



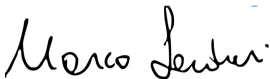
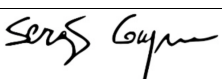
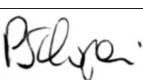
SOXS

Pipeline User Manual

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Change Record

Issue/Rev.	Date	Sec./Parag. affected	Reason/Initiation/Documents/Remarks
1.0	2024-10-01		First issue of Pipeline User Manual
1.1	2025-02-01		Added a section describing the instruments to the user
1.1	2025-02-01		Added a section describing the observing modes to the user
1.1	2025-02-01		Changed the GitHub clone instructions from SSH to HTTP
1.1	2025-02-01		Added information through the doc about how bad pixels are treated at various reduction stages.
1.1	2025-02-01		Descriptions of each of the recipe interfaces are now given (ala the Design Manual): input/output data parameters, qc metrics
1.1	2025-02-01		A section on ‘Collecting Data’ from the ESO SAF was added (as requested by pipeline users).
1.1	2025-02-01		Updated the Quickstart Guide to include direct links to the demo data in the ESO SAF with instructions on downloading the data. This replaces the Dropbox link to demo data.
1.1	2025-02-01		A note about error propagation used throughout the data reduction cascade has been added.
1.1	2025-02-01		Updated info about ACAM circular FOV
1.1	2025-02-01		Updated ACAM reduction cascade image to show where images will be WCS-calibrated.
1.1	2025-02-01		cite Refcat2 when referring to the all-sky catalogue of stars
1.1	2025-02-01		A note that the wavelength solutions are provided in air.
1.1	2025-02-01		Cleaned up the format of the parameters tables for each recipe
1.1	2025-02-01		For recipe entry points, ‘settings’ is now consistently renamed to ‘settings file’.
1.1	2025-02-01		A suggested minimum number of biases, darks, and flats were added for each master calibration frame recipe.
1.1	2025-02-01		The reference to a legacy ‘N NAN PIXELS’ QC parameter was removed.

1.1	2025-02-01		Added details about the ability to provide an absolute flux correction to the spectral data using the simultaneously acquired photometry from the ACAM.
1.1	2025-02-01		A table describing the ancillary/static data needed for each recipe was added.
1.1	2025-02-01		Added a resolution plot for both SOXS UV-VIS and NIR (from arc lamps via one arcsec slit).
1.1	2025-02-01		Added a ‘Reduction Tips’ for each recipe.
1.1	2025-02-01		A table of static/ancillary files was added for each recipe.
1.1	2025-02-01		Added DPR/PRO keywords to the tables of output data products for each recipe.
1.1	2025-02-01		In the QC plot showing order-edge detection in the ‘soxs-mflat’ recipe, we no longer plot data (green points) in the regions where the flat-lamp light is undetected (nor do we use this data to fit the order-edges).
1.1	2025-02-01		Added details on the inter-order background fitting parameters
1.1	2025-02-01		Reformatted the more extended QC plots for the dispersion solution, order centre and spatial solutions so that panels are now in 2 columns (easier to read).
1.1	2025-02-01		Added information about how to adjust the settings for the boxcar extraction.
1.2	2026-04-15		Added ‘horne-extraction-profile-poly-order’ and ‘use_lacosmic’ to the ‘soxs-nod’ and ‘soxs-stare’ parameter documentation.
1.2	2026-04-15		Added a note in the documentation about the ‘soxs_sof_map.yaml’ file.
1.2	2026-04-15		Added a QC plot for the response curve and efficiency.
1.2	2026-04-15		Added a section to the documentation about reducing data in multiprocessing mode.
1.2	2026-04-15		Added acceptable ranges to all recipe QC tables.
1.2	2026-04-15		Added a note about QC metric guardrails in the ‘qc-acceptable-ranges’ section of the settings.
1.2	2026-04-15		Added details of the ‘max_iteration’ and ‘poly_order’ response function parameters to the ‘soxs-nod’ and ‘soxs-stare’ documentation.

1.2	2026-04-15		Added documentation for targeting and reducing individual science SOF files.
1.2	2026-04-15		Added ‘GOODLINES FRAC’, ‘FWHM PIN SD’ & ‘PINHOLE COUNT MIN’ to the QC descriptions for dispersion solutions.
1.2	2026-04-15		Added ‘EFF MEDIAN’ & ‘SNR MEDIAN’ to the QC descriptions for standard star reductions.
1.2	2026-04-15		Updated some QC names and added several more (some detailed above).
1.2	2026-04-15		Added stare and nodding QC plots.
1.2	2026-04-15		Noted that the pipeline can now reduce entire datasets in parallel using multiprocessing.
1.2	2026-04-15		Noted that the pipeline can now specifically target and reduce individual SOF files.
1.2	2026-04-15		Replaced Xshooter example QC plots and images with SOXS versions.
1.2	2026-04-15		Updated the quickstart guide to use SOXS data instead of Xshooter.
1.2	2026-04-15		Tables throughout doc are now formatted to be clearer.

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Contents

1	Purpose and Scope of the Document	1
2	List of Applicable and Reference Documents	1
2.1	Applicable Documents	1
2.2	Reference Documents	1
3	An Introduction to soxspipe	1
3.1	Purpose	1
3.2	Terminology	2
4	Quickstart Guide	2
4.1	Install	2
4.2	Demo Data	2
4.3	Preparing the Data-Reduction Workspace	4
4.4	Reduce the Data	5
5	Instruments	5
5.1	UVVIS Spectrograph	5
5.2	NIR Spectrograph	8
5.3	Acquisition Camera	12
6	Observing Modes	12
6.1	Spectroscopic Observing Modes	12
6.1.1	More on Nodding Mode	13
7	Installation	13
8	Collecting Data	16
9	Preparing a Data-Reduction Workspace	16
9.1	Data Reduction Sessions	20
9.2	Listing The Content of a Workspace	21
9.2.1	List OBs	21
9.2.2	List SOF files	21
10	Reducing Data	21
10.1	Reducing Data with a Single Command	23
10.1.1	Speed up Reductions with Multiprocessing	23
10.1.2	Targetting a Science SOF file for Reduction	25
10.2	Running Individual Recipes	25
10.2.1	soxs_mbias	25
10.2.2	soxs_mdark	27
10.2.3	soxs_disp_solution	29
10.2.4	soxs_order_centres	35
10.2.5	soxs_mflat	37
10.2.6	soxs_spatial_solution	43
10.2.7	soxs_stare	49
10.2.8	soxs_nod	55
10.3	Automatic Reductions Using a Watched Workspace	60
11	Logging	62

1 Purpose and Scope of the Document

Here, we provide users of The SOXS Data Reduction Software (**soxspipe**) instructions on the installation of the pipeline and the steps required to reduce raw SOXS (or Xshooter) data into high-quality, science-ready data products.

One should refer to the SOXS Design Manual for in-depth details of the algorithms employed by **soxspipe** [RD11].

2 List of Applicable and Reference Documents

2.1 Applicable Documents

Reference	Title	Document Number

2.2 Reference Documents

Reference	Title	Document Number
[RD1]	Data flow for VLT/VLTI instruments : Deliverables Specifications	VLT-SPE-ESO-19000-1618 Issue 3 2011-02-01
[RD2]	SOXS Optical Design	SOXS-TRE-0001
[RD3]	SOXS Software Design	SOXS-SPE-0002
[RD4]	SOXS Operation Plan	SOXS-PLA-0011
[RD5]	UV-VIS Detector System Design and Performance Report	SOXS-TRE-0005
[RD6]	NIR Detector System Design and Performance Report	SOXS-TRE-0006
[RD7]	PESSTO: survey description and products from the first data release by the Public ESO Spectroscopic Survey of Transient Objects	2015, A&A, 579, A40
[RD8]	VLT Xshooter Pipeline User Manual	VLT-MAN-ESO-14650-4840
[RD9]	SOXS Calibration Plan	SOXS-PLA-0006
[RD10]	SOXS Commissioning Plan	SOXS-PLA-0007
[RD11]	SOXS Pipeline Design Manual	SOXS-SPE-0022
[RD12]	SOXS Pipeline Test Plan	SOXS-PLA-0012
[RD13]	SOXS Pipeline Performance Report	SOXS-TRE-0044

3 An Introduction to soxspipe

soxspipe is an open-source Python package that can be installed via pip or conda (via the community-maintained conda-forge channel). The code is hosted on GitHub¹, where users can report feature requests or bugs via GitHub issues. More adventurous Python-literate users are encouraged to fork the code, add features or fix bugs, and then issue a pull request for the **soxspipe** development team to consider.

3.1 Purpose

The purpose of the SOXS Data Reduction pipeline (**soxspipe**) is to remove all instrument signatures from SOXS scientific data frames using the appropriate calibration data. **soxspipe** supports reducing data taken in each available observation mode, converting this data into physical units, and delivering them with their associated error bars to the ESO SAF². The pipeline also generates QC metrics to monitor telescope, instru-

¹ <https://github.com/thespacedoctor/soxspipe>

² <http://archive.eso.org/cms.html>

ment, and detector health. Errors are propagated through each data reduction stage and delivered within the final data products.

Running at the summit in La Silla, **soxspipe** delivers science-ready, fully reduced data products immediately after an exposure completes. The target users of **soxspipe** are the ESO Data Products and Quality Control Group (DPQC), the La Silla Science Operators (to be used as a quick look tool), the SOXS consortium and the general user community that may want to perform tailored processing of SOXS data.

3.2 Terminology

soxspipe employs a ‘recipes’ concept to describe each discrete, modular data-reduction step. Each of these ‘recipes’ accepts a set of files (SOF) file containing a list of the input files, or ingredients, required by the recipe. The recipes are then strung together to form a complete data-reduction cascade (or cookbook if you like), which converts raw science frames into ESO Phase 3-compliant science data products.

The term ‘utility’ defines the reusable functions called from multiple recipes. Recipes are named with the prefix ‘soxs’ followed by a succinct recipe description (e.g. **soxs_mbias**).

4 Quickstart Guide

Warning

This quickstart guide is subject to change during the pipeline’s development. New features and ways of operating the pipeline are still being added.

4.1 Install

The best way to install **soxspipe** is to use **conda** and install the package in its own isolated environment (preferably using Miniforge¹; a minimal installation for the conda package and environment manager), as shown here:

```
conda create -n soxspipe python=3.12 soxspipe -c conda-forge
conda activate soxspipe
```

If you have previously installed **soxspipe**, a warning will be displayed indicating that a conda environment already exists; select **y** when prompted to remove the existing environment. This has proven to be the cleanest way to upgrade **soxspipe**.

To check if the installation was successful, run **soxspipe -v**. This should return the installation’s version number.

Please refer to the installation section for alternative installation methods for **soxspipe**.

4.2 Demo Data

The demo SOXS data for this quickstart guide are taken from the nights of 8th-12th October 2025 and 11th January 2026. The ‘science’ objects found in the data are actually spectroscopic standard stars taken in science mode.

To download the data from the ESO Science Archive Facility², select the the dates above and choose SOXS as the instrument you are interested in.

For each dataset, click on the ‘MarkAll’ button and then ‘Request marked datasets’ (see Fig. 1).

Collecting the associated raw calibration frames with the raw science frames is essential. Otherwise, the pipeline will not be able to reduce your data. To do this, click the ‘Run association’ button beside the ‘Associated raw calibrations’ checkbox (shown in Fig. 2). Once the association is completed, the ‘Associated raw calibrations’ checkbox should be checked.

¹ <https://github.com/conda-forge/miniforge>

² http://archive.eso.org/eso/eso_archive_main.html

SIMBAD coordinates for AT2020xnd : 22 20 02.0, -02 50 25.2.

Request marked datasets (old way) Reset MarkAll MarkPublic MarkProprietary

M	More	HDR	OBJECT	Target Ra, Dec	Night	Program ID	Instrument	Category	Type	Mode	Dataset ID	Release Date
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:02:38	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:02:38.166	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:02:43	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:02:43.716	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:02:46	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:02:46.688	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:32:57	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:32:57.305	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:36:47	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:36:47.978	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:36:54	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:36:54.179	Oct 22 2021

Request marked datasets (old way) Reset

Figure 1: Mark all of the data and request to download.

Requested raw data

Raw data for which processed data is available (see below)

- ☒ Raw data
- ☐ Associated processed calibrations
- ☐ Associated raw calibrations
- ☐ Night Logs

Run association

Run association

Run association

Raw data for which no processed data is available

None

Figure 2: Download the associated calibration data alongside the science data.

Finally, click the ‘Download ZIP file’ button.

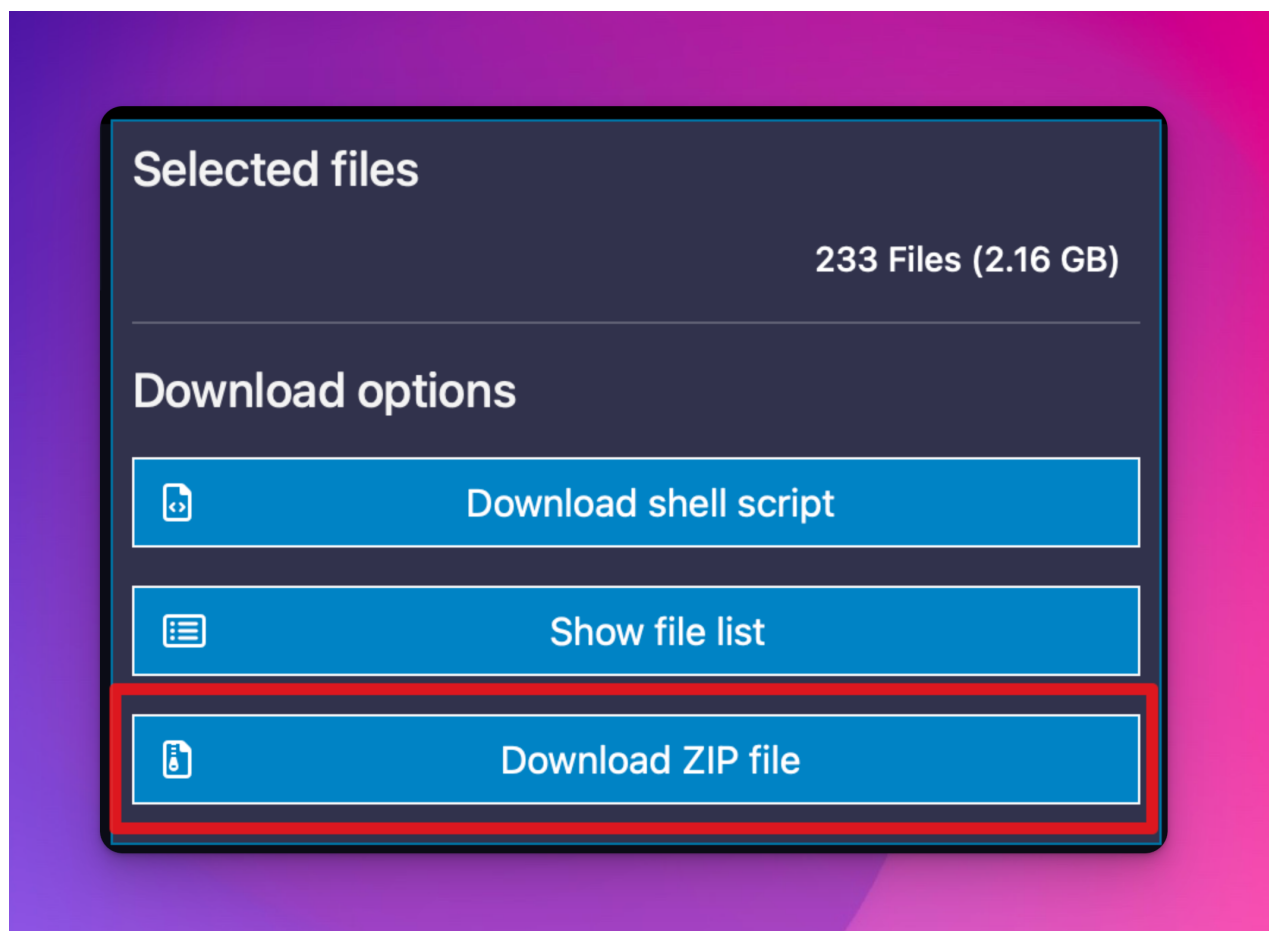


Figure 3: Download the data by clicking the ‘Download ZIP file’ button.

