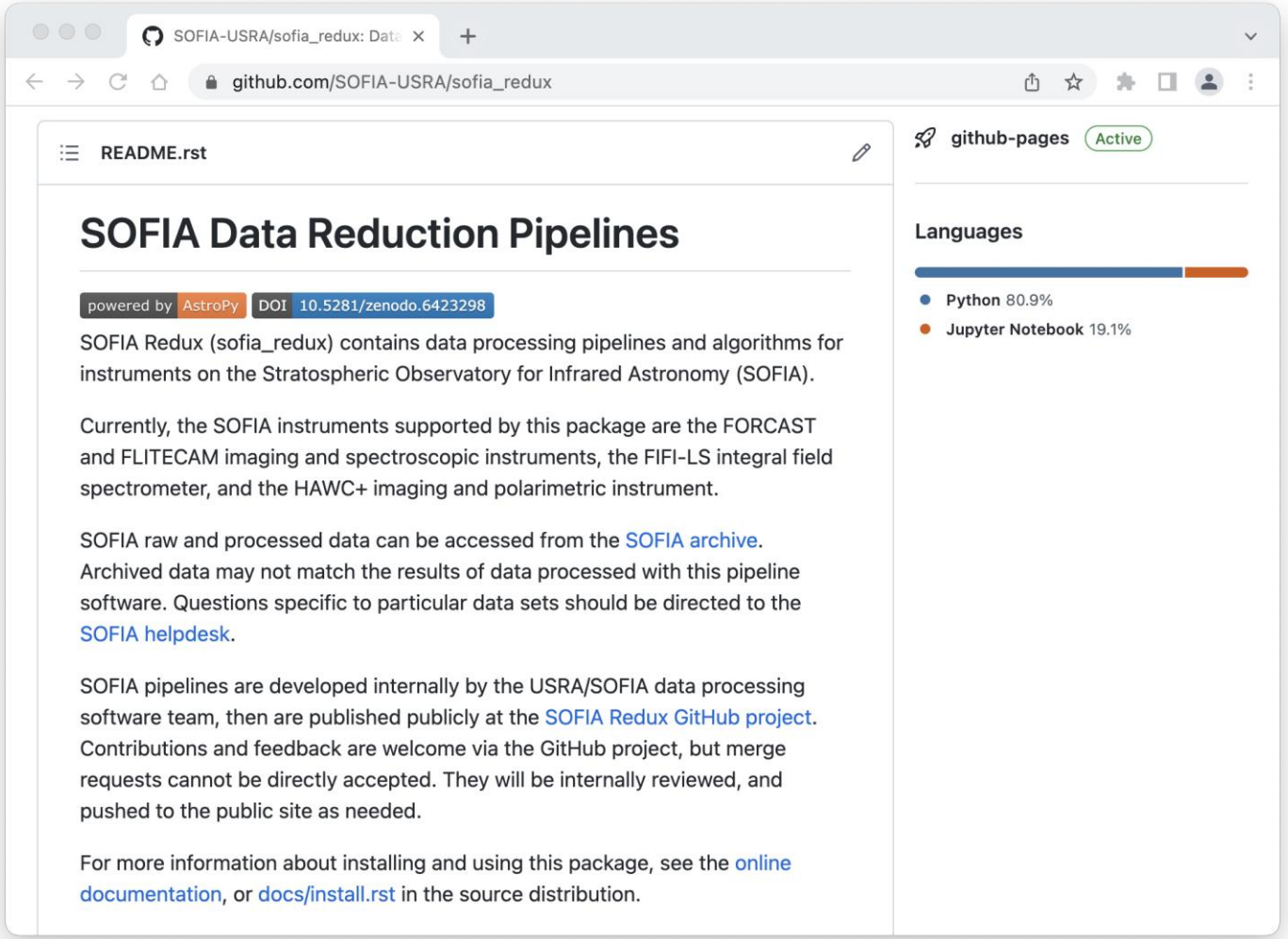


Package information

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

Contributions are welcome!

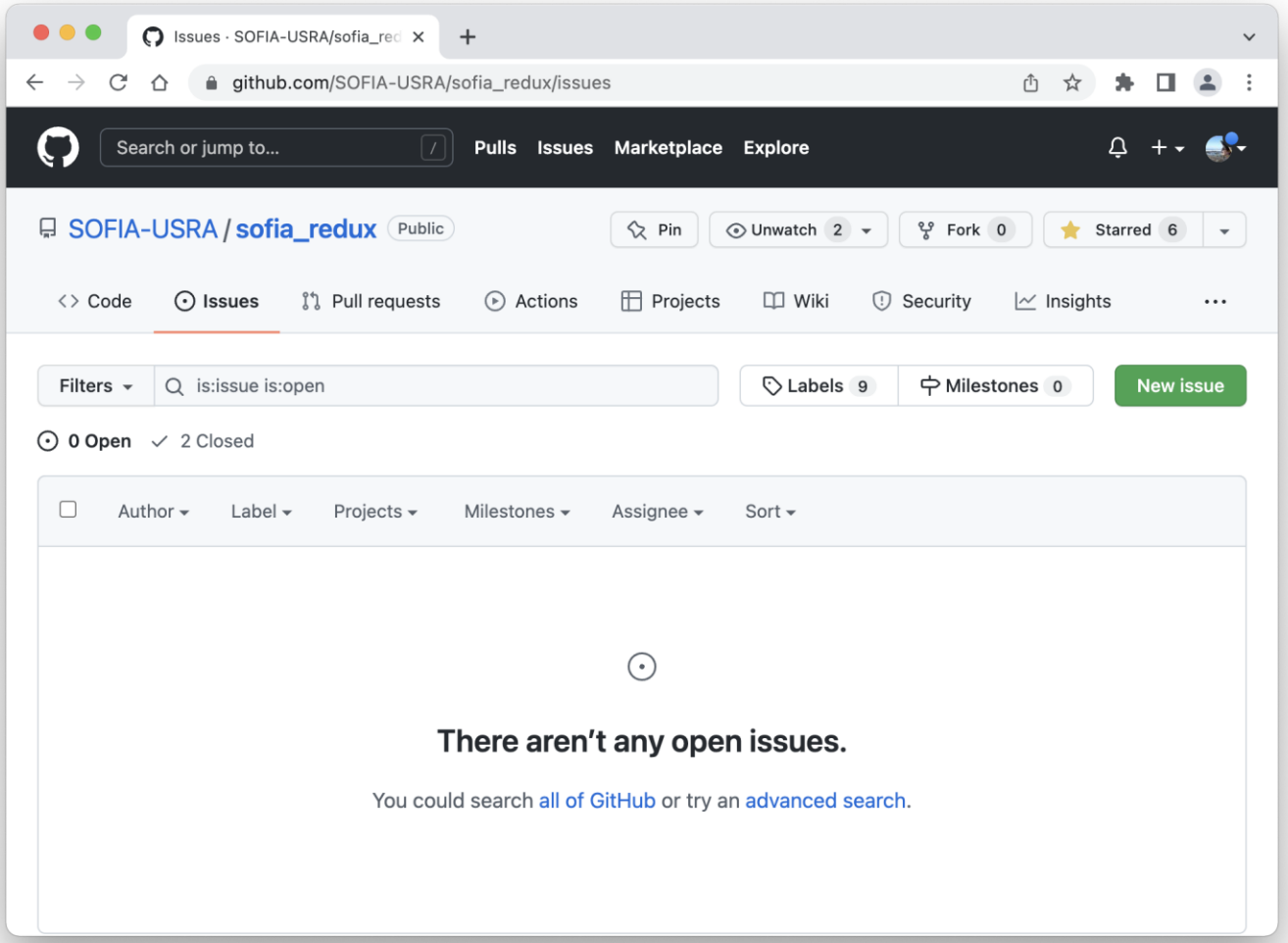
Feel free to fork, modify, experiment, and improve.



Package information

Feedback or contributions:

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



Installation

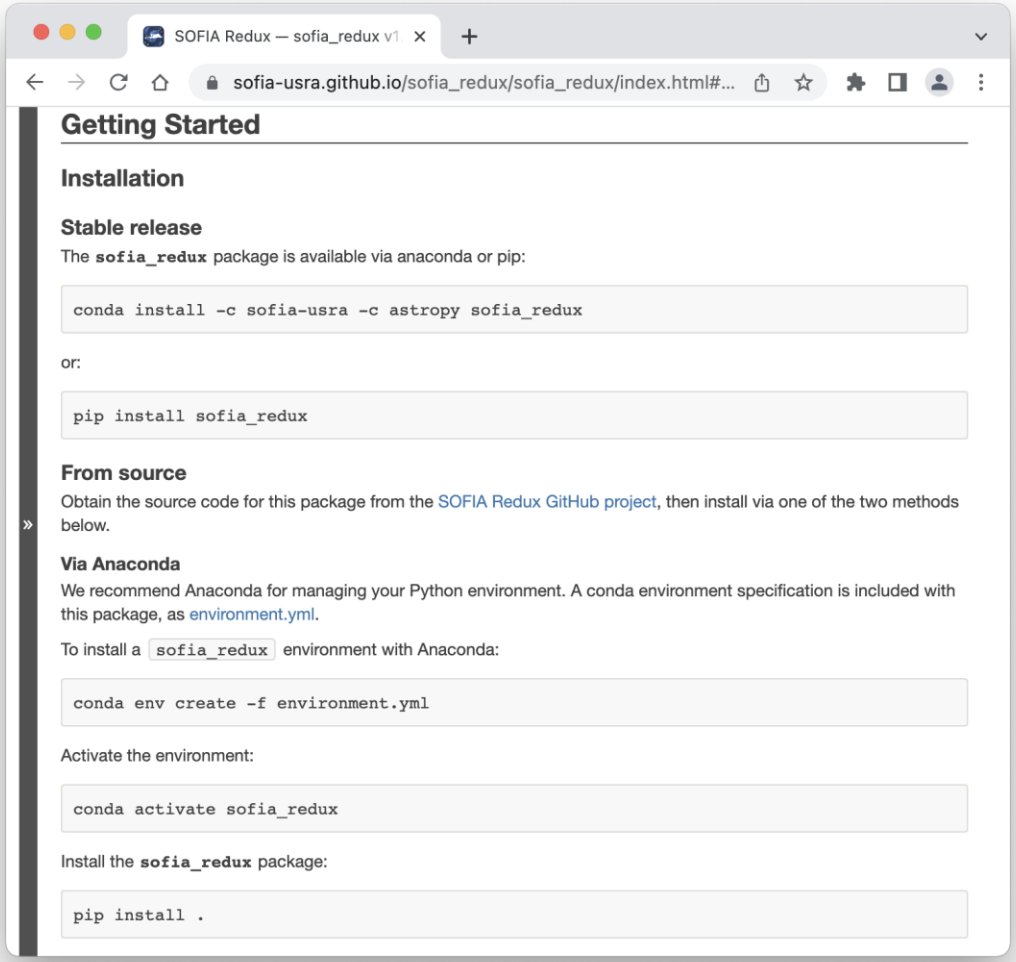
Install sofia_redux with standard tools

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

Installation

Install sofia_redux from source

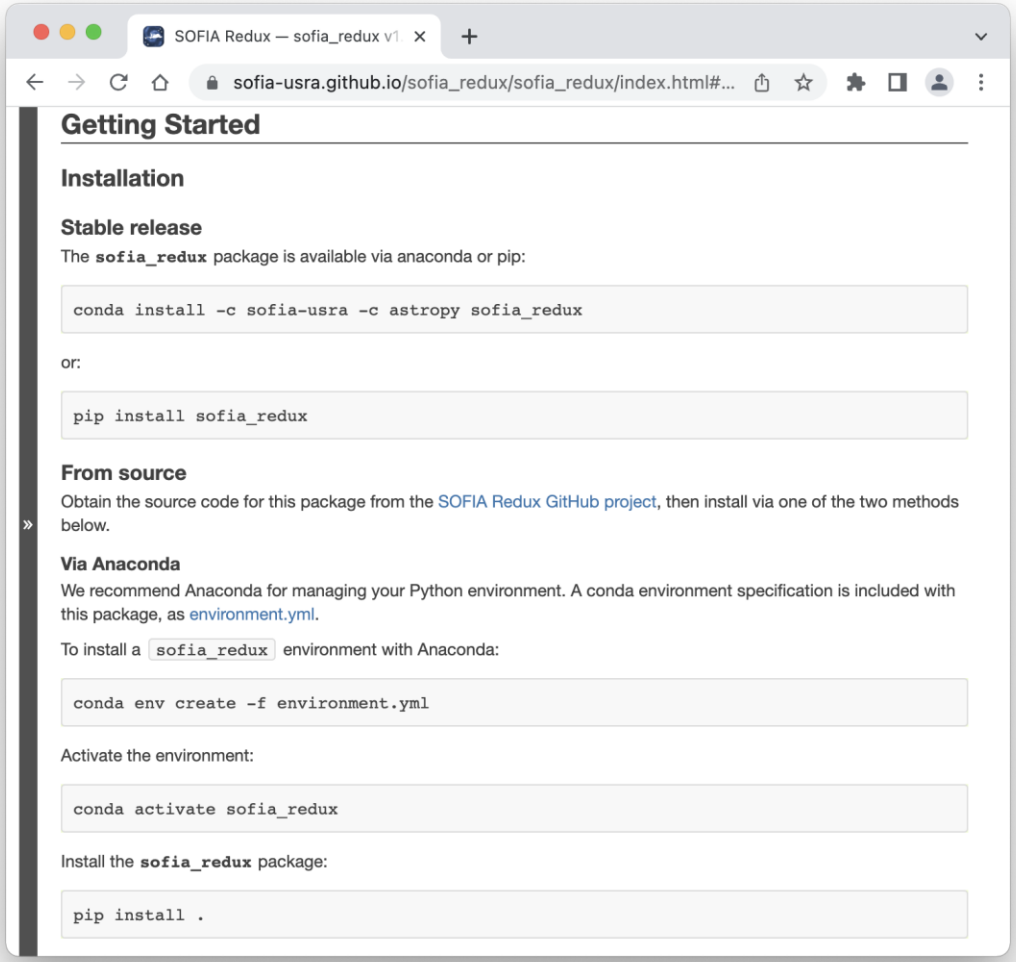
Recommended:

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



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.

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

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

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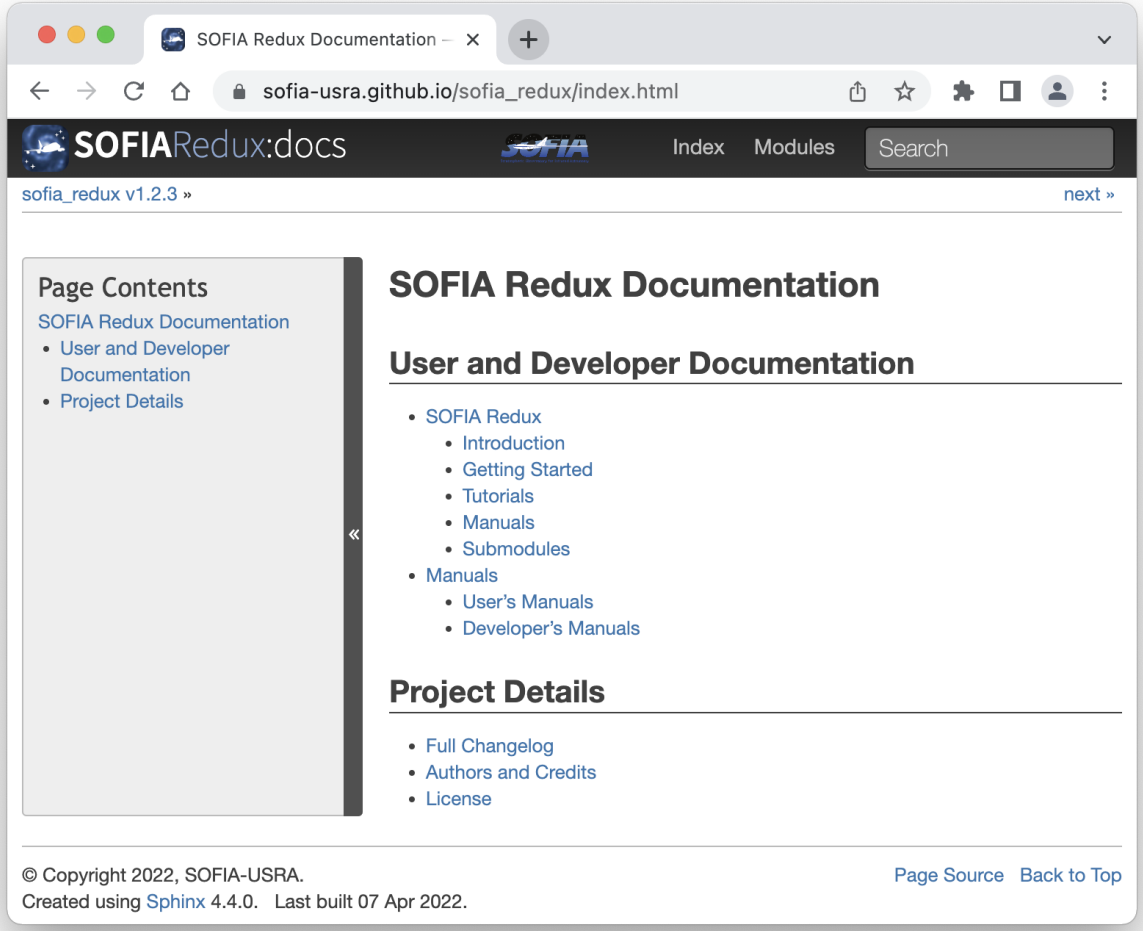
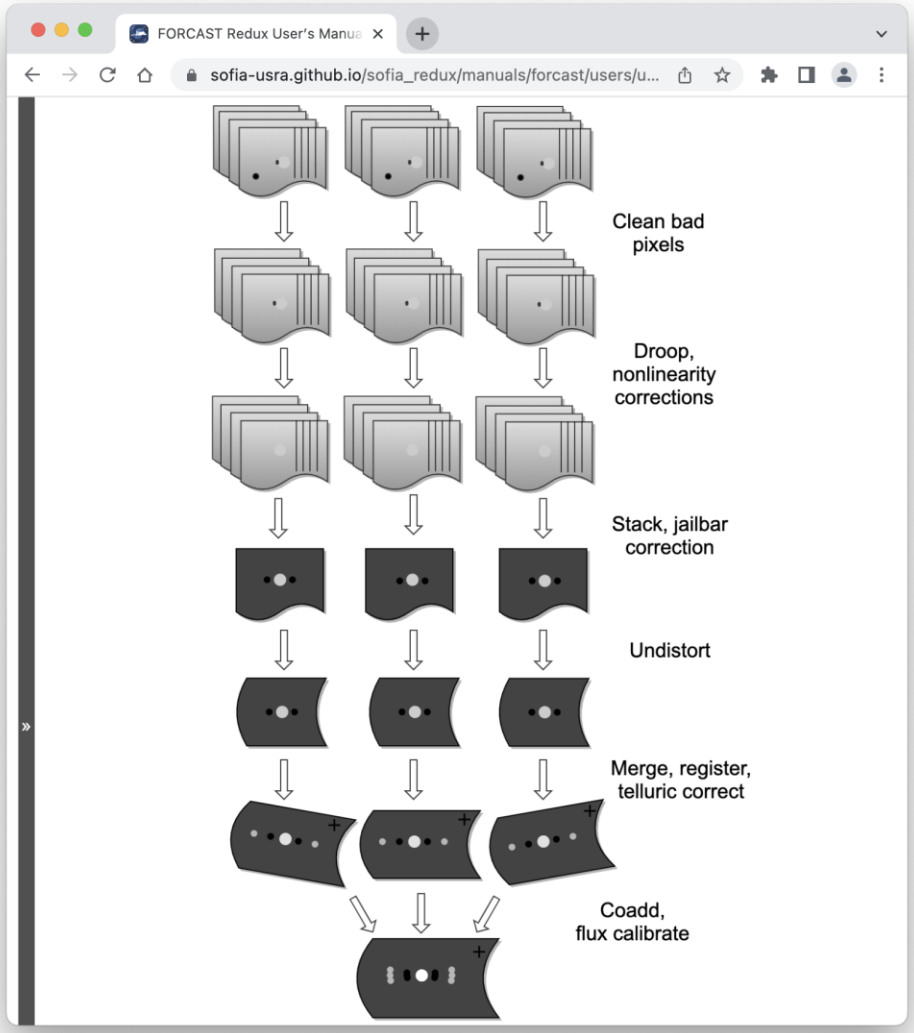
Understand your data