4.3 Preparing the Data-Reduction Workspace

Now that you have a sample data set to work with, it is time to prepare the `soxspipe-quickstart-demo` workspace. Start by creating a `soxspipe-quickstart-demo` folder somewhere appropriate on your machine (like your Desktop or home directory).

```
mkdir soxspipe-quickstart-demo
```

Next, locate the data you just downloaded from the ESO SAF (typically in an ‘archive.zip’ file), unzip it, and move it to the `soxspipe-quickstart-demo` workspace.

Now, change into the `soxspipe-quickstart-demo` directory and run the `soxspipe prep` command:

```
cd soxspipe-quickstart-demo
soxspipe prep .
```

Once the workspace has been prepared, you should find it contains the following files and folders:

- `misc/`: a lost-and-found archive of non-fits files
- `qc/`: a directory to host the quality control data and plots
- `raw/`: all raw frames to be reduced
- `reduced/`: a directory to host the reduced data
- `sessions/`: directory of data-reduction sessions

- `sof/`: the set-of-files (`sof`) files required for each reduction step
- `soxspipe.db`: an SQLite database needed by the data organiser; please do not delete
- `soxspipe.yaml`: a file containing the default settings for each pipeline recipe

soxspipe reduces data within a *reduction session*, and an initial `base` session is automatically created when running the `prep` command. For a more detailed guide to preparing a workspace, please refer to the Preparing a Data-Reduction Workspace section.

4.4 Reduce the Data

In most use cases, you will want to reduce all of the raw frames contained within your workspace. To do this, run the command:

```
soxspipe reduce all .
```

The `reduce` command stops when all data within the workspace has been reduced. For a more in-depth guide to using the reduce command, please refer to the Reducing Data section.

5 Instruments

5.1 UVVIS Spectrograph

Table 2: SOXS UV-VIS Spectrograph/CCD Characteristics

Parameter	Value
Detector	e2V CCD44-82
Pixel-Size	15 μm
Array-Size	2048 $\times$ 4096 px; 30.7 x 61.4 mm
Array-Scale	0.28 arcsec/px
Peak Signal	200,000 e^-/px
Gain	Slow: $0.6 \pm 0.1 e^-/\text{ADU}$ Fast: $2 \pm 0.2 e^-/\text{ADU}$
Read noise (rms)	Slow: $<3 e^-$ Fast: $<8 e^-$
Dark current @ 153K	$< 0.00001 e^-/\text{s/px}$
Resolution (R)	3500-7000 ($\simeq 4500$ mean)
Wavelength Range	350-850nm
Slit Widths	0.5, 1.0, 1.5, 5.0 arcsec
Slit Height	11 arcsec
Grating Blaze Angle	41°
Orders (quasi)	4

As shown in Fig. 4, the SOXS UV-VIS arm has four dispersing elements, each of which produces a dispersed beam, or pseudo-order (u, g, r, i), which are then all imaged onto the 4k x 2k e2v CCD44-82 device (15 μm pixels). Unlike a typical echelle spectrograph, no order curvature exists for any of these four orders [see CAS18, RBAH20, ZanmarSanchezMBA18]. The straight orders do not align precisely along a detector row but are tilted in the dispersion direction by a few pixels. As with the NIR, the slit height in 12". The SOXS UV-VIS spectra arm achieves a resolution $R > 5000$, for a 1 arcsec slit, in all four orders (as seen in Fig. 6).

The object trace in these orders is straight, but the skylines are not perpendicular to the object spectrum but are tilted in the cross-dispersion direction (see Fig. 5).

The full UV-VIS wavelength range is 350 – 850nm (providing a 50nm overlap with the NIR arm for cross-calibration), and with the deep-depleted CCD42-82 device, fringing in the red part of the spectrum is below

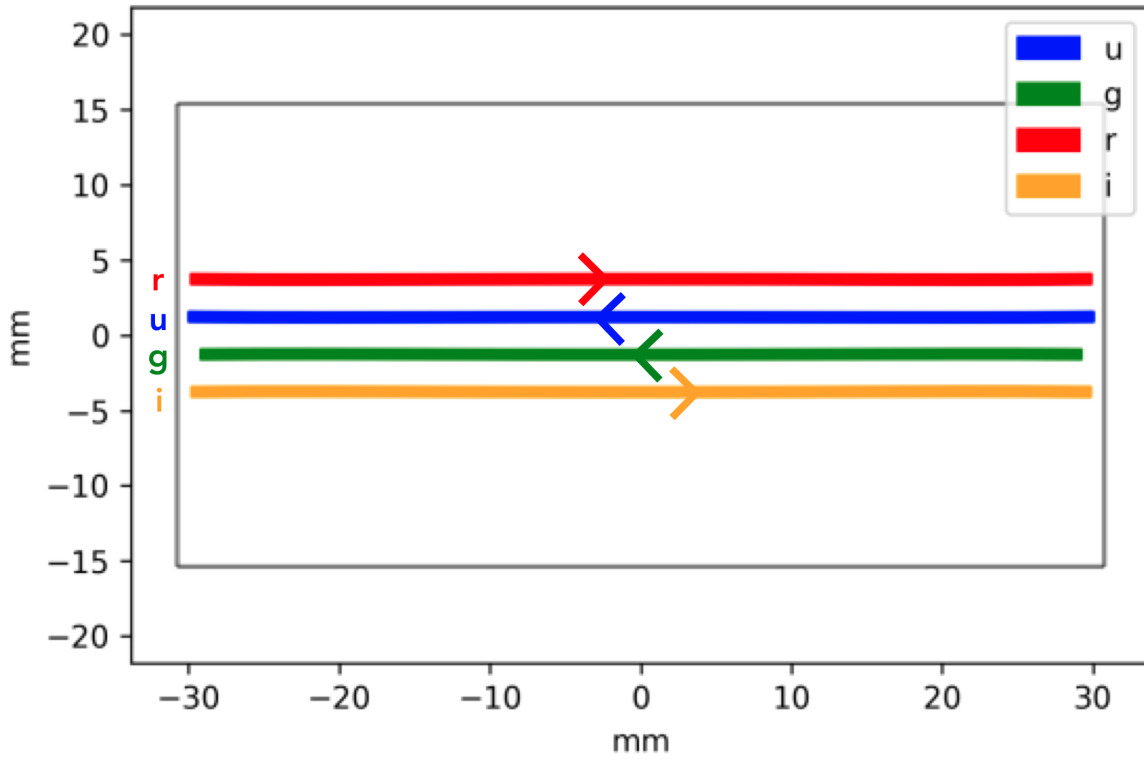


Figure 4: SOXS UV-VIS spectral format, Figure 4 of Zánmar Sánchez *et al.* [ZanmarSanchezMBA18] modified to show the dispersion direction for each pseudo-order.

5% and, therefore, the pipeline does not perform any fringing corrections. Also, due to the CCD's low dark current, calibration dark frames are not required. Unlike the NIR arm, the UV-VIS arm *will* include an ADC.

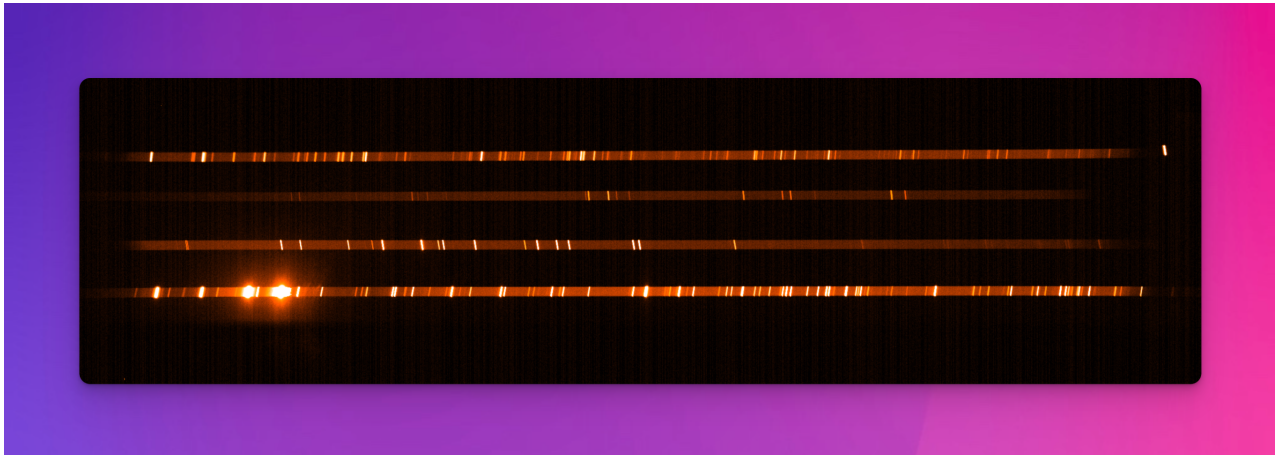


Figure 5: A SOXS UV-VIS Xenon arc lamp frame. The arc lines are not perpendicular to the dispersion axis, but tilted in the cross-dispersion direction.

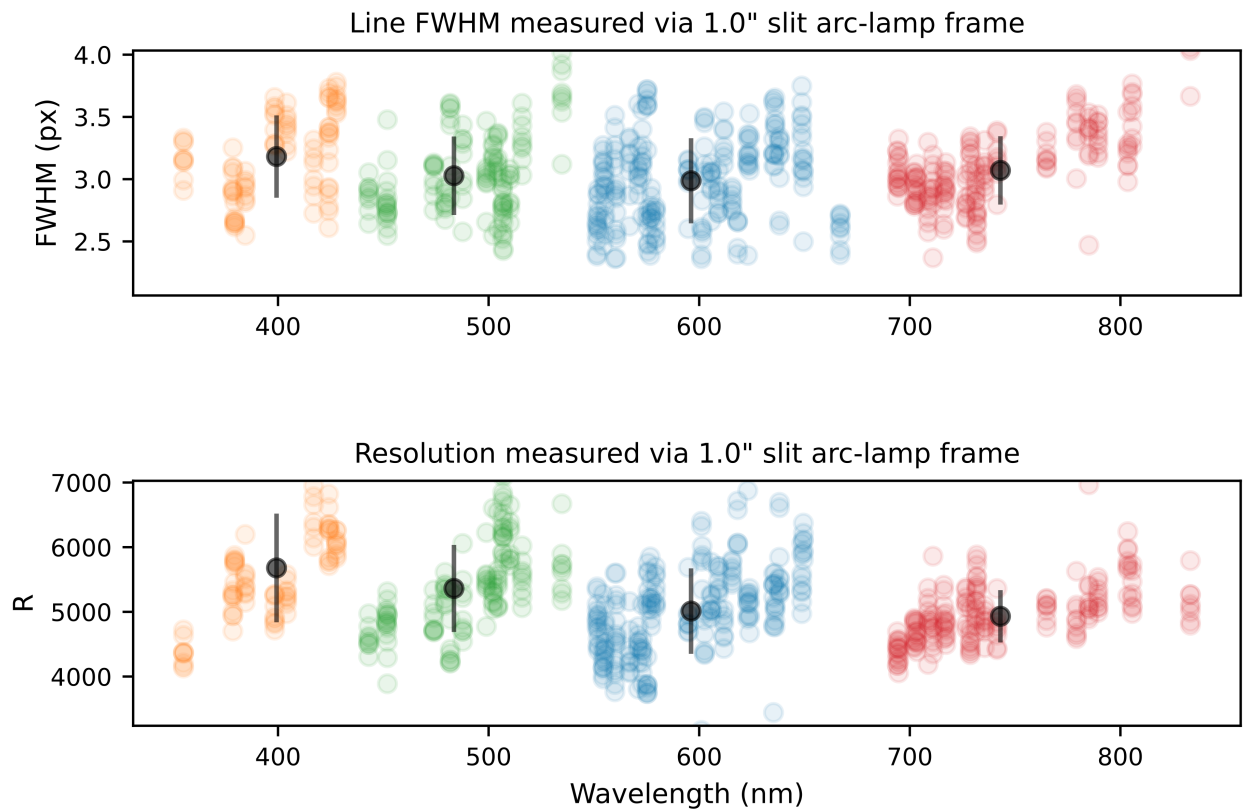


Figure 6: The spectral resolution of the SOXS UV-VIS spectral arm. This plot is generated during the execution of the `soxs_spatial_solution` recipe. For selected lines resulting from a QTH-lamp imaged through a 1 arcsec slit, the FWHM is measured at nine locations along the length of the slit. In the top panel, the measured FWHMs are displayed with respect to the wavelengths of the lines. The orange, green, blue and red circles represent the *u*, *g*, *r* and *i* pseudo orders of the spectrograph, and the black circles (with error bars) represent the mean FWHM for the order (and standard deviation). In the bottom panel, the measured pixel scale from the dispersion solution is used to convert FWHM to spectra resolution R . For a 1 arcsec slit, the SOXS UV-VIS detector achieves a resolution $R > 5000$ in all four orders. The wavelengths of the arc-lines detected range from 355 – 833nm.

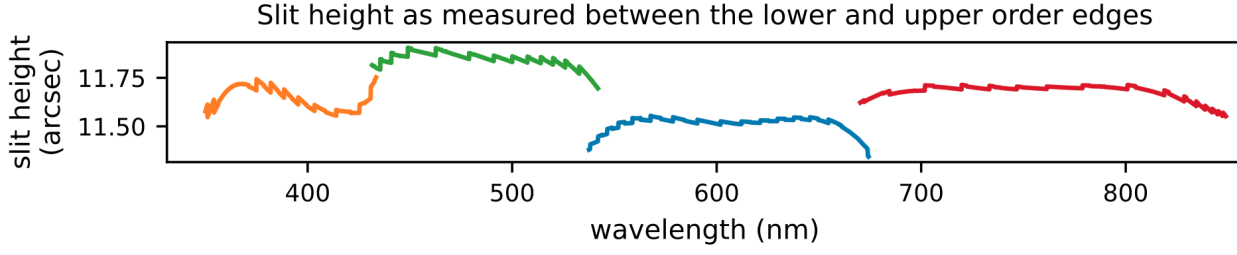


Figure 7: The UV-VIS slit-height as measured between the edges of each dispersion order on a UV-VIS through-slit flat frame. Each colour in the plot represents an individual dispersion order. The slit height is measured close to the expected ~ 12 arcsecs across all orders.

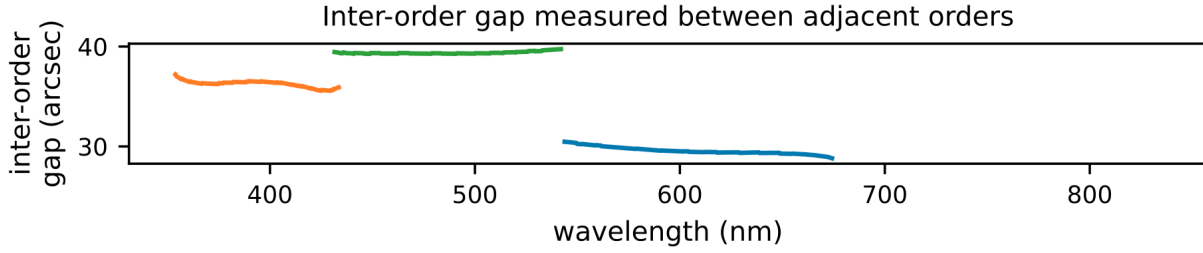


Figure 8: The UV-VIS inter-order gaps as measured between the edges of adjacent dispersion orders on an UV-VIS through-slit flat frame. Each colour in the plot represents an individual dispersion order. The minimum inter-order gap is ~ 28 arcsecs.