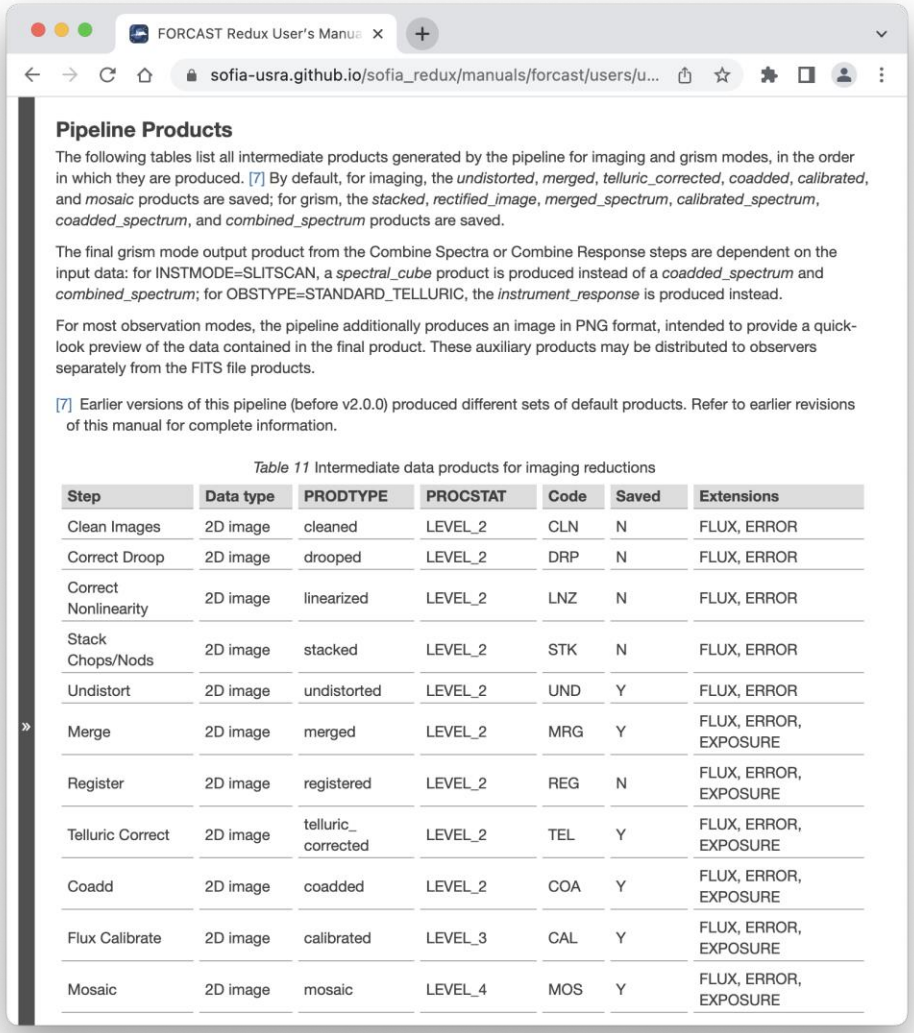
- Extensive documentation posted online, including user and developer manuals for all instruments
- Intermediate data products illustrate each step of the reduction process
- Visualization tools packaged with the pipeline can help you access and understand your data products more quickly



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

Manuals





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

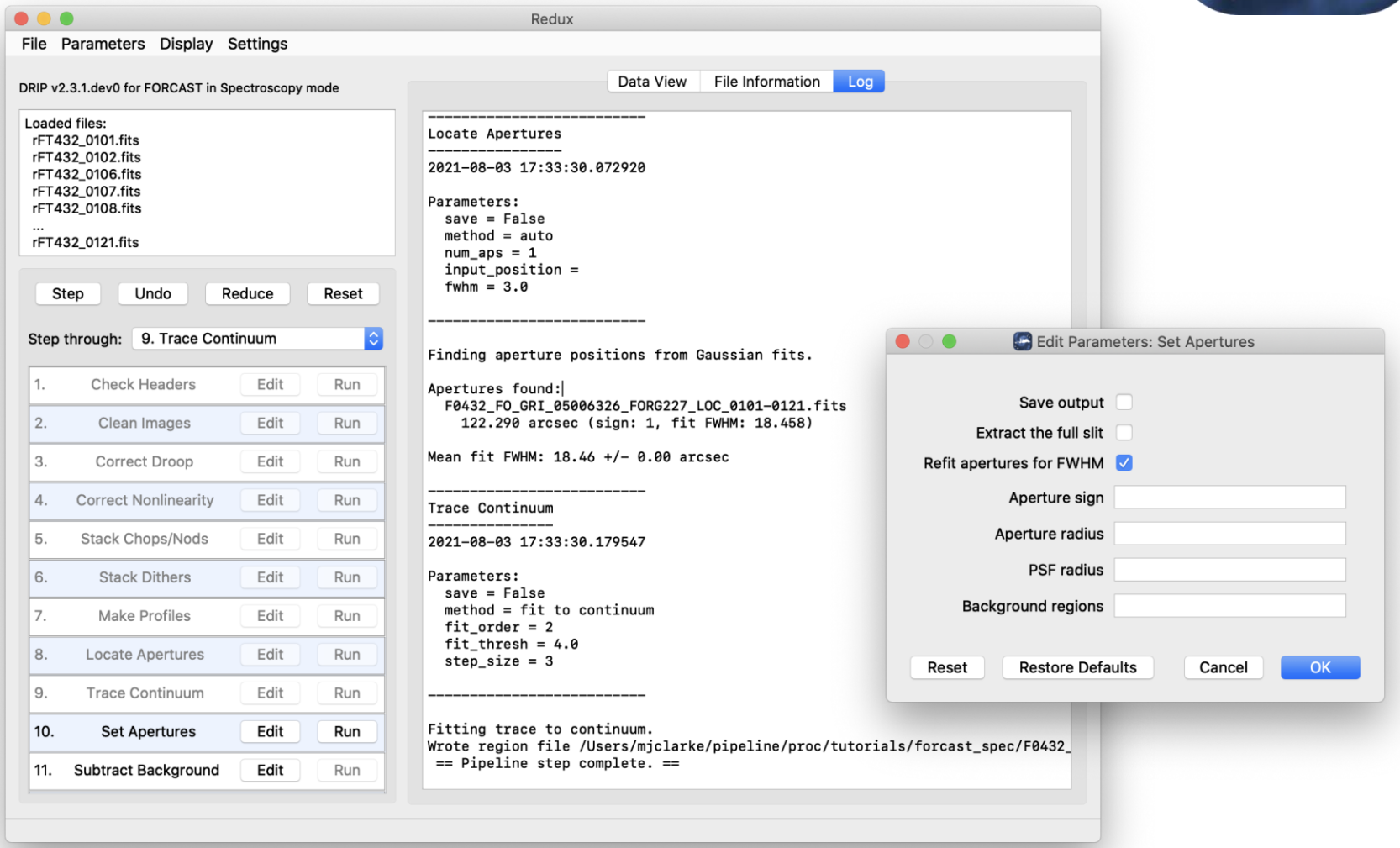
User manuals contain useful information about data processing steps and output data products.

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

Intermediate processing

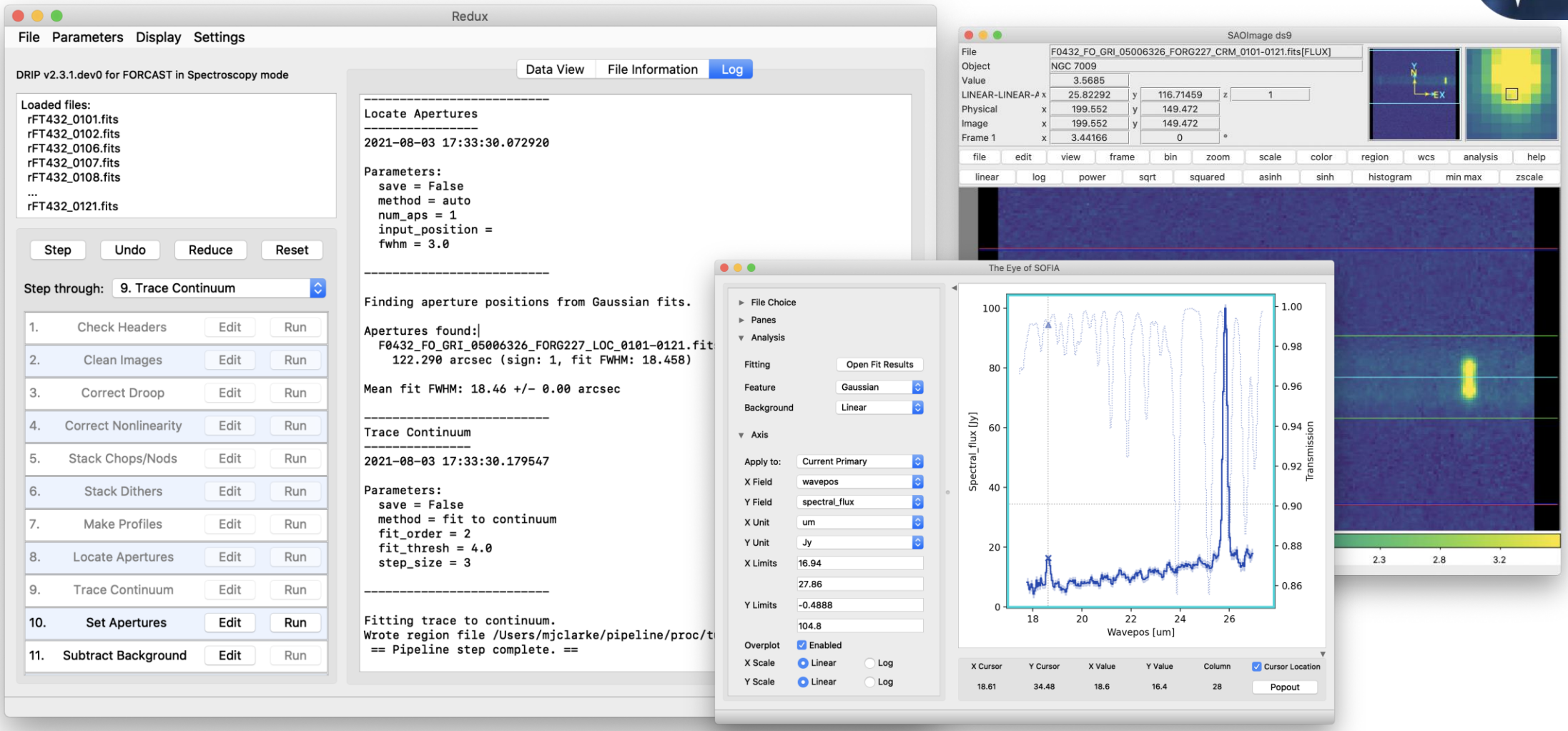
Loading SOFIA FITS files into the pipeline interface automatically selects the correct pipeline steps and default parameters.