5.2 NIR Spectrograph

Table 3: SOXS NIR Spectrograph/Array Characteristics

Parameter	Value
Detector	Teledyne H2RG
Pixel-Size	$18 \mu\text{m}$
Array-Size	$2048 \times 2048 \text{ px}$
Array-Scale	0.25 arcsec/px
Read noise (RMS)	Double correlated: $< 20e^-$ 16 Fowler pairs $< 7e^-$
Dark current @ 45K	$< 0.005e^-/s/px$
Resolution (R)	$\simeq 5000$ (1 arcsec slit)
Wavelength Range	800-2000 nm
Slit Widths	0.5, 1.0, 1.5, 5.0 arcsec
Slit Height	12 arcsec
Grating Blaze Angle	44°
Detector Operating Temp	45K
Spectrograph Operating Temp	140K
Orders	15
Penrays	Ar-Ne-Xe-Hg

As described in Vitali *et al.* [VAC18], the SOXS NIR spectrograph is a near-infrared, cross-dispersed echelle spectrograph, with $R = 5000$ (for a one-arcsec slit). It employs ‘4C’ (Collimator Correction of Camera

Chromatism) to cover a wavelength range from 800 to 2050nm over 15 orders. This wavelength range provides a 50nm overlap with the SOXS UV-VIS arm for cross-calibration.

As with the UV-VIS, four slits options (0.5, 1, 1.5 and 5 arcsec) are provided, which will project a FWHM for an unresolved spectral line onto four detector pixels. A slit height of 12 arcsec is employed. The detector is a $2k \times 2k$ 18-micron pixel Teledyne H2RG TM array. As atmosphere dispersion is less severe in the NIR regime, unlike the UV-VIS arm, the NIR arm does include an atmosphere dispersion corrector (ADC). The SOXS NIR spectral arm achieves a resolution $R > 6000$, for a 1 arcsec slit, across all dispersion orders (as seen in Fig. 11).

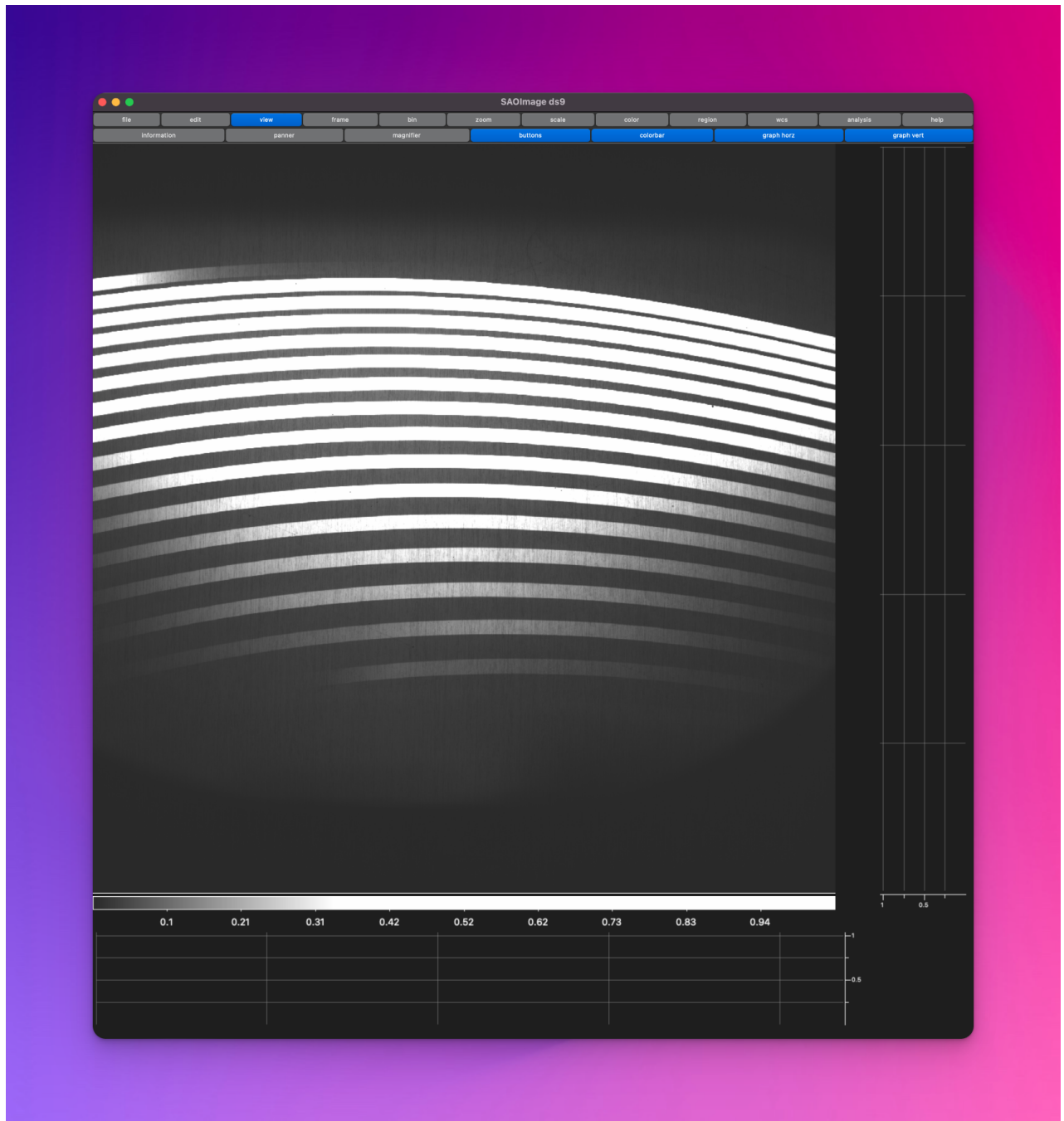


Figure 9: A SOXS flat-lamp calibration image.

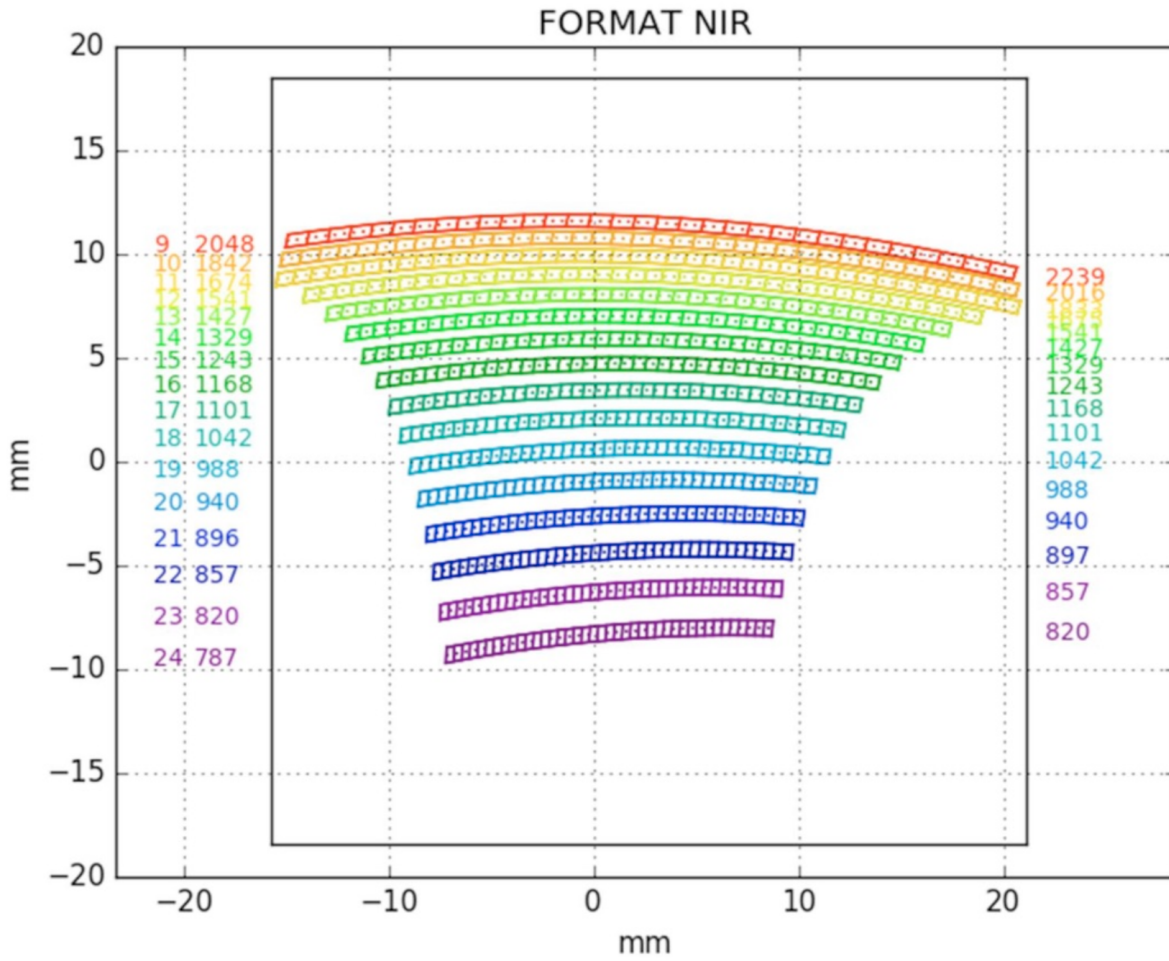


Figure 10: The SOXS NIR spectral format, Figure 5 of Vitali *et al.* [VAC18]. The inter-order gap is always $>10\text{px}$.

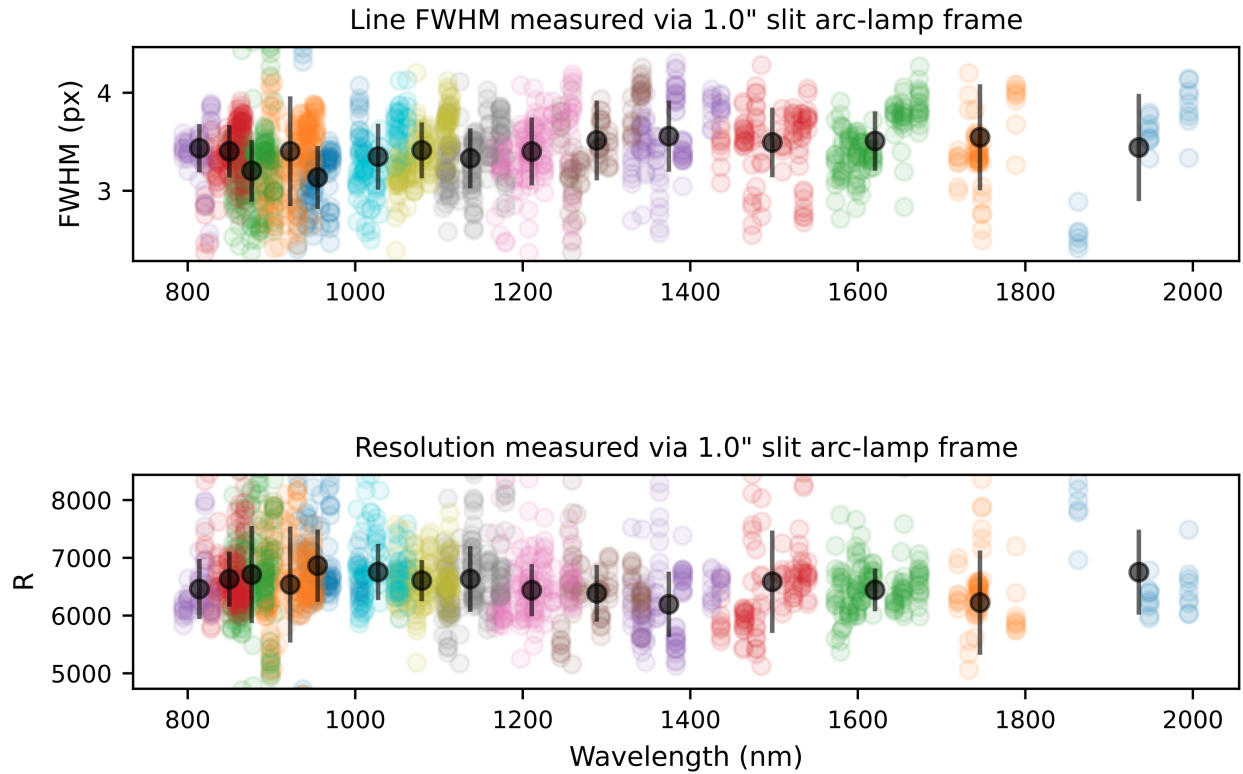


Figure 11: The spectral resolution of the SOXS NIR spectral arm. This plot is generated during the execution of the `soxs_spatial_solution` recipe. For selected lines resulting from Ar-Ne-Hg-Xe penray lamps, imaged through a 1 arcsec slit, the FWHM is measured at nine locations along the length of the slit. In the top panel, the measured FWHMs are displayed with respect to the wavelengths of the lines. The different coloured circles represent the unique dispersion orders of the spectrograph, and the black circles (with error bars) represent the mean FWHM for the order (and standard deviation). In the bottom panel, the measured pixel scale from the dispersion solution is used to convert FWHM to spectra resolution R . For a 1 arcsec slit, the SOXS NIR detector achieves a resolution $R > 6000$ across all orders. The wavelengths of the arc-lines detected range from 795 – 1995nm.

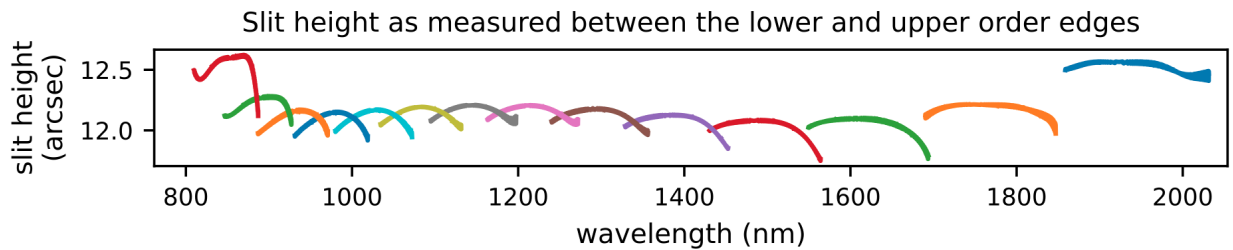


Figure 12: The NIR slit-height as measured between the edges of each dispersion order on an d NIR through-slit flat frame. Each colour in the plot represents an individual dispersion order. The slit height is measured at ~ 12 arcsecs across all orders, as expected.

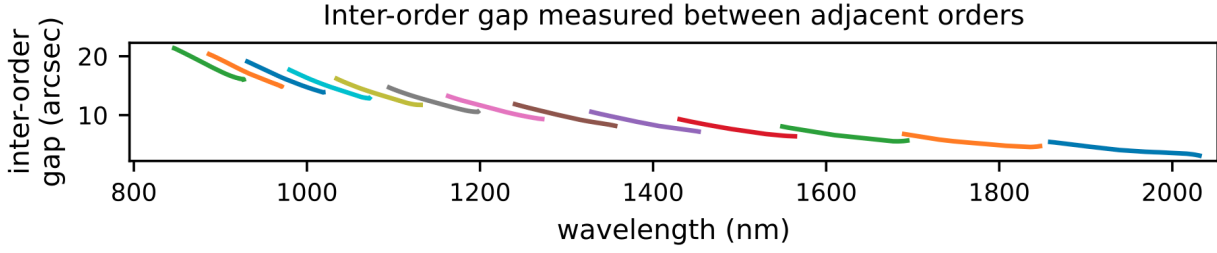


Figure 13: The NIR inter-order gaps as measured between the edges of adjacent dispersion orders on an NIR through-slit flat frame. Each colour in the plot represents an individual dispersion order. The minimum inter-order gap is ~ 6 arcsecs.

5.3 Acquisition Camera

The SOXS acquisition and guiding camera will mainly be used for the acquisition of sources to allow for the centring of targets on the slits. The Andor iKon M934 camera detector has a 1024×1024 pixel BEX2-DD CCD providing a circular FOV with a 3.5 arcmin diameter and a 0.205 arcsec pixel scale. 7 filters are provided; the 6 LSST u, g, r, i, z, y and the V Johnston filter. See Brucalassi *et al.* [BPADuran18] for more detail.

Table 4: Acquisition Camera Characteristics

Parameter	Value
Camera	Andor iKon M934
Detector	BEX2-DD
Pixel-Size	$13 \mu\text{m}$
Array-Size	1024×1024 ; $13.3 \times 13.3 \text{ mm}$
Array-Scale	0.205 arcsec/px
Peak Signal	$130000 e^-/\text{px}$
Dark Current @ 173 K	$0.00012 e^-/\text{s}/\text{px}$
Read noise (rms)	$2.9 e^-$
Filters	u, g, r, i, z, y, V

The fixed format of the SOXS UV-VIS and NIR spectrometers means the only changeable part of the instrument is the slit width. Reducing science frames requires flat-field and flux-calibration frames exposed with an identical slit-width. The bulk of the SOXS usage will be with a one arcsec slit, with options for a wider slit for accurate throughput measurements and absolute flux calibration in some instances and in times of poor seeing.

6 Observing Modes

6.1 Spectroscopic Observing Modes

The glow of thermal emission from the earth’s atmosphere, and even the telescope itself, starts to dominate photon counts at NIR wavelengths, seriously contaminating the signal from target sources. This thermal emission glow is typically dubbed ‘sky background’ (even though it originates in the foreground of the target source).

SOXS has multiple observation modes to provide astronomers with flexibility and a choice of methods to isolate and remove the noise generated by the sky background from their science frames.

The main spectroscopic observation modes are (click links for more detail):

1. Stare mode is a simple ‘point and shoot’ observation with simultaneous UV-VIS and NIR exposures.

With stare mode observations, the on-source sky background is modelled, fitted, and removed with software. Although background removal is less accurate than the other observation modes, the time lost in overheads is lower. Also, unlike the other observation modes, the need for image subtraction, which increases the random noise in the data by $\sqrt{2}$, is bypassed. Multiple exposures of the target can be taken, and combined exposures help remove cosmic ray hits and avoid saturation of skylines.

2. Nodding mode employs an observational technique to measure the sky background of an empty patch of sky near in time and spatially close to the source. This spectral measurement of the sky background flux is removed from the on-source spectrum. Although generating more overhead time than stare mode, unlike offset mode, this technique allows the source and sky to be observed on the same frames.

6.1.1 More on Nodding Mode

The driving motivation for observing with nodding over stare mode is to isolate the target flux more accurately by providing a cleaner sky background subtraction.

To ensure a clean subtraction, we need a spectral image of the night sky closely resembling the profile of the sky, contributing to flux in the target image. As sky flux varies on a timescale of minutes, ideally, we would observe a relatively empty area of the night sky as close as possible to our target source in both space and time. The ‘nodding’ observational technique was designed to fulfil these criteria.

Cycles and Sequences

During nodding-observations we consider 2 locations on the slit, A and B, separated by a few arcseconds. Observations are performed in pairs of equal length exposures called *cycles*. First a spectrum is taken with the target located at slit-position A. The telescope is then shifted, or ‘nodded’, so the target is at slit-position B and a second spectrum is taken. This completes an AB *cycle*. This process is then repeated in reverse to acquire the third and forth exposures at slit-positions B and A respectively; a BA cycle.

Two or more cycles are then combined into a *sequence*. The shortest sequence possible is AB and BA, or ABBA, but sequences can be compiled by many cycles. e.g. an 8 cycle sequence ABBAABBAABBAABBA.

Jittering

Alongside nodding it is also possible to introduce *jittering* which allows for the target to be shifted by a very small random offset each time it is placed at slit positions A and B. This jittering helps avoid the case where the same portion of a target spectrum may be masked by bad-pixels/columns on the detectors.

When including jitter an ABBA sequence becomes $A^1 B^1 B^2 A^2$, where the subscript indicates a location at the slit-positions A or B but now including a small random offset (a jitter).

Combining Frames

For each cycle exposure pair, 2 difference images are produced; A-B and B-A. Each difference image will contain a trace of the target with the sky-background removed (and also a trace of the sky-background with the target flux removed). For all difference images, each echelle order can be identified and straightened (rectified) into its own image. Then for each set of order images, the target trace can be aligned and images combined to improve the signal-to-noise ratio in a final stacked image.

7 Installation

There are multiple methods for installing soxspipe, and you can choose the method that best suits your needs.

Miniforge

Miniforge¹ provides a minimal installation for the conda package and environment manager. It uses the community-maintained conda-forge² distribution channel by default and, therefore, completely avoids any

¹ <https://github.com/conda-forge/miniforge>

² <https://conda-forge.org>

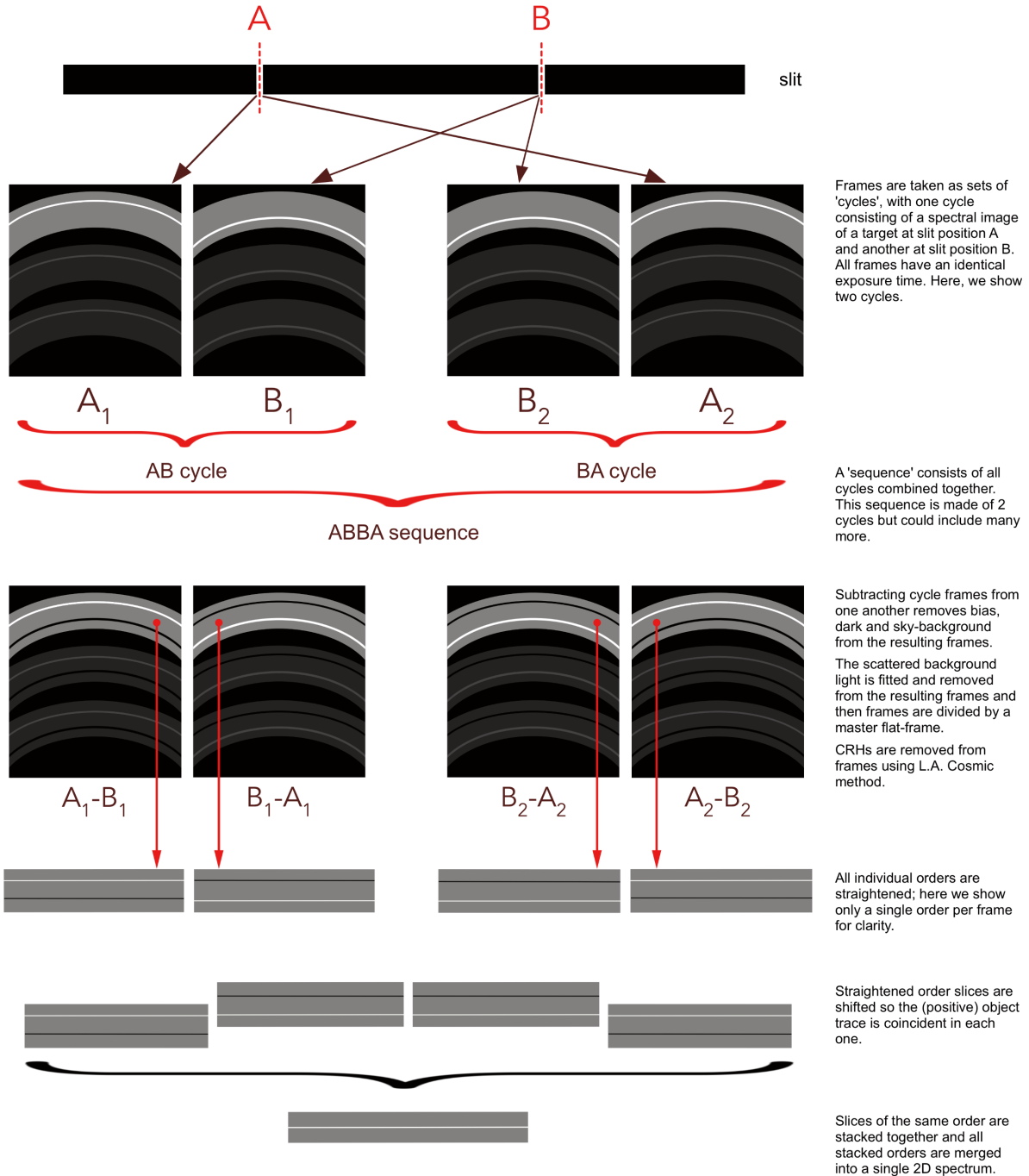


Figure 14: The nodding method of sky-subtraction.

commercial licensing issues. To install soxspipe via Miniforge, you will first need an up-to-date installation on your machine. Please refer to the Miniforge documentation³ for installation instructions.

With Miniforge initialised, generate an isolated environment for soxspipe and install it from the conda-forge distribution channel with the following command:

```
conda create -n soxspipe python=3.12 soxspipe -c conda-forge
```

If you have previously installed soxspipe, a warning will be issued stating that a conda environment already exists; select **y** when asked to remove the existing environment. This has proven to be the cleanest way to upgrade soxspipe.

Once the installation completes, activate the soxspipe conda environment and check soxspipe is installed.

```
conda activate soxspipe
soxspipe -v
```

Anaconda

Anaconda⁴ and its lighter-weight alternative Miniconda⁵, are distributions for Python and other programming languages. To install soxspipe via Anaconda or Miniconda, you will first need an up-to-date installation on your machine. Please refer to their documentation for installation instructions.

With Anaconda/Miniconda initialised, generate an isolated environment for soxspipe and install it from the conda-forge distribution channel with the following command:

```
conda create -n soxspipe python=3.12 soxspipe -c conda-forge
```

If you have previously installed soxspipe, a warning will be issued stating that a conda environment already exists; select **y** when asked to remove the existing environment. This has proven to be the cleanest way to upgrade soxspipe.

Once the installation completes, activate the soxspipe conda environment and check soxspipe is installed.

```
conda activate soxspipe
soxspipe -v
```

Pip

You can install soxspipe via pip within a virtual environment (recommended) or directly into your machine's native Python environment.

To create and activate a virtual environment in your home folder, run the following:

```
cd ~/
mkdir soxspipe
cd soxspipe
python -m venv venv
source venv/bin/activate
```

You can now install soxspipe via pip:

```
pip install soxspipe
```

Finally, check soxspipe is installed correctly by checking the version number:

```
soxspipe -v
```

Each time you wish to use soxspipe, remember to first activate the virtual environment with:

³ <https://github.com/conda-forge/miniforge>

⁴ <https://docs.anaconda.com/anaconda/install/index.html>

⁵ <https://docs.conda.io/en/latest/miniconda.html>

```
source ~/soxspipe/venv/bin/activate
```

Github

You can download the source code for soxspipe directly from Github. This is the best installation method if you plan to change/bug-fix the source code (pull requests are welcome!). First, clone the repository somewhere on your machine:

```
cd ~/
git clone https://github.com/thespacedoctor/soxspipe.git
cd soxspipe
```

You can install source code via pip within a virtual environment (recommended) or directly into your machine's native Python environment.

To create and activate a virtual environment in your home folder, run the following:

```
python -m venv venv
source venv/bin/activate
```

You can now install soxspipe via pip:

```
pip install -e .
```

Finally, check soxspipe is installed correctly by checking the version number:

```
soxspipe -v
```

Each time you wish to use soxspipe, remember to first activate the virtual environment with:

```
source ~/soxspipe/venv/bin/activate
```

8 Collecting Data

Before you can reduce SOXS data, you will first need to download the data from the ESO Science Archive Facility¹ (SAF). As a first step, navigate to the SAF query interface² and enter the details of the object dataset you want to download. Add the target's name and, optionally, the night the data was acquired. Select SOXS under the Spectroscopy column (and Imaging if required) and check 'Science' under the Category section (see Fig. 15). Now, click the green 'Search' button.

Now, click on the 'MarkAll' button and then 'Request marked datasets' (see `request_data`).

Collecting the associated raw calibration frames with the raw science frames is essential. Otherwise, the pipeline will not be able to reduce your data. To do this, click the 'Run association' button beside the 'Associated raw calibrations' checkbox (shown in `associated_calibration_data`). Once the association is completed, the 'Associated raw calibrations' checkbox should be checked.

Finally, click the 'Download ZIP file' button.

The data will be collected in an 'archive.zip' archive, which can be uncompressed with the 'unzip' terminal command or typically by double-clicking the archive in your machine's file browser.

9 Preparing a Data-Reduction Workspace

A 'workspace' is simply a directory you create and designate as the location on your machine where you will reduce your data. It is advisable to have multiple workspaces (folders) for multiple datasets.

First, create your workspace (you can call it whatever you want):

¹ https://archive.eso.org/eso/eso_archive_main.html

² https://archive.eso.org/eso/eso_archive_main.html

Search/Filter Section:

- Target Name:** ☒ AT2020xnd
- Resolved by:** SIMBAD
- Night:** ☒ 2020 10 21 (YYYY MM(M) DD)
- Search Box:** 00 10 00
- DEC:** J2000
- Input:** RA(h) DEC(deg)
- Output:** ☒ Sexagesimal (h, deg)
- Program ID:**
- Program Type:** Any
- PI Col:**
- SV:** Any
- Title:**

Observing Information Section:

- Imaging:** ALL NONE
 - ☐ EFOSC2/LaSilla
 - ☐ EMMI/LaSilla
 - ☐ ERIS/VLT
 - ☐ FORS1/VLT
 - ☐ FORS2/VLT
 - ☐ HAWKI/VLT
 - ☐ GROND/LaSilla
 - ☐ ISAAC/VLT
 - ☐ NACO/VLT
 - ☐ OMEGACAM/VST
 - ☐ SOFI/LaSilla
 - ☐ SPHERE/VLT
 - ☐ SUSI2/LaSilla
 - ☐ TIMMI2/LaSilla
 - ☐ VIRCAM/VISTA
 - ☐ VISIR/VLT
 - ☐ WFI/LaSilla
 - ☐ XSHOOTER/VLT
- Spectroscopy:** ALL NONE
 - ☐ CES/LaSilla
 - ☐ CRIRES/VLT
 - ☐ EFOSC2/LaSilla
 - ☐ EMMI/LaSilla
 - ☐ ERIS/VLT
 - ☐ ESPRESSO/VLT
 - ☐ FEROS/LaSilla
 - ☐ FORS1/VLT
 - ☐ FORS2/VLT
 - ☐ GIRAFFE/VLT
 - ☐ HARPS/LaSilla
 - ☐ ISAAC/VLT
 - ☐ KMOS/VLT
 - ☐ MUSE/VLT
 - ☐ NACO/VLT
 - ☐ NIRPS/LaSilla
 - ☐ SPHERE/VLT
 - ☐ TIMMI2/LaSilla
 - ☐ UVES/VLT
 - ☐ VIMOS/VLT
 - ☐ VISIR/VLT
 - ☒ XSHOOTER/VLT
- Interferometry:** ALL NONE
 - ☐ AMBER/VLT
 - ☐ GRAVITY/VLT
 - ☐ MATISSE/VLT
 - ☐ MIDI/VLT
 - ☐ PIONIER/VLT
 - ☐ VINCI/VLT
 - ☐ POLARIMETRY
 - ☐ EFOSC2/LaSilla
 - ☐ FORS1/VLT
 - ☐ FORS2/VLT
 - ☐ ISAAC/VLT
 - ☐ NACO/VLT
 - ☐ SOFI/LaSilla
 - ☐ SPHERE/VLT
 - ☐ CORONAGRAPHY
 - ☐ EFOSC2/LaSilla
 - ☐ ERIS/VLT
 - ☐ NACO/VLT
 - ☐ SPHERE/VLT
 - ☐ VISIR/VLT
- Other:** ALL NONE
 - ☐ ALPACA/Paranal
 - ☐ APICAM/Paranal
 - ☐ BOL/APEX
 - ☐ HET/APEX
 - ☐ FAIM6/OASIS
 - ☐ FAIM7/OASIS
 - ☐ GRIPS19/OASIS
 - ☐ LGSF/VLT
 - ☐ MAD/VLT
 - ☐ MASCOT/Paranal
 - ☐ SPECULOOS/Paranal
 - ☐ WFCAM/UKIRT
 - ☐ SPP/VLT
 - ☐ ERIS/VLT
 - ☐ NACO/VLT
 - ☐ SPHERE/VLT
 - ☐ VISIR/VLT
- Category:** ☒ SCIENCE
 - ☐ CALIB
 - ☐ ACQUISITION

Data Product Info Section:

- Type:** ☒ Any
- Mode:** ☒ Any
- Dataset ID:**
- Orig Name:**
- Release Date:**
- OB Name:**
- OB ID:**
- TPL START:**
- Instrumental Setup:**
 - TPL ID:** ☒
 - Exptime:** ☒
 - Filter bandpass:** ☒
 - Bandpass FWHM:** ☒
 - Grism:** ☐
 - Grating:** ☐
 - Slit:** ☐

Instrument & Mode: ☒ XSHOOTER/VLT

Figure 15: The Query Interface of the ESO Science Archive Facility (select SOXS as your instrument).