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



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

Intermediate processing

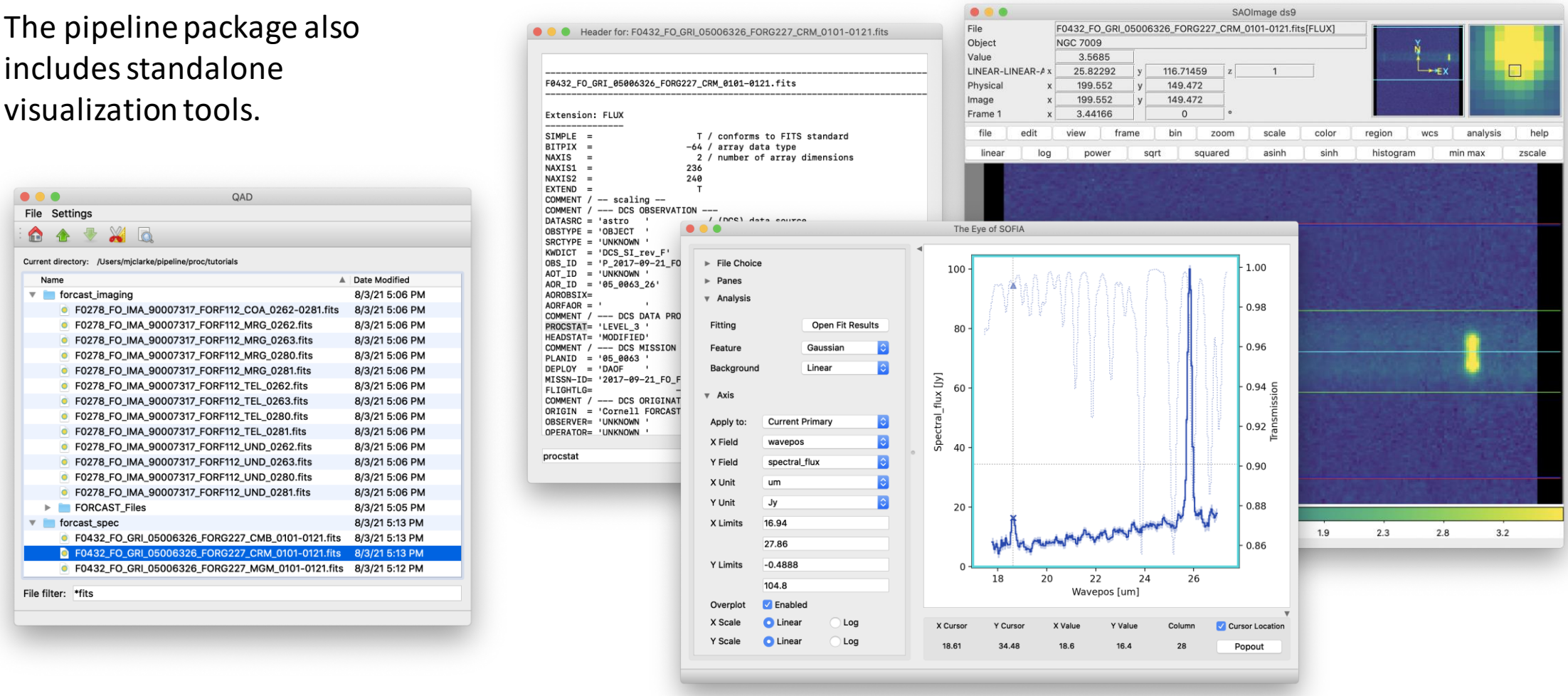


Online documentation: https://sofia-usra.github.io/sofia_redux

Data reduction example from the FORCAST imaging tutorial

Visualization tools

The pipeline package also includes standalone visualization tools.



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

Standalone QA tools

qad:
Quality Analysis and Display tool

eospec:
The Eye of SOFIA spectral viewer

Audience

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Why install the pipeline software?

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

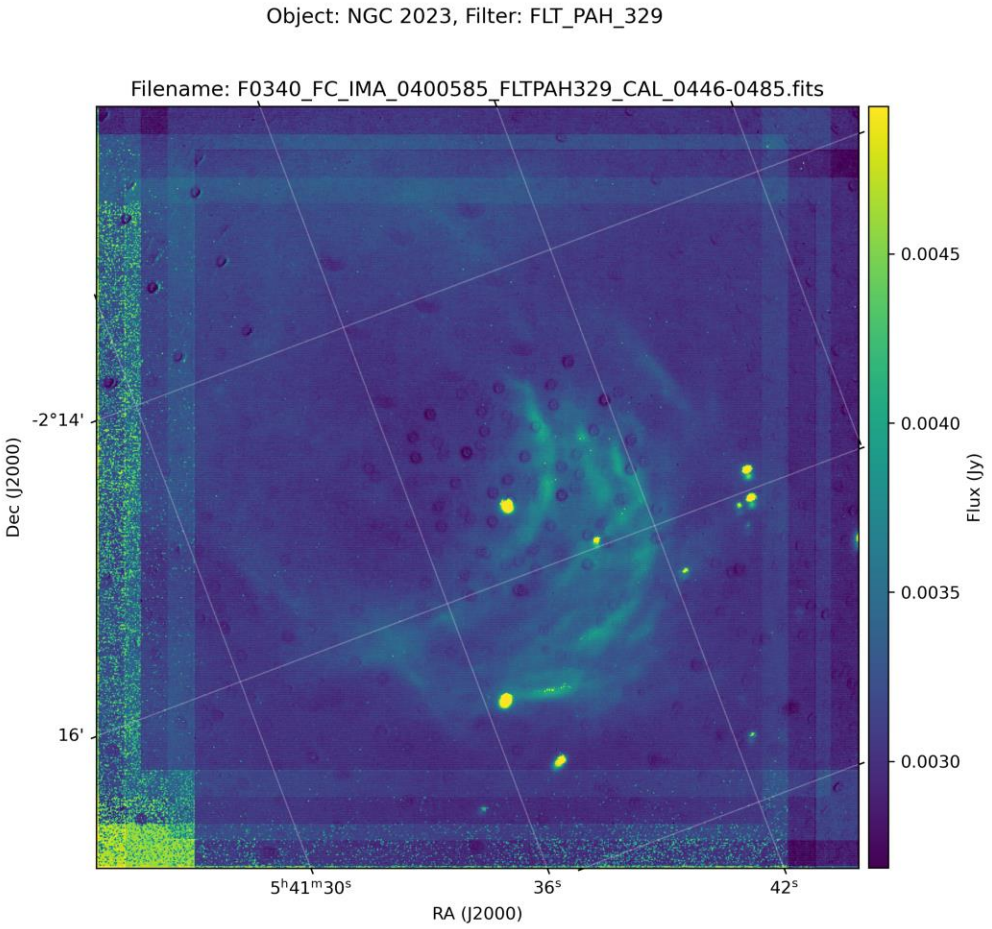
Archival data reprocessing

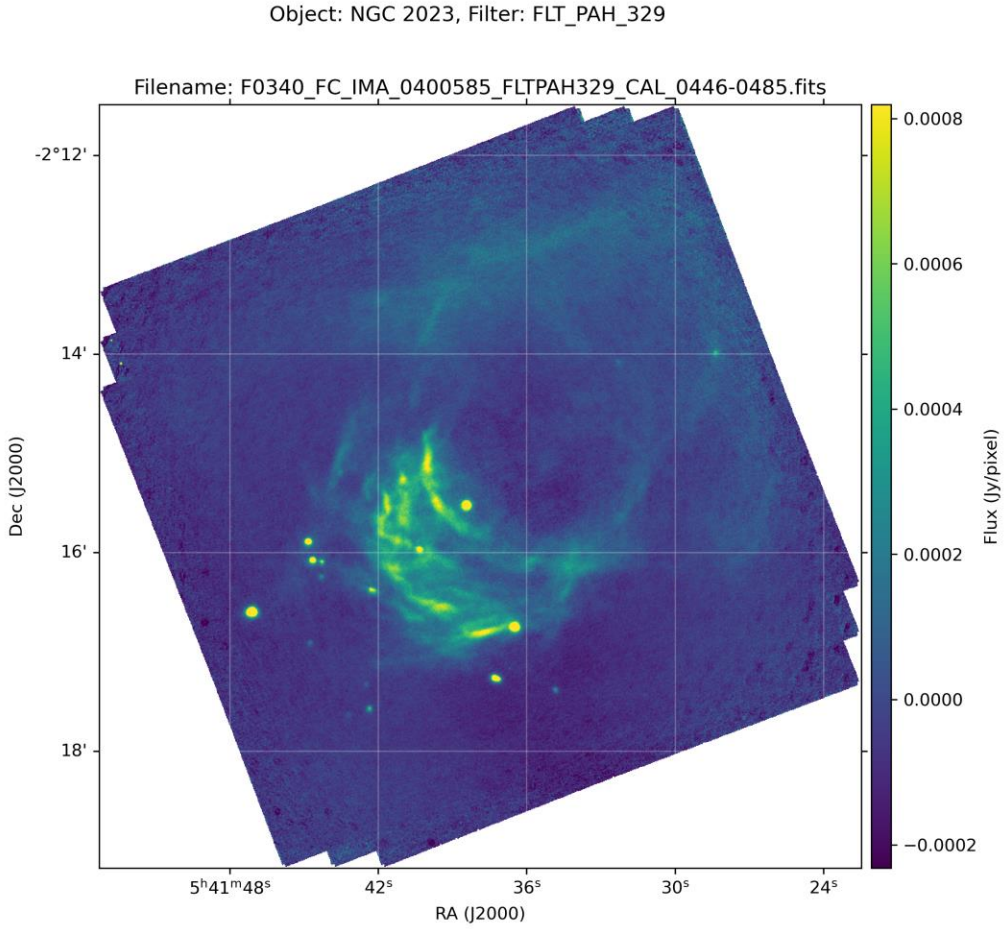
Archived data from recent flights are likely good as is, but older data might benefit from re-reduction.