SIMBAD coordinates for AT2020xnd : 22 20 02.0, -02 50 25.2.

Request marked datasets (old way) Reset MarkAll MarkPublic MarkProprietary

M	More	HDR	OBJECT	Target Ra, Dec	Night	Program ID	Instrument	Category	Type	Mode	Dataset ID	Release Date
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:02:38	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:02:38.166	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:02:43	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:02:43.716	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:02:46	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:02:46.688	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:32:57	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:32:57.305	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:36:47	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:36:47.978	Oct 22 2021
		Header	AT2020XND	22:20:02.14 -02:50:24.8	2020 Oct 22 02:36:54	106.21QU.001	XSHOOTER	SCIENCE	OBJECT	ECHELLE,SLIT,STARE	XSHOO.2020-10-22T02:36:54.179	Oct 22 2021

Request marked datasets (old way) Reset

Figure 16: Mark all of the data and request to download.

Requested raw data

Raw data for which processed data is available (see below)

- ☒ Raw data
- ☐ Associated processed calibrations
- ☐ Associated raw calibrations
- ☐ Night Logs

Run association

Run association

Run association

Raw data for which no processed data is available

None

Figure 17: Download the associated calibration data alongside the science data.

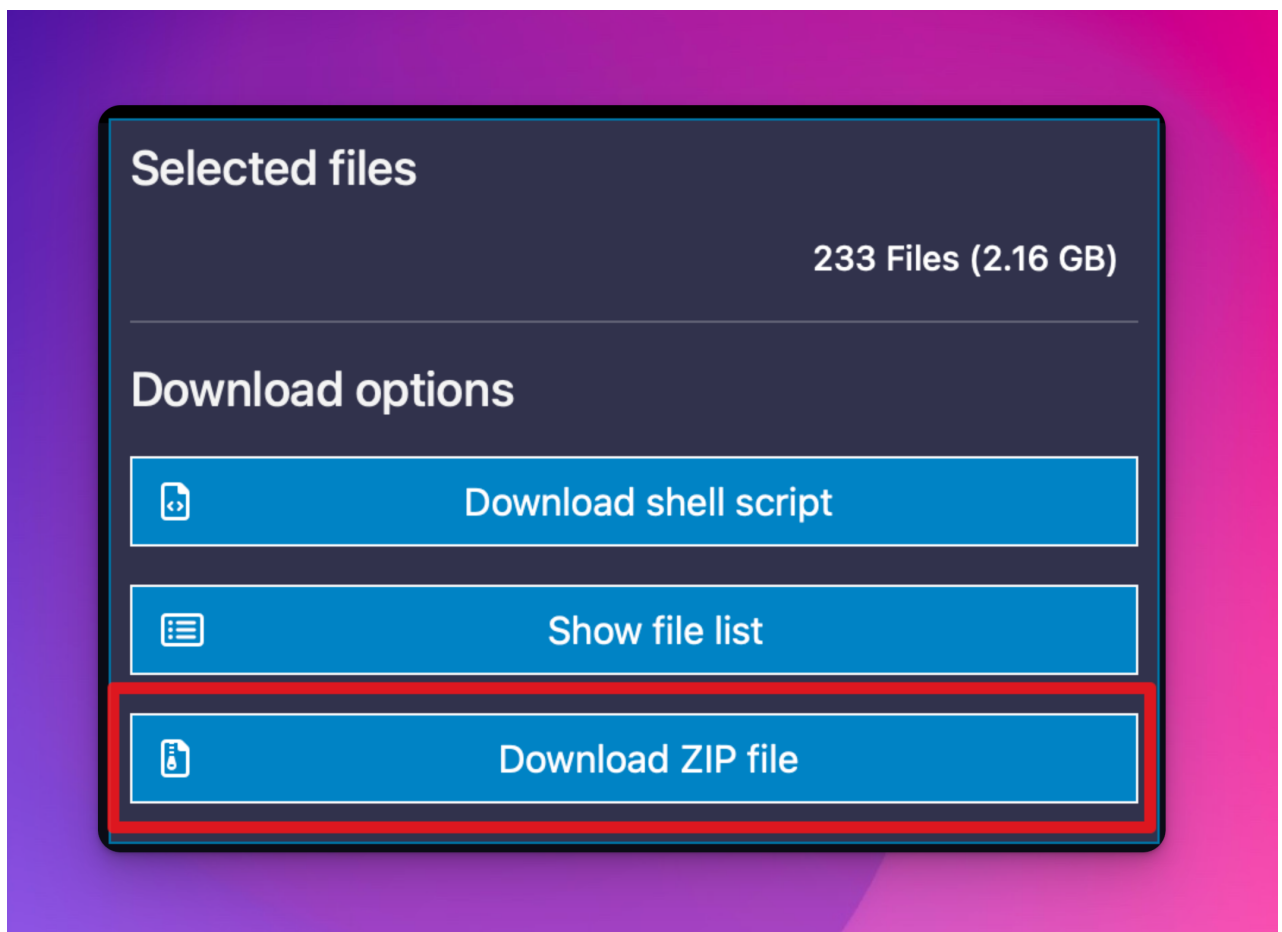


Figure 18: Download the data by clicking the 'Download ZIP file' button.

```
cd ~/
mkdir soxs-workspace-one
cd soxs-workspace-one
```

Now download/move all of the SOXS raw data from your data set into the root of this workspace. There is no need for nested folders; just fill the directory with FITS files.

soxspipe has a built-in data organiser that does the heavy lifting of sorting and preparing your raw data for data reduction. So to prepare your workspace, change into the workspace directory and run the **soxspipe prep** command:

```
cd ~/soxs-workspace-one
soxspipe prep .
```

Once the workspace has been prepared, you should find it contains the following files and folders:

- **misc/**: a lost-and-found archive of non-fits files
- **qc/**: a directory to host the quality control data and plots
- **raw/**: all raw frames to be reduced
- **reduced/**: a directory to host the reduced data
- **sessions/**: directory of data-reduction sessions
- **sof/**: the set-of-files (sof) files required for each reduction step
- **soxspipe.db**: an SQLite database needed by the data-organiser; please do not delete
- **soxspipe.yaml**: file containing the default settings for each pipeline recipe

Your workspace is now prepared, and you are now ready to reduce your data.

9.1 Data Reduction Sessions

soxspipe reduces data within a ‘reduction session’. These sessions are designed to be self-contained and isolated from other sessions, allowing users to reduce the same set of raw data with multiple different pipeline settings. An initial ‘base’ session is automatically created when a workspace is first prepared (using the **soxspipe prep** command). Sessions are stored in the **sessions** directory of the workspace and contain their own settings file, products and QC directories. **soxspipe** will remember and use the latest session you were working with unless you create a new session or switch to another one.

To see which reduction session you are working within and all other sessions available, run the command:

```
soxspipe session ls
```

To create a new session, run the command:

```
soxspipe session new
```

The new session will be named with the date-time stamp of its creation date. Alternatively, you can also supply a memorable name for the session. The name can be up to 16 characters long and use alpha-numeric characters, - or _.

```
soxspipe session new my_supernova
```

Or to switch to an existing session, run the command:

```
soxspipe session <sessionId>
```

For user convenience, when you switch to a new session, the symbolic links found within the workspace root folder are automatically switched to point to the current session assets (**products**, **qc**, **sof**, **soxspipe.yaml**, **soxspipe.db** etc). If you run **ls -lrt** within your workspace root directory, you will see these symlinks reported:

```
products -> ./sessions/base/products
qc -> ./sessions/base/qc
soxspipe.db -> ./sessions/base/soxspipe.db
soxspipe.yaml -> ./sessions/base/soxspipe.yaml
sof -> ./sessions/base/sof
```

9.2 Listing The Content of a Workspace

9.2.1 List OBs

The `soxspipe list` commands can be used to list the science content of the workspace. To list all of the science OBs contained within a workspace, run the command `soxspipe list obs <workspaceDirectory>`.

THE CURRENT WORKSPACE CONTAINS 7 SCIENCE OBSERVATION BLOCKS:

eso seq arm	night start date	night start mjd	eso obs name	eso obs id
VIS	2025-10-07	60955	SOXS_LTT7987-STD_stare_nod_SMARTT_science	1000598091
VIS	2025-10-07	60955	SOXS_Feige110-STD_stare_nod_SMARTT_science	1000598097
VIS	2025-10-07	60955	NGC_1068_stare	1000598106
VIS	2025-10-07	60955	SOXS_AT2025yrt_stare	1000598249
VIS	2025-10-07	60955	SOXS_SN2025pht_stare	1000598246
VIS	2025-10-08	60956	SOXS_LTT7987-STD_stare_nod_SMARTT_SCI	1000598442
VIS	2025-10-08	60956	SOXS_Feige110-STD_stare_nod_SMARTT_SCI	1000598448

Figure 19: Listing the OBs contained within a workspace with the `soxspipe list obs .` command.

9.2.2 List SOF files

An OB can contain multiple telescope-instrument setups (slit-widths, observing modes etc), but each individual setup will be listed in a unique SOF file. To list all of the science set-of-files (SOF) files contained within a workspace, run the command `soxspipe list sof <workspaceDirectory>`.

THE CURRENT WORKSPACE CONTAINS 9 SCIENCE SOF FILES:

eso seq arm	night start date	mjd-obs	eso obs name	eso obs id	slit	sof
VIS	2025-10-07	60956.1	SOXS_LTT7987-STD_stare_nod_SMARTT_science	1000598091	SLIT1.0	20251008T024138_VIS_1X1_1_NOD_SLIT1.0_300.05_SOXS_CD30_17.sof
VIS	2025-10-07	60956.1	SOXS_LTT7987-STD_stare_nod_SMARTT_science	1000598091	SLIT1.5	20251008T022958_VIS_1X1_1_NOD_SLIT1.5_300.05_SOXS_CD30_17.sof
VIS	2025-10-07	60956.1	SOXS_LTT7987-STD_stare_nod_SMARTT_science	1000598091	SLIT5.0	20251008T021829_VIS_1X1_1_NOD_SLIT5.0_300.05_SOXS_CD30_17.sof
VIS	2025-10-07	60956.1	SOXS_LTT7987-STD_stare_nod_SMARTT_science	1000598091	SLIT1.0	20251008T021242_VIS_1X1_1_STARE_SLIT1.0_300.05_SOXS_CD30_17.sof
VIS	2025-10-07	60956.1	SOXS_LTT7987-STD_stare_nod_SMARTT_science	1000598091	SLIT1.5	20251008T020702_VIS_1X1_1_STARE_SLIT1.5_300.05_SOXS_CD30_17.sof
VIS	2025-10-07	60956.1	SOXS_LTT7987-STD_stare_nod_SMARTT_science	1000598091	SLIT5.0	20251008T020113_VIS_1X1_1_STARE_SLIT5.0_300.05_SOXS_CD30_17.sof
VIS	2025-10-07	60956.2	SOXS_Feige110-STD_stare_nod_SMARTT_science	1000598097	SLIT1.0	20251008T045427_VIS_1X1_1_NOD_SLIT1.0_300.05_SOXS_FEIGE_11.sof
VIS	2025-10-07	60956.2	SOXS_Feige110-STD_stare_nod_SMARTT_science	1000598097	SLIT1.5	20251008T044258_VIS_1X1_1_NOD_SLIT1.5_300.05_SOXS_FEIGE_11.sof
VIS	2025-10-07	60956.2	SOXS_Feige110-STD_stare_nod_SMARTT_science	1000598097	SLIT5.0	20251008T043128_VIS_1X1_1_NOD_SLIT5.0_300.05_SOXS_FEIGE_11.sof

Figure 20: Listing the science SOF files contained within a workspace with the `soxspipe list sof .` command.

10 Reducing Data

`soxspipe` has an extensive set of usage commands. Running `soxspipe -h` will give the complete list of these commands.

Documentation for `soxspipe` can be found here: <http://soxspipe.readthedocs.org>

Usage:

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```

soxspipe --version
soxspipe prep [<workspaceDirectory> --vlt --refresh]
soxspipe [-qwpVm] reduce all [<workspaceDirectory> -b <batchSize> -s
→<pathToSettingsFile>]
soxspipe [-qxV] reduce sof <sofFile> [<workspaceDirectory> -s <pathToSettingsFile>]
soxspipe session ((ls|new|<sessionId>)|new <sessionId>)
soxspipe list (ob|sof) [<workspaceDirectory> -s <pathToSettingsFile>]
soxspipe raw sof <sofFile> [<workspaceDirectory> -s <pathToSettingsFile>]
soxspipe [-Vxd] mdark <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
soxspipe [-Vxd] mbias <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
soxspipe [-Vxd] disp_solution <inputFrames> [-o <outputDirectory> -s
→<pathToSettingsFile> --poly=<ooww>]
soxspipe [-Vxd] order_centres <inputFrames> [-o <outputDirectory> -s
→<pathToSettingsFile> --poly=<ooww>]
soxspipe [-Vxd] mflat <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
soxspipe [-Vxd] spat_solution <inputFrames> [-o <outputDirectory> -s
→<pathToSettingsFile> --poly=<oowwss>]
soxspipe [-Vxd] stare <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
soxspipe [-Vxd] nod <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
soxspipe watch (start|stop|status) [-s <pathToSettingsFile>]

Options:
    list ob                list all observations within the workspace
    list sof               list all science object SOF files within
→the workspace
    prep                   prepare a folder of raw data (workspace)
→for data reduction
    session ls             list all available data-reduction sessions
→in the workspace
    session new [<sessionId>] start a new data-reduction session,
→optionally give a name up to 16 characters A-Z, a-z, 0-9 and/or _-
    session <sessionId>    use an existing data-reduction session (use
→`session ls` to see all IDs)
    reduce all             reduce all of the data in a workspace.
    reduce sof             reduce a single science object SOF file.
    raw sof                export all the raw frames needed to reduce
→a science object SOF file to a directory called `exported` in the current working
→directory.

    mbias                  the master bias recipe
    mdark                  the master dark recipe
    mflat                  the master flat recipe
    disp_solution          the disp solution recipe
    order_centres          the order centres recipe
    spat_solution          the spatial solution recipe
    stare                  reduce stare mode science frames
    nod                    reduce nodding mode science frames

    start                  start the watch daemon
    stop                   stop the watch daemon
    status                 print the status of the watch daemon

    inputFrames            path to a directory of frames or a set-of-
→files file

    -b, --batch            reduce data in batches of <batchSize>

```

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```

→ recipes (only when reducing all data)
    -d, --debug                show debugging plots
    -h, --help                show this help message
    -m, --multiprocess        run reductions of recipe in parallel
→ (experimental, use with caution and check your results carefully if using this flag)
    -p, --prep                prepare a workspace before reducing data
    -q, --quitOnFail          stop the pipeline if a recipe fails
    -r, --refresh              trigger a complete refresh the workspace
→ during preparation (delete database and do a complete prepare)
    -s, --settings <pathToSettingsFile> the settings file
    -v, --version              show version
    -V, --verbose              more verbose output
    -w, --watch                watch the workspace and reduce new raw data
→ as it is added (similar to 'watch' mode but runs in the foreground)
    -x, --overwrite           more verbose output
    --poly=<ORDERS>            polynomial degrees (overrides parameters
→ found in setting file). oowwss = order_x,order_y,wavelength_x,wavelength_y,slit_x,slit_y
→ e.g. 345435. od = order,dispersion-axis
    --vlt                      only use this flag if setting up a
→ workspace on a VLT environment workstation

```

Like ESO pipelines, `soxspipe` is designed to execute **recipes**, which accept set-of-files (SOF) files as inputs and output specific data products. Each recipe reduces data from a particular stage of the data-reduction cascade (e.g., bias or flat frames). As each subsequent recipe in the data-reduction cascade relies on products generated by previous recipes, the recipes need to be run in order. Of course, the user is free to *run the pipeline recipe-by-recipe*, but most users will opt to use the `soxspipe reduce`, which allows for the reduction of all data in the correct order, with one command.