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





Improvements to:

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

Archived: FLITECAM Redux v1.2.0

Reprocessed: sofia_redux v1.1.0

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Custom data reduction

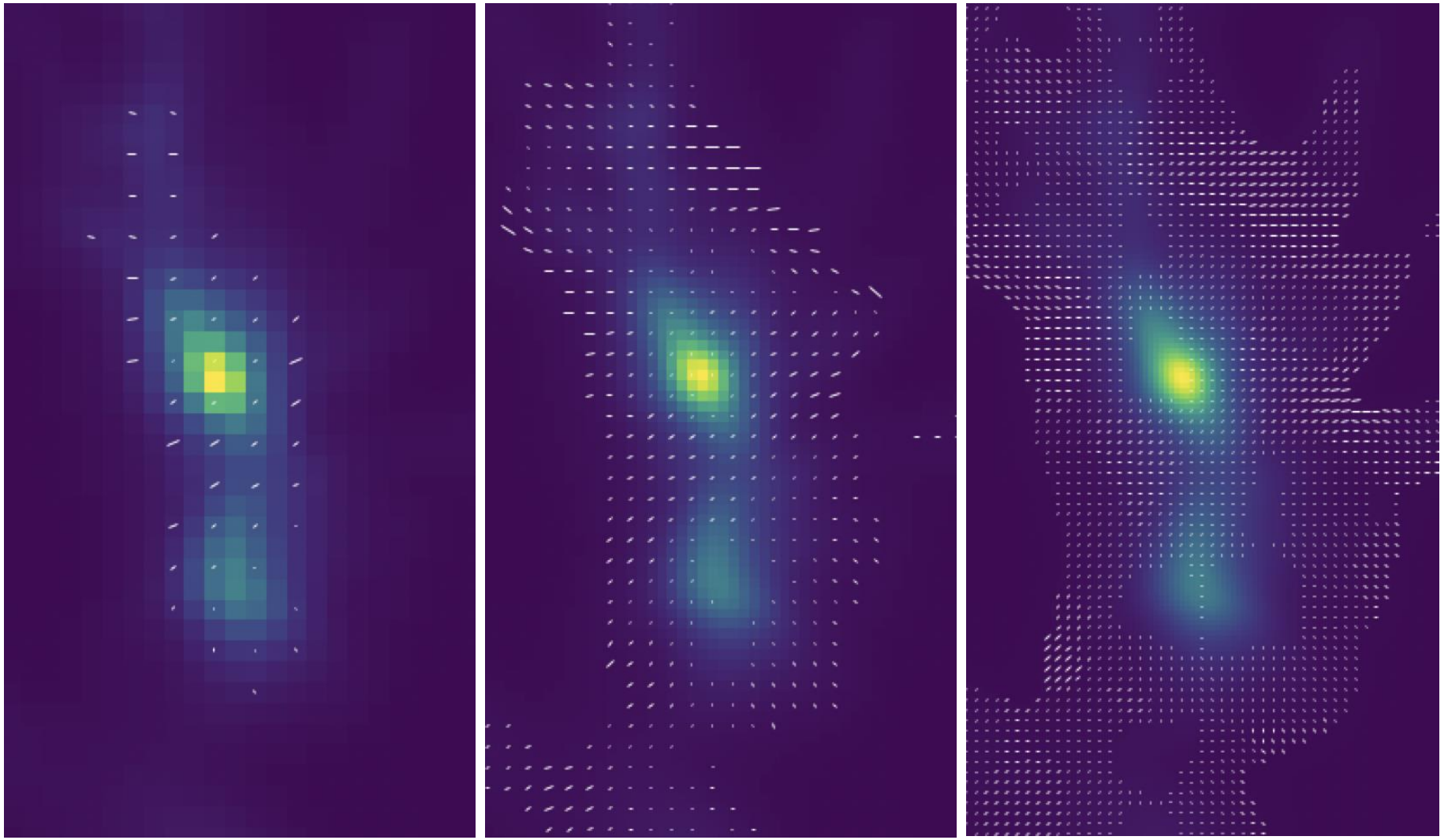
Archived data is usually reduced with default pipeline parameters.

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.

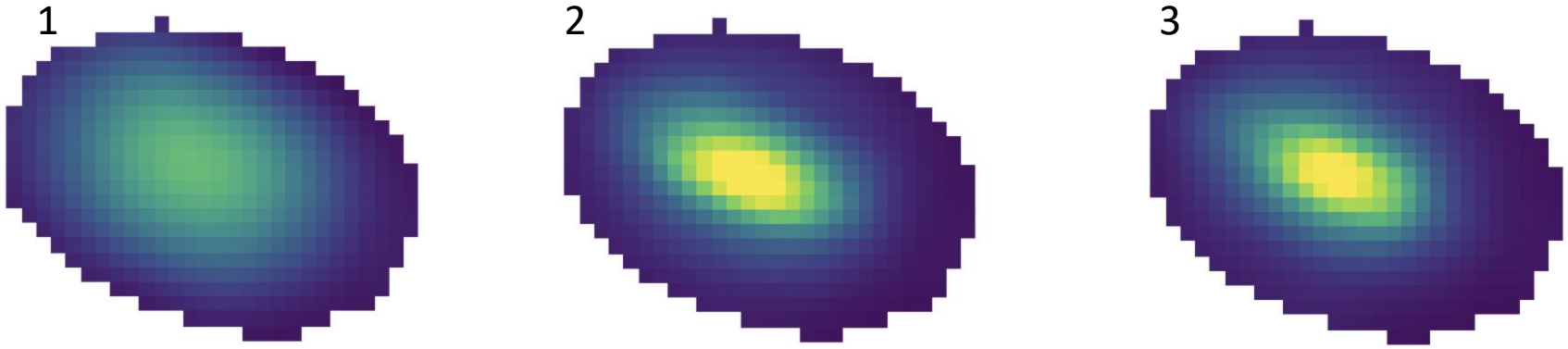
Custom data reduction

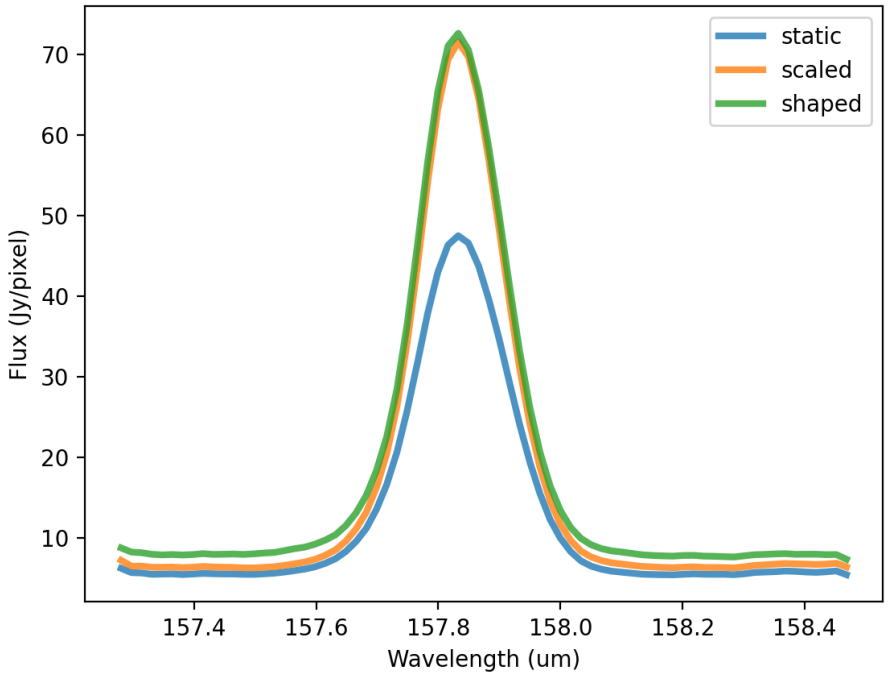


Example:
Rebin HAWC+
polarimetry data.

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

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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
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│   ├── forcast
│   └── hawc
├── pipeline
├── scan
├── spectroscopy
├── toolkit
└── visualization
```
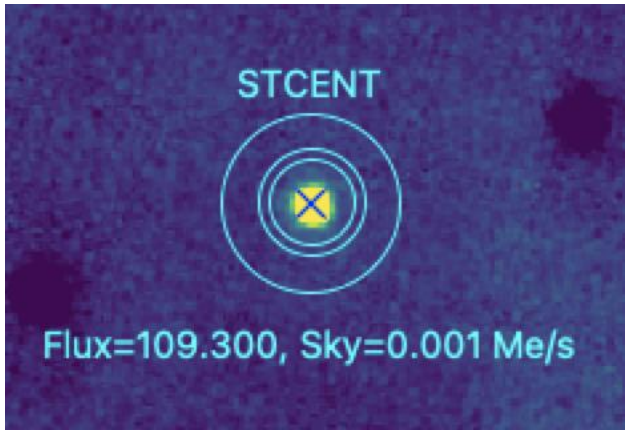

sofia_redux.calibration:

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%
```

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

Software solutions: instrument artifacts

```
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├── calibration
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│   └── hawc
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├── scan
├── spectroscopy
├── toolkit
└── visualization
```

sofia_redux.instruments:

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

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

Software solutions: pipelines

```
sofia_redux
├── calibration
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│   ├── forcast
│   └── hawc
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├── scan
├── spectroscopy
├── toolkit
└── visualization
```
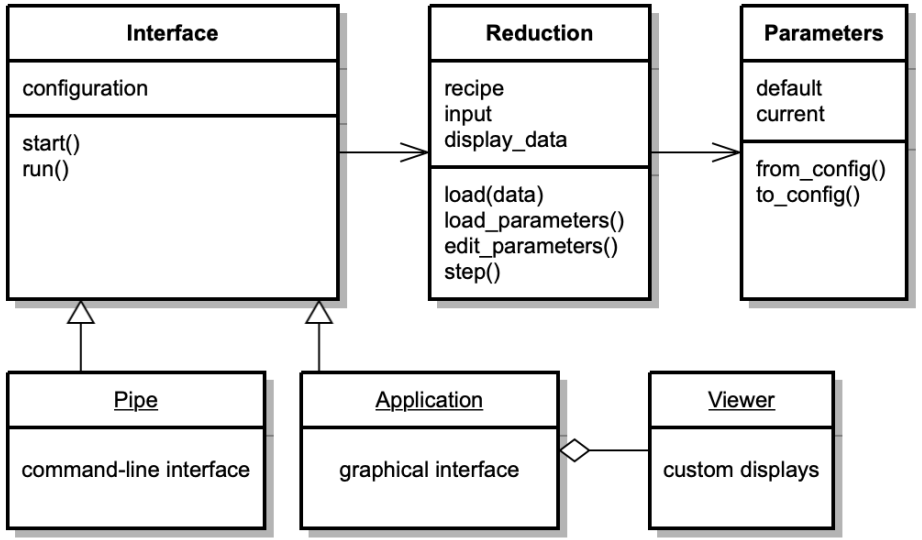

sofia_redux.pipeline:

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



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

Software solutions: scan maps

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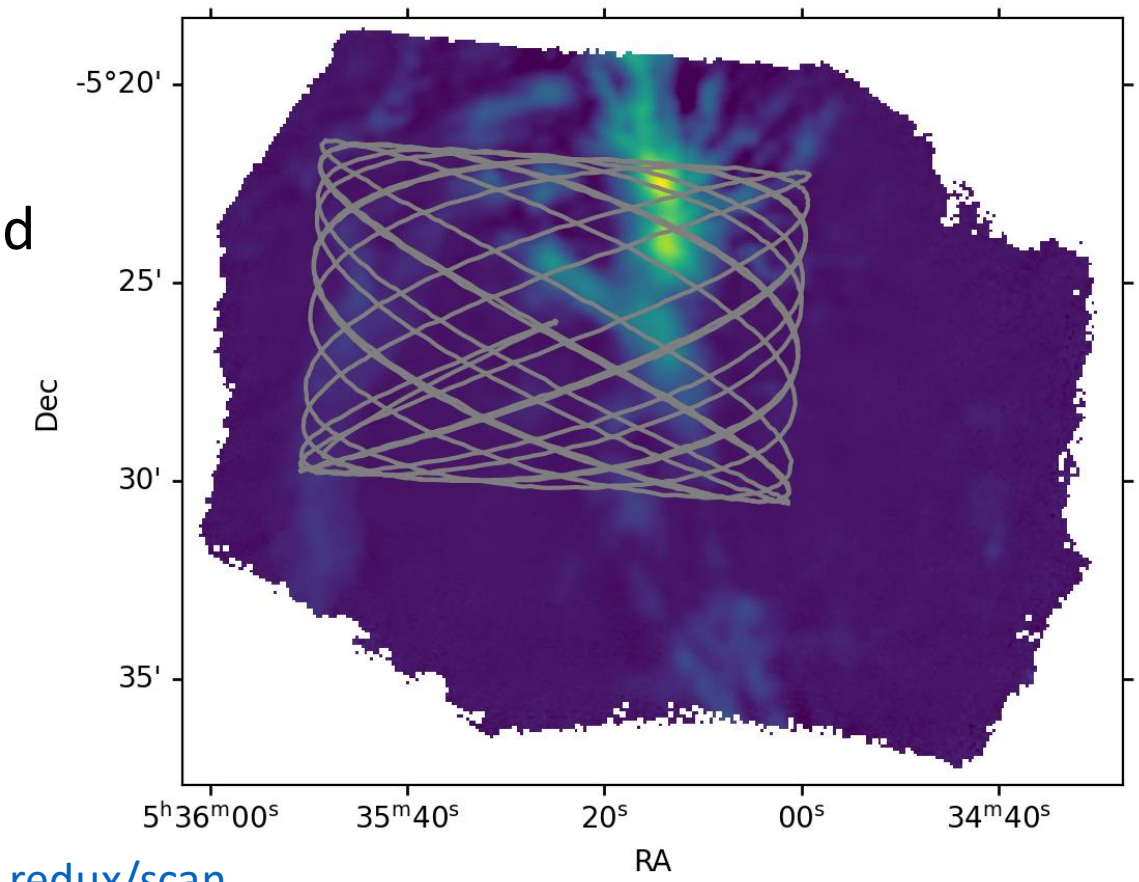

sofia_redux.scan:

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



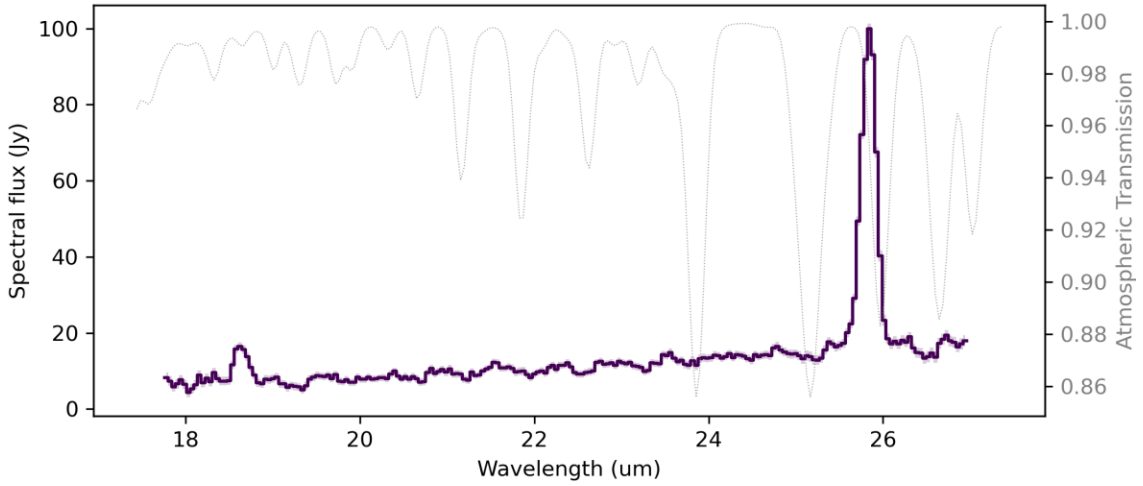
Online documentation: https://sofia-usra.github.io/sofia_redux/sofia_redux/scan

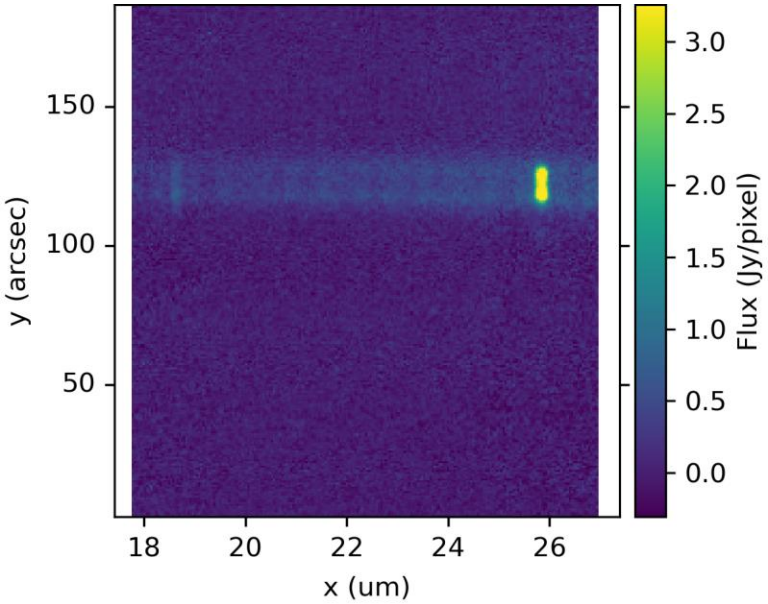
Software solutions: spectroscopy

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

sofia_redux.spectroscopy:

Algorithms for spectroscopic rectification, calibration, and extraction.