10.1 Reducing Data with a Single Command

In most use cases, you will want to reduce all raw frames within your workspace with a single command. This allows you to run the pipeline at a high level without worrying about individual recipe commands.

To do this, from the root directory of your workspace, run:

```
soxspipe reduce all .
```

Once running, the `reduce` command will execute the pipeline recipes (in order) and generate new data products. During execution, the pipeline writes useful logs to the terminal, providing a status of data-reduction progress. These logs are also written to individual recipe log files. If, at any stage, a recipe fails to create a data product, the pipeline will attempt to pivot to use the next-best available product. The `reduce` command stops when all data within the workspace has been reduced.

During runtime, recipes write plots and files to a `qc` (Quality Control) folder within the workspace. Each recipe writes to its own named directory (see Fig. 21).

Each recipe generates products written to the `products` folder within the workspace, with each recipe writing to its own directory. Recipe log files are also written to the `products` folder adjacent to their associated products.

10.1.1 Speed up Reductions with Multiprocessing

If you have a large dataset, you can dramatically speed up reductions by using the `--multiprocess` (`-m`) flag. In this mode, the `reduce` command will reduce recipes in parallel. Instead of seeing each recipe's output logs in the terminal, the user will see a progress bar showing the pipeline's progress as it reduces all the sof files for each recipe.

To do this, from the root directory of your workspace, run:

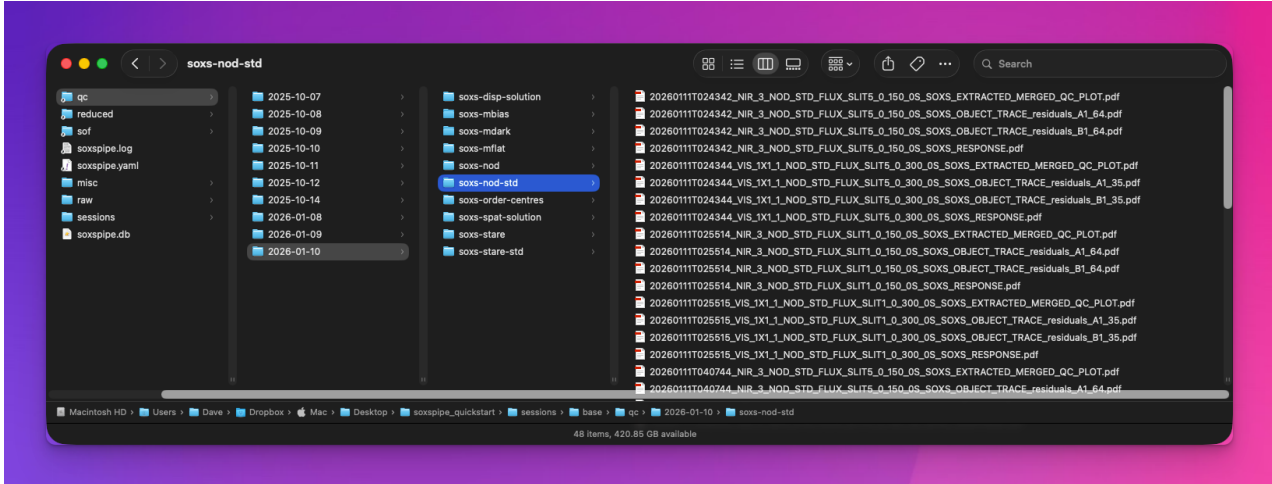


Figure 21: QC files and plots are written to the workspace **qc** folder.

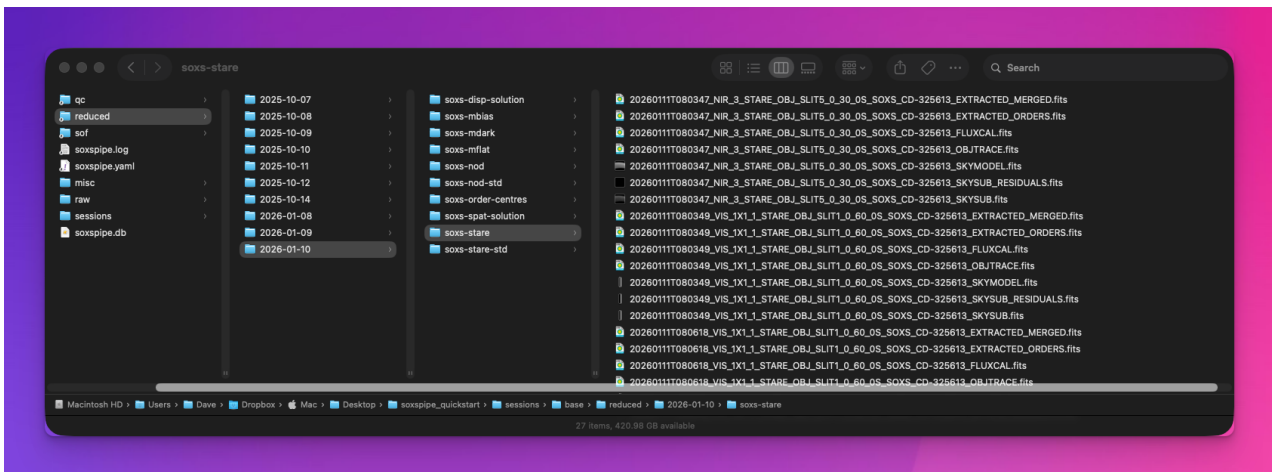


Figure 22: Recipe products, files and plots are written to the workspace **reduced** folder.

```
soxspipe reduce all . -m
```

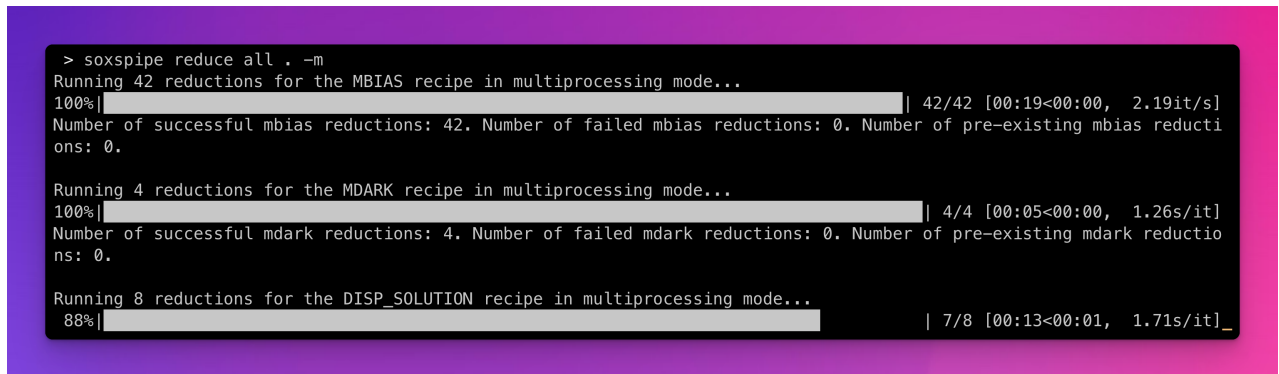


Figure 23: In multiprocessing mode, recipe sof files are reduced in parallel, and the user is presented with a progress bar for each recipe.

10.1.2 Targetting a Science SOF file for Reduction

In addition to reducing an entire directory of data, **soxspipe** can target specific science SOF files. In this mode of operation, the pipeline will only reduce the calibration data needed to reduce the targeted science SOF file. To list all of the science SOF files in a workspace, run the command:

```
soxspipe list sof .
```

Then select an SOF file to target, and run the **reduce** command with the **sof** sub-command, for example:

```
soxspipe reduce sof 20260111T080805_VIS_1X1_1_NOD_OBJ_SLIT5_0_60_0S_SOXS_CD-325613.sof
```

As with reducing data with the `all` sub-command, if a recipe fails to create a required calibration product, the pipeline will attempt to pivot to use the next-best available product (as long as other calibration data is available in the workspace).

10.2 Running Individual Recipes

After reducing data with *the single **reduce** command*, a user may attempt to improve the pipeline’s default reductions by tailoring the settings for some or all of the recipes. The following sections explain how to adjust the pipeline settings and rerun the individual recipes.

10.2.1 soxs mbias

A zero-second exposure will contain only read-noise, and $\sim$ half of the pixels within this Gaussian distribution centred around zero counts will always contain negative flux. To avoid negative counts, an offset *bias* voltage is applied at the amplifier stage so that even when no photons are detected, the A/D converter will always register a positive value. This bias-voltage offset must be accounted for in the data reduction process.

The purpose of the `soxs_mbias` recipe is to provide a master-bias frame that can be subtracted from science/calibration frames to remove the contribution of pixel counts resulting from the bias voltage.

Usage

The `soxs_mbias` recipe can be run with the following convention:

```
soxspipe [-Vx] mbias <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
```

To rerun a previously executed `soxs_mbias` recipe, you can find the execution command at the end of the recipe log file (found in the workspace `products/soxs_mbias` directory). Use the `-x` flag to overwrite the product files if they already exist. For example, from the root of your workspace, you would run a command like:

```
soxspipe mbias sof/20251010T091927_VIS_1X1_1_MBIAS_SOXS.sof -s ./sessions/base/soxspipe.
→yaml -x
```

To adjust the default settings for the `soxs_mbias` recipe, open the `soxspipe.yaml` file referenced in the command above in a text editor, navigate to the `soxs_mbias` dictionary, save the file and rerun the recipe command. The settings' descriptions can be found in Table 5.

Product files are written in the `products/soxs_mbias`, and QC plots are in the `qc/soxs_mbias` workspace directory. A report of the product files, QC plots and metrics is also printed to the terminal. The QC metrics calculated for `soxs_mbias` are found in Table 8.

Reduction Tips

The `soxs_mbias` recipe is one of the simpler recipes, and therefore, it is typically very robust against failures. To reduce the time it takes to run the recipe (at the expense of allowing a few more outlying pixels into your master bias frame), you can experiment with reducing both `frame-clipping-iterations` and `stacked-clipping-iterations` (although speed gains will be very moderate).

Parameters

Table 5: The `soxs_mbias` recipe parameters.

Parameter	Description	Type	Entry Point	Related Util
<code>frame_clipping_sigma</code>	number of σ from the median <i>frame</i> flux beyond which pixel is added to the bad-pixel mask	float	settings file	<i>clip_and_stack</i>
<code>frame_clipping_--iterations</code>	number of σ -clipping iterations to perform when adding pixels to the bad-pixel mask	int	settings file	<i>clip_and_stack</i>
<code>stacked_clipping_--sigma</code>	number of σ deviations from the median <i>pixel</i> flux beyond which pixel is excluded from stack	float	settings file	<i>clip_and_stack</i>
<code>stacked_clipping_--iterations</code>	number of σ -clipping iterations to perform before stacking	int	settings file	<i>clip_and_stack</i>

Input

Table 6: Input files for the `soxs_mbias` recipe. The files are typically passed to the `soxs_mbias` recipe via a set-of-file (sof) file listing one file per line.

Data Type	Content	Related OB	Min. Frame Count
FITS images	raw bias frames (UV-VIS/AC exposures with exptime = 0)	SOXS_img_cal_Bias, gen_cal_VISBias	SOXS_- 5

Output

Table 7: Output files for the `soxs_mbias` recipe and their respective ESO PRO keywords.

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
MBIAS	Master bias frame (frame containing typical bias-voltage applied to the detector)	FITS image	MASTER_BIAS_- <ARM>	REDUCED	IMAGE

QC Metrics

Table 8: Quality Control metrics calculated in the `soxs_mbias` recipe.

Label	Description	Unit	Acceptable Range
BADPIX FRAC	Fraction of bad pixels	-	-
MBIAS MEDIAN	Median flux level of master bias	electrons	VIS: [0, 2000]
BADPIX NUM	Number of bad pixels	-	-
FPN FRACMAX	Maximum periodic pattern noise ratio in raw bias frames	-	VIS: [0,3]
RAW RON	RON in single BIAS	electrons	VIS: [0,15]
MASTER RON	Combined RON in MBIAS	electrons	VIS: [0,10]
STRUCTX	Slope of BIAS in X direction	-	VIS: [-3,1]
STRUCTY	Slope of BIAS in Y direction	-	VIS: [0.0,0.6]

10.2.2 soxs_mdark

Every raw CCD image contains counts resulting from a ‘dark current’, electrons released due to the thermal effects in the CCD material. For both the UVB-VIS ($< 0.00012 \text{ e}^-/\text{s/pixel}$) and NIR detectors ($< 0.005 \text{ e}^-/\text{s/pixel}$), the dark current is almost negligible. Not all pixels will have the same dark current, with some pixels having a higher-than-typical current. These are so-called ‘hot-pixels’, and these must be identified and recorded (using the `create_noise_map` utility).

The purpose of the `soxs_mdark` recipe is to generate a master-dark frame used to remove flux attributed to the dark current from other frames.

Usage

The `soxs_mdark` recipe can be run with the following convention:

```
soxspipe [-Vx] mdark <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
```

To rerun a previously executed `soxs_mdark` recipe, you can find the execution command at the end of the recipe log file (found in the workspace `products/soxs_mdark` directory). Use the `-x` flag to overwrite the product files if they already exist. For example, from the root of your workspace, you would run a command like:

```
soxspipe mdark sof/20260111T082924_NIR_3_MDARK_5_OS_SOXS.sof -s ./sessions/base/soxspipe.  
→yaml -x
```

To adjust the default settings for the `soxs_mdark` recipe, open the `soxspipe.yaml` file referenced in the command above in a text editor, navigate to the `soxs_mdark` dictionary, save the file and rerun the recipe command. The settings' descriptions can be found in Table 9.

Product files are written in the `products/soxs_mdark`, and QC plots are in the `qc/soxs_mdark` workspace directory. A report of the product files, QC plots and metrics is also printed to the terminal. The QC metrics calculated for `soxs_mdark` are found in Table 12.

Reduction Tips

As with `soxs_mbias`, the `soxs_mdark` recipe is one of the simpler recipes, and therefore, it is typically very robust against failures. To reduce the time it takes to run the recipe (at the expense of allowing a few more outlying pixels into your master bias frame), you can experiment with reducing both `frame-clipping-iterations` and `stacked-clipping-iterations` (although speed gains will be very moderate).

Parameters

Table 9: The `soxs_mdark` recipe parameters.

Parameter	Description	Type	Entry Point	Related Util
<code>frame_clipping_sigma</code>	number of σ from the median <i>frame</i> flux beyond which pixel is added to the bad-pixel mask	float	settings file	<i>clip_and_stack</i>
<code>frame_clipping_--iterations</code>	number of σ -clipping iterations to perform when adding pixels to the bad-pixel mask	int	settings file	<i>clip_and_stack</i>
<code>stacked_clipping_--sigma</code>	number of σ deviations from the median <i>pixel</i> flux beyond which pixel is excluded from stack	float	settings file	<i>clip_and_stack</i>
<code>stacked_clipping_--iterations</code>	number of σ -clipping iterations to perform before stacking	int	settings file	<i>clip_and_stack</i>

Input

Table 10: Input files for the `soxs_mdark` recipe. The files are typically passed to the `soxs_mdark` recipe via a set-of-file (sof) file listing one file per line.