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

Software solutions: image processing

```
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├── calibration
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└── visualization
```

sofia_redux.toolkit:

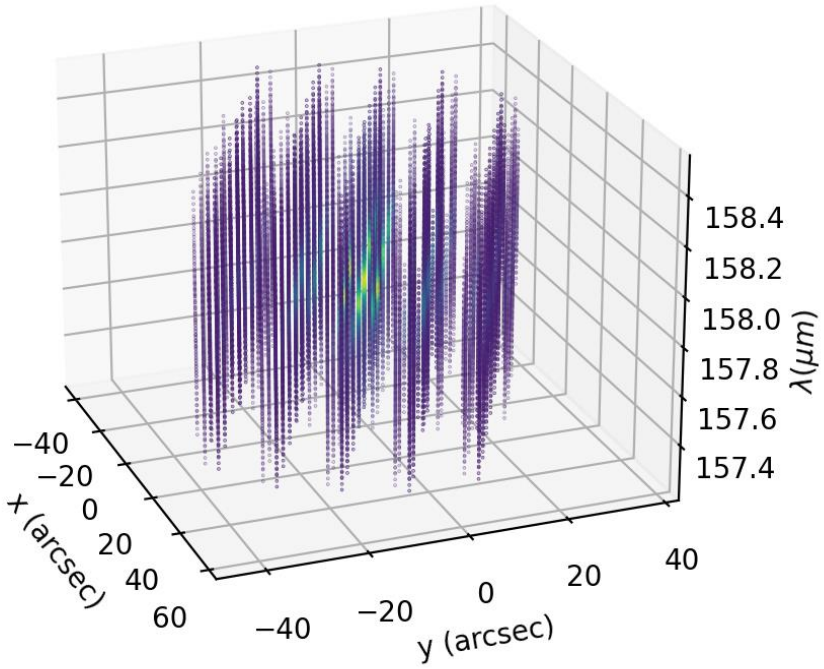
Scientific and numerical processing algorithms

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

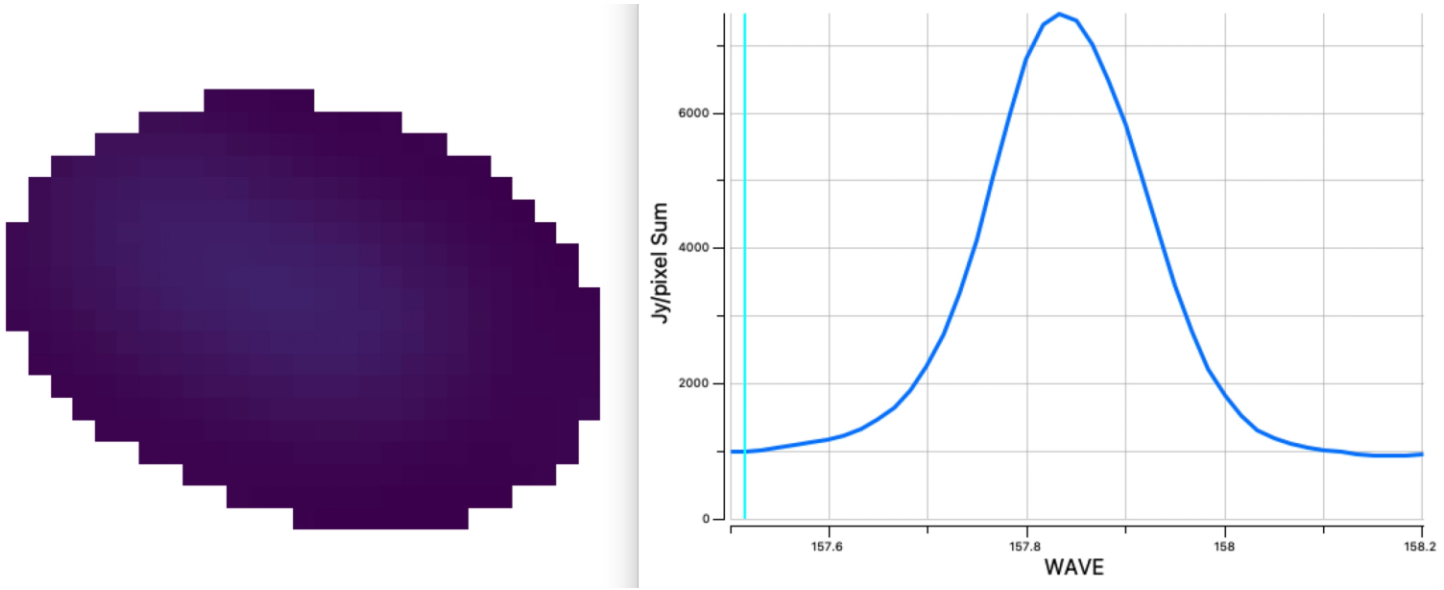
Online documentation: https://sofia-usra.github.io/sofia_redux/sofia_redux/toolkit

Software solutions: data resampling

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



Sample distribution (x, y, wavelength)

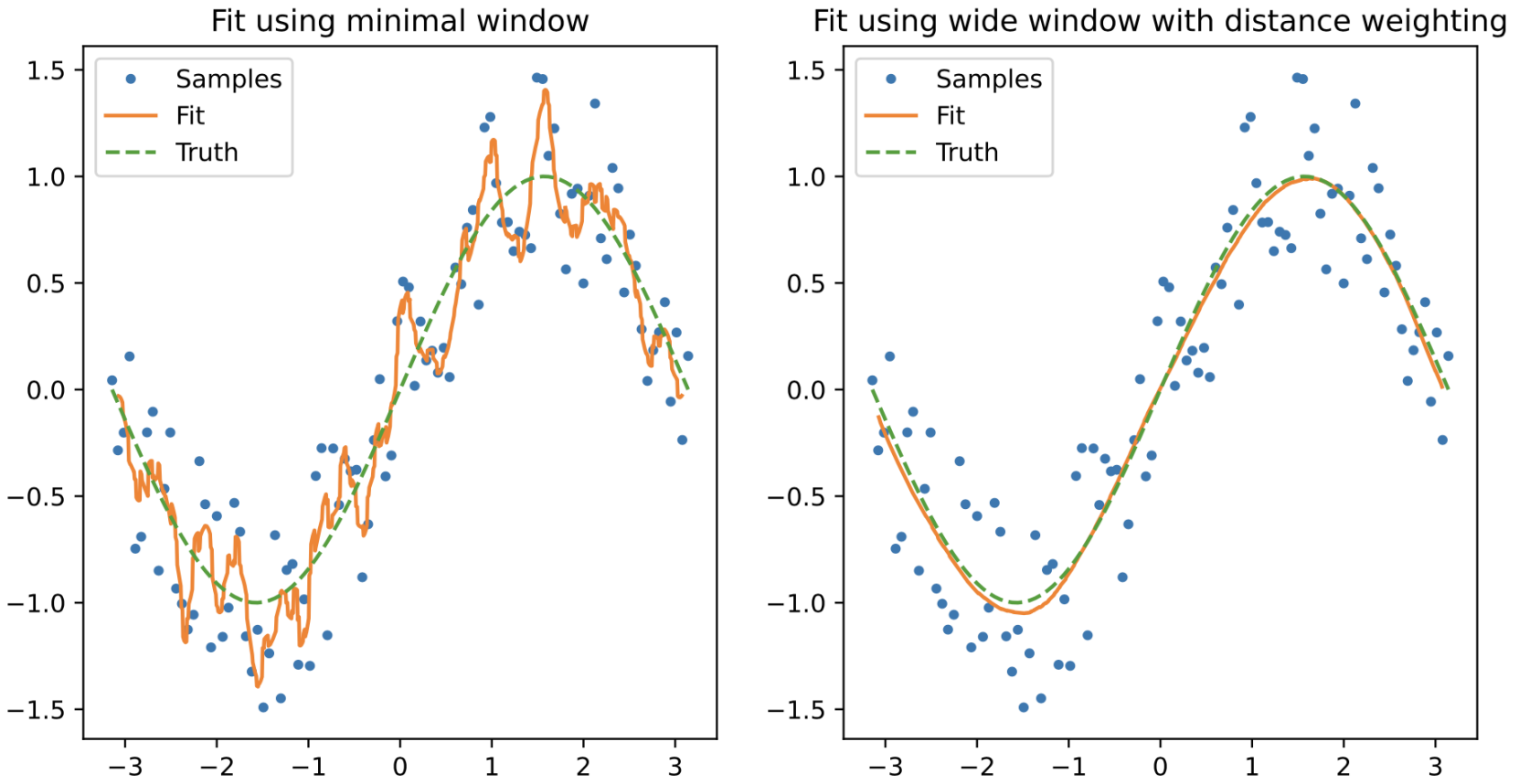


Resampled spectral flux cube

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

Software solutions: data resampling

Other use cases in image and signal processing:



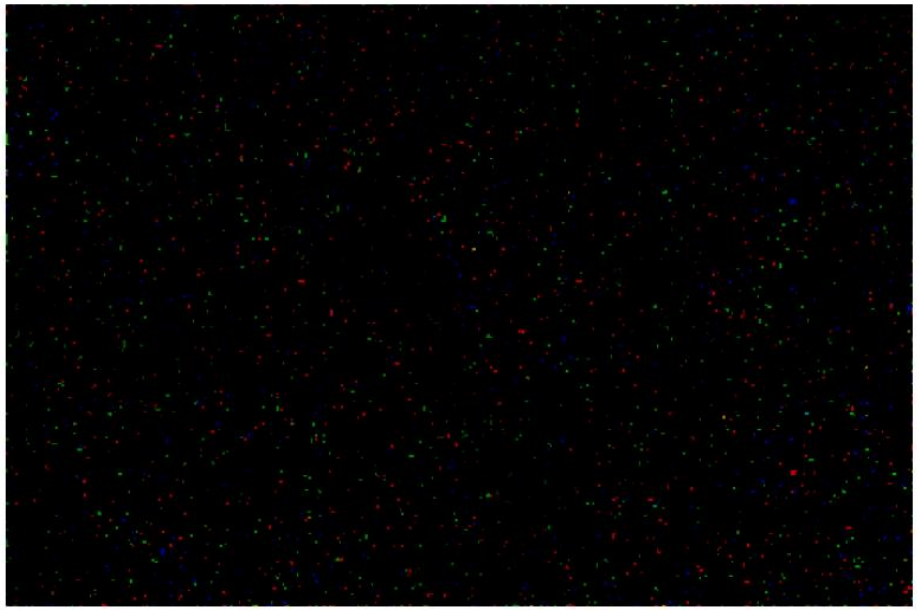
Fit noisy data

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

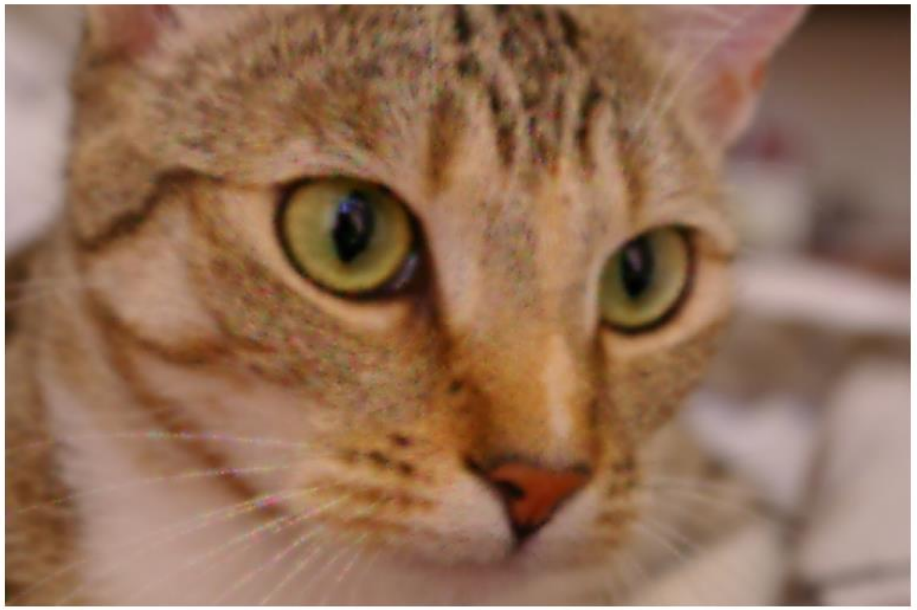
Software solutions: data resampling

Other use cases in image and signal processing:

Corrupted image (70% NaN)



Reconstructed image

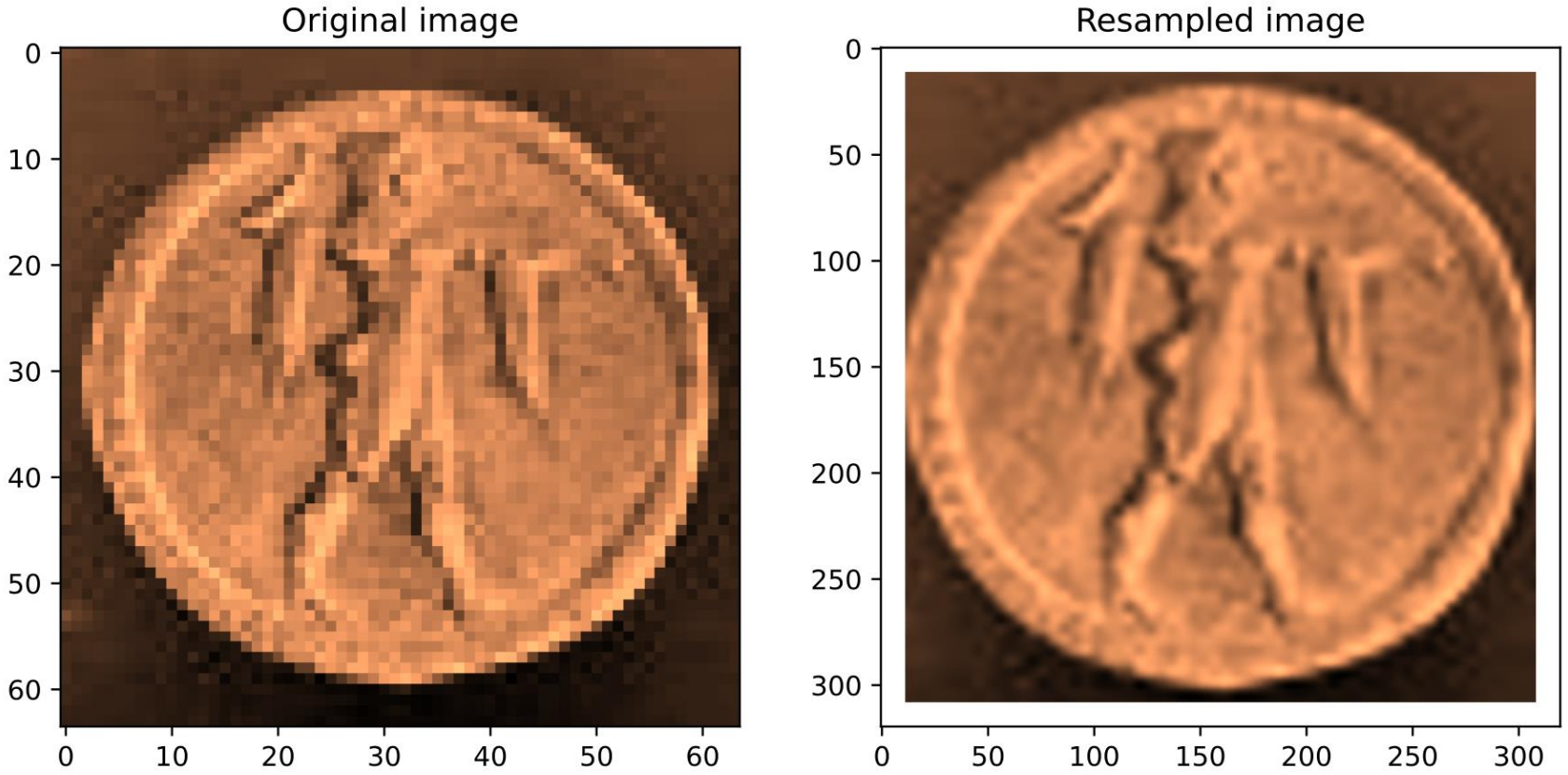


Reconstruct corrupted data

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

Software solutions: data resampling

Other use cases in image and signal processing:



Enhance resolution

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

Develop new software: data visualization

```
sofia_redux
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```
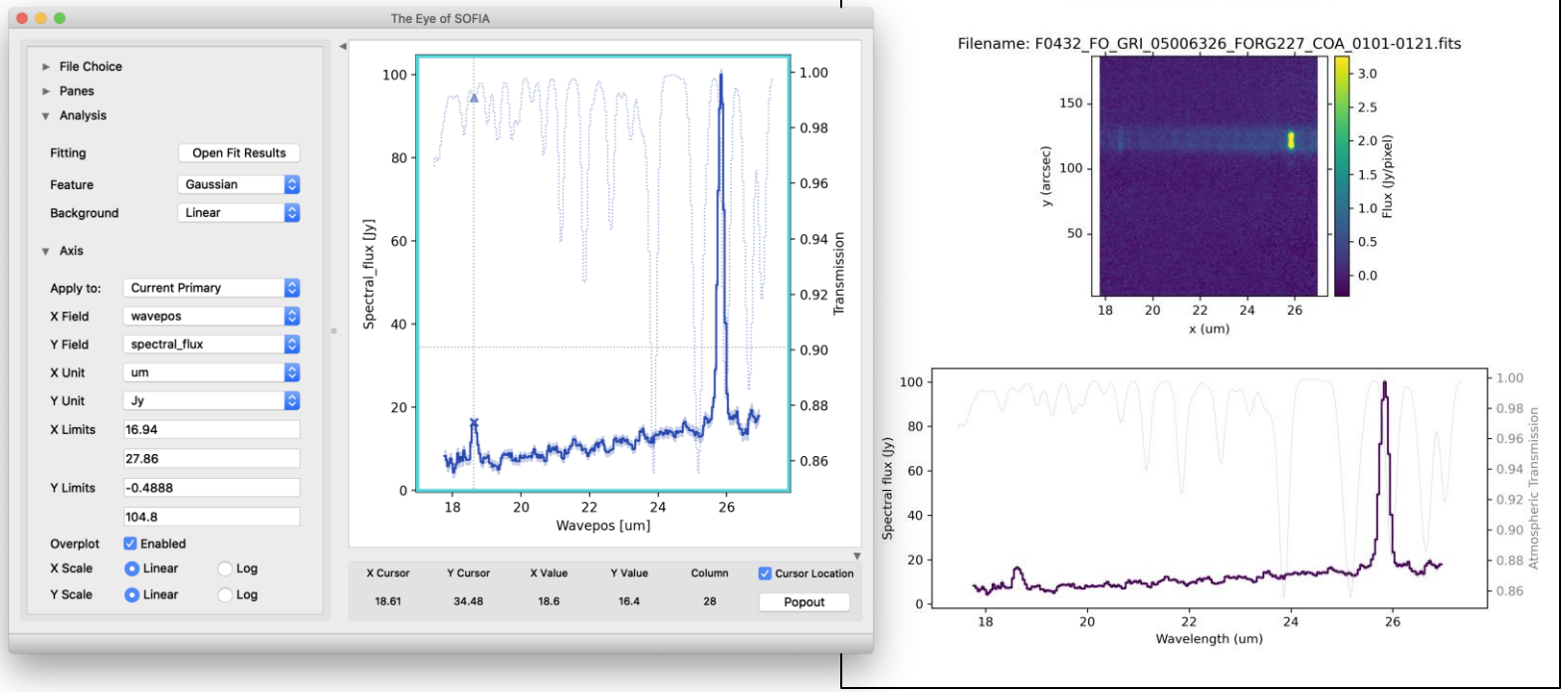

sofia_redux.visualization:

Interactive and static data visualization tools.



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

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

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Arpan Das
Dario Fadda
Christian Fischer
Nicole Karnath
Mark Langer
Enrique Lopez-Rodriguez
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Contributors to earlier pipeline versions

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Giles Novak
Fabio Santos
Klara Shabun
David Shupe
Ralph Shuping
John Vaillancourt
Carrie Volpert

Authors and acknowledgements: https://sofia-usra.github.io/sofia_redux/credits.html

Acknowledgements

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

astropy
: packaging, documentation, coding style and standards

astropy-powered
astropy.org

CRUSH
: original work of authorship for the scan module

CRUSH

Copyright ©2010–2019 Attila Kovács
attila[AT]sigmyne.com

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).

Authors and acknowledgements: https://sofia-usra.github.io/sofia_redux/credits.html

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