Data Type	Content	Related OB	Min. Frame Count
FITS images	raw dark frames (exposures with identical exposure time and detectors readout parameters).	SOXS_gen_cal_VISDark, SOXS_gen_cal_NIRDark, SOXS_img_cal_Dark	3

Output

Table 11: Output files for the `soxs_mdark` recipe and their respective ESO PRO keywords.

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
MDARK	Master dark frame (frame containing typical dark-current flux accumulated over the exposure time of the input frames)	FITS image	DARK_<ARM>	REDUCED	IMAGE

QC Metrics

Table 12: Quality Control metrics calculated in the `soxs_mdark` recipe.

Label	Description	Unit	Acceptable Range
HOTPIX FRAC	Fraction of hot pixels	-	-
MDARK MEDIAN	Median flux level of master dark	electrons	NIR: [-15, 50]
HOTPIX NUM	Number of hot pixels	-	-
RAW RON	RON in single DARK	electrons	NIR: [0,30]

10.2.3 soxs_disp_solution

The `soxs_disp_solution` recipe generates a first-guess dispersion solution for the instrument (measured along the central trace for each echelle order).

Usage

The `soxs_disp_solution` recipe can be run with the following convention:

```
soxspipe [-Vx] disp_solution <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile> --poly=<od>]
```

To rerun a previously executed `soxs_disp_solution` recipe, you can find the execution command at the end of the recipe log file (found in the workspace `products/soxs_disp_solution` directory). Use the `-x` flag to overwrite the product files if they already exist. For example, from the root of your workspace, you would run a command like:

```
soxspipe disp_solution sof/20260111T095553_NIR_3_DSOL_PINHOLE_15_OS_SOXS.sof -s ./sessions/base/soxspipe.yaml -x
```

While the default polynomial fitting orders have been carefully tuned to robustly reduce most data, it is possible to execute this recipe while providing the dispersion-solution polynomial fitting orders through the command line, with command line settings overriding those in the YAML settings file. For instance, to attempt a dispersion solution fit using 3rd (x) and 4th-order (y) spectral-order (oo) component and a 5th-order (for both x and y) wavelength (ww) component:

```
soxspipe disp_solution sof/20260111T095553_NIR_3_DSOL_PINHOLE_15_OS_SOXS.sof -s ./sessions/base/soxspipe.yaml --poly=3455
```

To adjust the default settings for the `soxs_disp_solution` recipe, open the `soxspipe.yaml` file referenced in the command above in a text editor, navigate to the `soxs_disp_solution` dictionary, save the file and rerun the recipe command. The settings' descriptions can be found in Table 13.

Product files are written in the `products/soxs_disp_solution`, and QC plots are in the `qc/soxs_disp_solution` workspace directory. A report of the product files, QC plots and metrics is also printed to the terminal. The QC metrics calculated for `soxs_disp_solution` are found in `soxs_disp_solution_qc` and a typical QC plot in `soxs_disp_solution_qc_fig`.

Reduction Tips

If this recipe fails because a fit for the dispersion solution is not found, the first parameter to adjust is `poly-fitting-residual-clipping-sigma`. Try setting a value lower than the default value by 0.5 and running the recipe again. If the recipe still fails, repeat the reduction in steps of 0.5 down to 3 sigma.

You can also try adjusting the polynomial fitting orders in `order-deg`, `wavelength-deg` and `slit-deg`. However, please be advised the pipeline itself will dynamically adjust these values if they fail to fit the default set. It will slowly reduce the orders and refit until it finds a fit or decides a fit can not be found (after five iterations of decreasing the orders).

Parameters

Table 13: The `soxs_disp_solution` recipe parameters.

Parameter	Description	Type	Entry Point	Related Util
<code>pixel_window_size</code>	the size of the square window used to search for an arc-lamp emission line, centred on the predicted pixel position of the line	int	settings file	<code>create_dispersion_map</code>
<code>pinhole_detection_thresh_sigma</code>	minimum significance required for arc-line to be considered ‘detected’	float	settings file	<code>create_dispersion_map</code>
<code>order_deg</code>	degree of echelle order number component of global polynomial fit to the dispersion solution [x, y]	int/list	settings file or command-line	<code>create_dispersion_map</code>
<code>wavelength_deg</code>	degree of wavelength component of global polynomial fit to the dispersion solution [x, y]	int/list	settings file or command-line	<code>create_dispersion_map</code>
<code>poly_clipping_iteration_limit</code>	number of sigma-clipping iterations to perform before settling on a polynomial fit for the dispersion solution	int	settings file	<code>create_dispersion_map</code>
<code>poly_fitting_residual_clipping_sigma</code>	sigma clipping limit when fitting global polynomial to the dispersion solution	float	settings file	<code>create_dispersion_map</code>

Input

Table 14: Input files for the `soxs_disp_solution` recipe. The files are typically passed to the `soxs_disp_solution` recipe via a set-of-file (sof) file listing one file per line.

Data Type	Content	Related OB
FITS Image	Arc Lamp through single pinhole mask	SOXS_slt_cal_VISArcsPinhole, SOXS_slt_cal_NIRArcsPinhole
FITS Image	Master Dark Frame (VIS only, optional)	-
FITS Image	Master Bias Frame (VIS only)	-
FITS Image	Dark frame (Lamp-Off) of equal exposure length as single pinhole frame (Lamp-On) (NIR only)	SOXS_slt_cal_NIRArcsPinhole

Output

Table 15: Output files for the `soxs_disp_solution` recipe and their respective ESO PRO keywords.

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
DISP MAP	first pass dispersion solution	FITS Table	DISP_TAB_<ARM>	REDUCED	ECHELLE, PINHOLE
DISP MAP LINES	dispersion solution fitted lines	FITS Table	-	-	-
DISP MAP LINES MISSING	undetected arc lines	FITS Table	-	-	-
DISP MAP RES	dispersion solution QC plots	PDF	-	-	-

QC Metrics

Table 16: Quality Control metrics calculated in the `soxs_disp_solution` recipe.

Label	Description	Unit	Acceptable Range
DETLINES CLIP NUM	Total number of detected lines clipped during solution fitting	lines	-
DETLINES NUM	Number of lines detected in single pinhole frame	lines	-
DETLINES FRAC	Proportion of input line-list lines detected on single pinhole frame		VIS: [0.9,1.0], NIR: [0.9,1.0]
DETLINES TOT	Total number of line in single line-list	lines	-
GOODLINES FRAC	Proportion of good, unclipped lines in single pinhole frame	lines	-

continues on next page

Table 16 – continued from previous page

Label	Description	Unit	Acceptable Range
X RES MAX	Maximum residual in fitting of pinholes along x-axis (global)	pixels	-
X RES MIN	Minimum residual in fitting of pinholes along x-axis (global)	pixels	-
X RES MEDIAN	Median of absolute residuals in fitting of pinholes along x-axis (global)	pixels	VIS: [0.0,0.15], NIR: [0.0,0.35]
X RES SD	Std-dev of residuals in fitting of pinholes along x-axis (global)	pixels	VIS: [0,0.4], NIR: [0,1.0]
Y RES MAX	Maximum residual in fitting of pinholes along y-axis (global)	pixels	-
Y RES MIN	Minimum residual in fitting of pinholes along y-axis (global)	pixels	-
Y RES MEDIAN	Median of absolute residuals in fitting of pinholes along y-axis (global)	pixels	VIS: [0.0,0.9], NIR: [0.0,0.13]
Y RES SD	Std-dev of residuals in fitting of pinholes along y-axis (global)	pixels	VIS: [0,1.2], NIR: [0,0.25]
XY RES MAX	Maximum residual in fitting of pinholes (global)	pixels	-
XY RES MIN	Minimum residual in fitting of pinholes (global)	pixels	-
XY RES MEDIAN	Median residual in fitting of pinholes (global)	pixels	NIR: [0,1.0]
XY RES SD	Std-dev of residuals in fitting of pinholes (global)	pixels	VIS: [0,1.5], NIR: [0,1.0]
X DIFF MEDIAN	Median difference between observed and predicted pinhole detector locations along the x-axis (global)	pixels	-
X DIFF SD	Std-dev in difference between observed and predicted pinhole detector locations along the x-axis (global)	pixels	VIS: [0,3.0], NIR: [0,1.3]
Y DIFF MEDIAN	Median difference between observed and predicted pinhole detector locations along the y-axis (global)	pixels	-
Y DIFF SD	Std-dev in difference between observed and predicted pinhole detector locations along the y-axis (global)	pixels	VIS: [0,10.0], NIR: [0,1.5]
XY DIFF MEDIAN	Median difference between observed and predicted pinhole detector locations (global)	pixels	NIR: [0,6.0]
XY DIFF SD	Std-dev of difference between observed and predicted pinhole detector locations (global)	pixels	NIR: [0,1.9]
FWHM PIN MEDIAN	Median FWHM of detected lines in pinhole frames (global)	pixels	VIS: [1.60,1.75], NIR: [1.75,1.89]
FWHM PIN SD	Std-dev in FWHM of detected lines in pinhole frames (global)	pixels	VIS: [0.1,0.2], NIR: [0,0.211]
R PIN MEDIAN	Median spectral resolution measured from detected lines in pinhole frames (global)		-

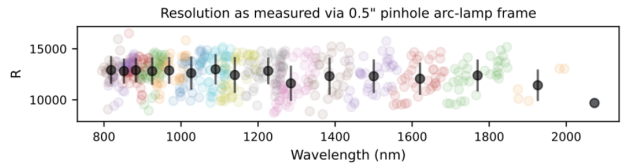
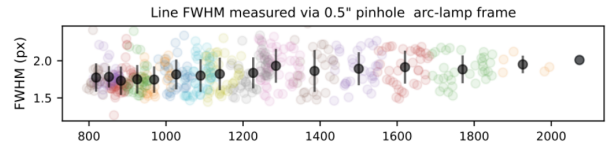
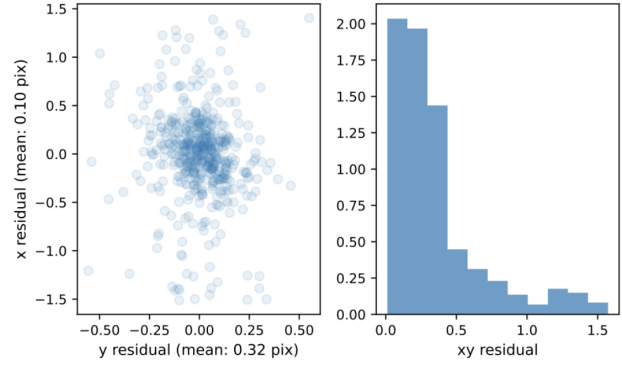
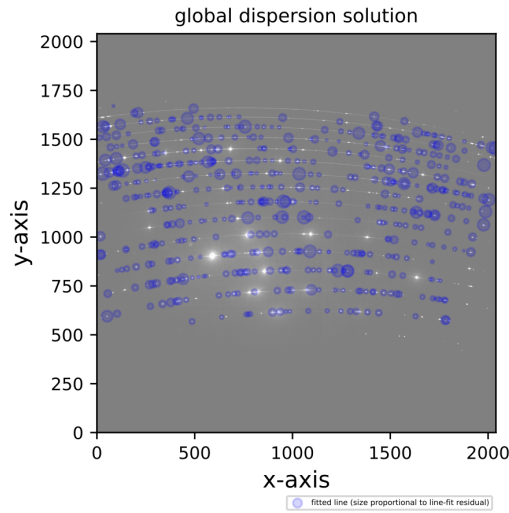
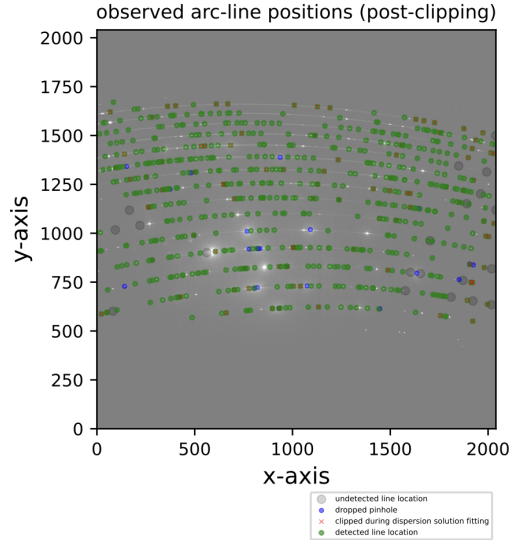
continues on next page

Table 16 – continued from previous page

Label	Description	Unit	Acceptable Range
X RES MAX O<N>	Maximum residual in fitting of pinholes along x-axis (order N)	pixels	-
X RES MIN O<N>	Minimum residual in fitting of pinholes along x-axis (order N)	pixels	-
X RES MEDIAN O<N>	Median of absolute residuals in fitting of pinholes along x-axis (order N)	pixels	-
X RES SD O<N>	Std-dev of residuals in fitting of pinholes along x-axis (order N)	pixels	-
Y RES MAX O<N>	Maximum residual in fitting of pinholes along y-axis (order N)	pixels	-
Y RES MIN O<N>	Minimum residual in fitting of pinholes along y-axis (order N)	pixels	-
Y RES MEDIAN O<N>	Median of absolute residuals in fitting of pinholes along y-axis (order N)	pixels	-
Y RES SD O<N>	Std-dev of residuals in fitting of pinholes along y-axis (order N)	pixels	-
XY RES MAX O<N>	Maximum residual in fitting of pinholes (order N)	pixels	-
XY RES MIN O<N>	Minimum residual in fitting of pinholes (order N)	pixels	-
XY RES SD O<N>	Std-dev of residuals in fitting of pinholes along (order N)	pixels	-
X DIFF MEDIAN O<N>	Median difference between observed and predicted pinhole detector locations along the x-axis (order N)	pixels	-
X DIFF SD O<N>	Std-dev in difference between observed and predicted pinhole detector locations along the x-axis (order N)	pixels	-
Y DIFF MEDIAN O<N>	Median difference between observed and predicted pinhole detector locations along the y-axis (order N)	pixels	-
Y DIFF SD O<N>	Std-dev in difference between observed and predicted pinhole detector locations along the y-axis (order N)	pixels	-
XY DIFF MEDIAN O<N>	Median difference between observed and predicted pinhole detector locations (order N)	pixels	-
FWHM PIN MEDIAN O<N>	Median FWHM of detected lines in pinhole frames (order N)	pixels	-
FWHM PIN SD O<N>	Std-dev in FWHM of detected lines in pinhole frames (order N)	pixels	-
R PIN MEDIAN O<N>	Median spectral resolution measured from detected lines in pinhole frames (order N)		-

The typical solution for the `soxs_disp_solution` recipe has sub-pixel residuals.

residuals of global dispersion solution fitting - NIR single pinhole
mean res: 0.35 pix, res stdev: 0.33



value	qc_comment	value
TLINE 637 lines	Total number of line in single line-list	pixel-window-size 10
NLINE 637 lines	Number of lines detected in single pinhole frame	pinhole-detection-thres-sigma 5
PLINE 0.969559	Proportion of input line-list lines detected on single pinhole frame	order-deg [5, 3]
CLINE 118 lines	Total number of detected lines clipped during solution fitting	wavelength-deg [4, 5]
		poly-fitting-residual-clipping-sigma 7
		poly-clipping-iteration-limit 7
		exptime 15.0

Figure 24: A QC plot resulting from the `soxs_disp_solution` recipe as run on a SOXS NIR single pinhole arc lamp frame. A ‘good’ dispersion solution will have sub-pixel residuals (mean residuals < 0.5 pixels). The top-left panel shows an SOXS NIR arc-lamp frame, taken with a single pinhole mask. The green circles represent arc lines detected in the image, and the blue circles and red crosses were detected but dropped due to poor DAOSTarFinder fitting or clipped during the polynomial fitting, respectively. The grey circles represent arc lines reported in the static calibration table that were not detected in the image. The bottom-left panel shows the same arc-lamp frame with the dispersion solution overlaid at the pixel locations modelled for the original lines in the line list. The top-right panels show the residuals of the dispersion solution fit, and the final panels (bottom-right) the resolution measured for each line (as projected through the pinhole mask) with different colours for each echelle order and the mean order resolution in black.

10.2.4 soxs_order_centres

Starting with the first pass dispersion solution from the `soxs_disp_solution` recipe, the `soxs_order_centres` recipe finds and fits a global polynomial model to the central trace of each echelle order.

Usage

The `soxs_order_centres` recipe can be run with the following convention:

```
soxspipe [-Vx] order_centres <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile> --
↳poly=<ooww>]
```

To rerun a previously executed `soxs_order_centres` recipe, you can find the execution command at the end of the recipe log file (found in the workspace `products/soxs_order_centres` directory). Use the `-x` flag to overwrite the product files if they already exist. For example, from the root of your workspace, you would run a command like:

```
soxspipe order_centres sof/20251011T094554_VIS_1X1_1_OLOC_QTH_PINHOLE_10_OS_SOXS.sof -s ./
↳sessions/base/soxspipe.yaml
```

While the default polynomial fitting orders have been carefully tuned to robustly reduce most data, it is possible to execute this recipe while providing the order-trace polynomial fitting orders through the command line, with command line settings overriding those in the YAML settings file. For instance, to attempt a order trace fit using 3rd (x) and 6th-order (y) spectral-order (oo) component and a 4th-order (x) and 3rd-order (y) wavelength (ww) component:

```
soxspipe order_centres sof/20251011T094554_VIS_1X1_1_OLOC_QTH_PINHOLE_10_OS_SOXS.sof -s ./
↳sessions/base/soxspipe.yaml --poly=3643
```

To adjust the default settings for the `soxs_order_centres` recipe, open the `soxspipe.yaml` file referenced in the command above in a text editor, navigate to the `soxs_order_centres` dictionary, save the file and rerun the recipe command. The settings' descriptions can be found in Table 17.

Product files are written in the `products/soxs_order_centres`, and QC plots are in the `qc/soxs_order_centres` workspace directory. A report of the product files, QC plots and metrics is also printed to the terminal. The QC metrics calculated for `soxs_order_centres` are found in `soxs_order_centres_qc` and a typical QC plot in `soxs_order_centres_qc_fig`.

Reduction Tips

If this recipe fails the order centre traces, the first parameter to adjust is `poly-fitting-residual-clipping-sigma`. Try reducing this to 3-5 sigma and rerun the recipe to see if a fit is found. If the fit still fails, next try and increase the `slice-width` to 5-9 pixels to give the code a better chance of detecting the trace.

You can also try adjusting the polynomial fitting orders in `order-deg` and `disp-axis-deg`. However, please be advised the pipeline itself will dynamically adjust these values if they fail to fit the default set. It will slowly reduce the orders and refit until it finds a fit or decides a fit can not be found (after five iterations of decreasing the orders).

Parameters

Table 17: The `soxs_order_centres` recipe parameters.

Parameter	Description	Type	Entry Point	Related Util
<code>order_sample_count</code>	number of cross-order slices per order	int	settings file	<i>detect_continuum_utility</i>
<code>slice_length</code>	length of each slice (pixels)	int	settings file	<i>detect_continuum_utility</i>
<code>slice_width</code>	width of each slice (pixels)	int	settings file	<i>detect_continuum_utility</i>
<code>peak_sigma_limit</code>	height gaussian peak must be above median flux to be “detected” by code (std via median absolute deviation).	float	settings file	<i>detect_continuum_utility</i>
<code>disp_axis_deg</code>	degree of y-component of global polynomial fit to order centres	int	settings file or command-line	<i>detect_continuum_utility</i>
<code>order_deg</code>	degree of echelle order number component of global polynomial fit to order centres	int	settings file or command-line	<i>detect_continuum_utility</i>
<code>poly_fitting_residual_clipping_sigma</code>	sigma clipping limit when fitting global polynomial to order centres	float	settings file	<i>detect_continuum_utility</i>
<code>poly_clipping_iteration_limit</code>	maximum number of clipping iterations when fitting global polynomial to order centres	int	settings file	<i>detect_continuum_utility</i>

Input

Table 18: Input files for the `soxs_order_centres` recipe. The files are typically passed to the `soxs_order_centres` recipe via a set-of-file (sof) file listing one file per line.

Data Type	Content	Related OB
FITS Image	Flat lamp through a single-pinhole mask	SOXS_slt_cal_VISLampFlatPinhole, SOXS_slt_cal_NIRLampFlatPinhole
FITS Image	Master Dark Frame (VIS only, optional)	-
FITS Image	Master Bias Frame (VIS only)	-
FITS Image	Dark frame (Lamp-Off) of equal exposure length as single-pinhole frame (Lamp-On) (NIR only)	SOXS_slt_cal_NIRLampFlatPinhole
FITS Table	First guess dispersion solution	-

Output

Table 19: Output files for the `soxs_order_centres` recipe and their respective ESO PRO keywords.

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
ORDER CENTRES	Polynomial fits to the order centre traces	FITS	ORDER_TAB_<ARM>	REDUCED	ECHELLE, SLIT
ORDER CENTRES RES	Residuals of the order centre polynomial fit	PDF	-	-	-

QC Metrics

Table 20: Quality Control metrics calculated in the `soxs_order_centres` recipe.

Label	Description	Unit	Acceptable Range
N ORDERS	Number of order centre traces found		-
SAMPLES DET NUM	Number of samples where a continuum is detected		-
SAMPLES DET FRAC	Fraction of samples where a continuum is detected		VIS: [0.85,1.0], NIR: [0.80,1.0]
SAMPLES TOT NUM	Total number of samples along orders		-
SAMPLES CLIP NUM	Number of continuum sample clipped during solution fitting		-
SAMPLES CLIP FRAC	Fraction of detected continuum samples clipped during solution fitting		-
X RES MAX	Maximum residual in order centre fit along x-axis	px	-
X RES MIN	Minimum residual in order centre fit along x-axis	px	-
X RES SD	Std-dev of residual order centre fit along x-axis		VIS: [0,0.1]
Y RES MAX	Maximum residual in order centre fit along y-axis	px	-
Y RES MIN	Minimum residual in order centre fit along y-axis	px	-
Y RES SD	Std-dev of residual order centre fit along y-axis		NIR: [0,0.1]

Plots similar to the one below are generated after each execution of `soxs_order_centres`. The residuals of a ‘good’ fit typically have a mean and standard deviation of $<0.2\text{px}$.

10.2.5 soxs_mflat

The `soxs_mflat` recipe creates a single normalised master-flat frame used to correct for non-uniformity in response to light across the detector plane. Hot and dead pixels are also detected and added to a bad-pixel mask. Finally, the echelle order edges are detected and fitted with a polynomial model.

traces of order-centre locations - NIR Qth lamp pinhole flat-frame
mean res: 0.09 pix, res stdev: 0.14

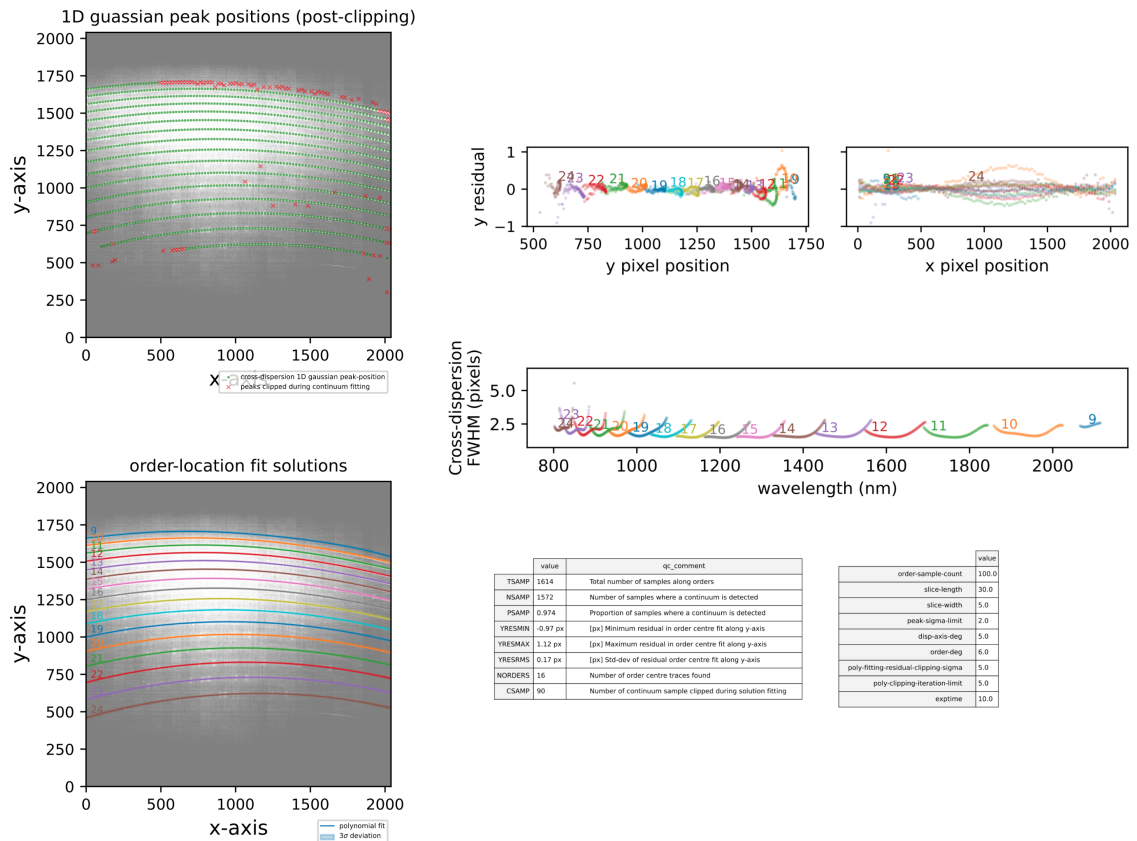


Figure 25: A QC plot resulting from the `soxs_order_centres` recipe as run on a SOXS NIR single pinhole QTH flat lamp frame. The top-left panel shows the frame with green circles representing the locations on the cross-dispersion slices where a flux peak was detected. The red crosses indicate the centres of the slices where a peak was not detected. The bottom-left panel shows the global polynomial fitted to the detected order-centre trace with the different colours representing individual echelle orders. The top-right panels show the fit residuals in the X and Y axes. The bottom-right panel shows the FWHM of the trace fits (in pixels) as a function of echelle order and wavelength.

Sources of this non-uniformity include: Varying pixel sensitivities. Obstructions in the optical path (e.g., dust or pollen grains). Vignetting at the edges of the detector. A flat frame is ideally an image taken with uniform illumination across the detector's light-collecting pixels. This evenly exposed image can be used to identify irregularities in the detector's response.

Usage

The `soxs_mflat` recipe can be run with the following convention:

```
soxspipe [-Vx] mflat <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
```

To rerun a previously executed `soxs_mflat` recipe, you can find the execution command at the end of the recipe log file (found in the workspace `products/soxs_mflat` directory). Use the `-x` flag to overwrite the product files if they already exist. For example, from the root of your workspace, you would run a command like:

```
soxspipe mflat sof/20251012T111444_VIS_2X2_3_MFLAT_QTH_SLIT0_5_20_OS_SOXS.sof -s ./
↳sessions/base/soxspipe.yaml -x
```

To adjust the default settings for the `soxs_mflat` recipe, open the `soxspipe.yaml` file referenced in the command above in a text editor, navigate to the `soxs_mflat` dictionary, save the file and rerun the recipe command. The settings' descriptions can be found in Table 21.

Product files are written in the `products/soxs_mflat`, and QC plots are in the `qc/soxs_mflat` workspace directory. A report of the product files, QC plots and metrics is also printed to the terminal. The QC metrics calculated for `soxs_mflat` are found in `soxs_mflat_qc` and a typical QC plot in `soxs_mflat_qc_fig`.

Reduction Tips

If this recipe fails during the fitting of the order edge, the first parameter to adjust is `poly-fitting-residual-clipping-sigma`. Try reducing this to 3-5 sigma and rerun the recipe to see if a fit is found. If the fit still fails, next try and increase the `slice-width-for-edge-detection` to 5-9 pixels to give the code a better chance of detecting the order-edges.

If the previous adjustments have not helped, you can slowly reduce `min-percentage-threshold-for-edge-detection` and/or increase `max-percentage-threshold-for-edge-detection` by 2-3 percent and attempt a refit.

You can also try adjusting the polynomial fitting orders in `order-deg` and `disp-axis-deg`. However, please be advised the pipeline itself will dynamically adjust these values if they fail to fit the default set. It will slowly reduce the orders and refit until it finds a fit or decides a fit can not be found (after five iterations of decreasing the orders).

Parameters

Table 21: The `soxs_mflat` recipe parameters.

Parameter	Description	Type	Entry Point	Related Util
<code>subtract_background</code>	fit and subtract the intra-order background light	bool	settings file	<code>subtract_background</code>
<code>stacked_clipping_sigma</code>	the sigma clipping limit used when stacking frames into a composite frame	float	settings file	<code>clip_and_stack</code>
<code>stacked_clipping_iterations</code>	the maximum sigma-clipping iterations used when stacking frames into a composite frame	int	settings file	<code>clip_and_stack</code>

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Table 21 – continued from previous page

Parameter	Description	Type	Entry Point	Related Util
centre_order_window	size of the window (in pixels) used to measure flux in the central band to determine median exposure	int	settings file	-
slice_length_for_- edge_detection	length of the cross_dispersion slices used to determine order edges	int	settings file	<i>detect_order_- edges</i>
slice_width_for_- edge_detection	width of the cross_dispersion slices used to determine order edges	int	settings file	<i>detect_order_- edges</i>
min_percentage_- threshold_for_edge_- detection	minimum value flux can drop to as percentage of central flux and be counted as an order edge	int	settings file	<i>detect_order_- edges</i>
max_percentage_- threshold_for_edge_- detection	maximum value flux can climb to as percentage of central flux and be counted as an order edge	int	settings file	<i>detect_order_- edges</i>
disp_axis_deg	degree of y-component of global polynomial fit to order edges	int	settings file or command- line	<i>detect_order_- edges</i>
order_deg	degree of echelle order number component of global polynomial fit to order edges	int	settings file or command- line	<i>detect_order_- edges</i>
poly_fitting_- residual_clipping_- sigma	sigma clipping limit when fitting global polynomial to order edges	float	settings file	<i>detect_order_- edges</i>
poly_clipping_- iteration_limit	maximum number of clipping iterations when fitting global polynomial to order edges	int	settings file	<i>detect_order_- edges</i>
low_sensitivity_- clipping_sigma	pixels with a flux less than this many sigma (mad) below the median flux level added to the bp map	float	settings file	-
scale_d2_to_qth	scale d2 to qth lamp flats when stitching	bool	settings file	-
background_- subtraction: bspline_deg	degree of bsplines used to fit the inter-order background (if subtract_background == True)	int	settings file	<i>subtract_- background</i>
background_- subtraction: gaussian_blur_sigma	Standard deviation of Gaussian kernel used to smooth background image (if subtract_background == True)	int	settings file	<i>subtract_- background</i>

Input

Table 22: Input files for the `soxs_mflat` recipe. The files are typically passed to the `soxs_mflat` recipe via a set-of-file (sof) file listing one file per line.

Data Type	Content	Related OB	Min. Frame Count
FITS image	Raw flats frames (exposures with identical exposure time, slit-width and detectors readout parameters).	SOXS_slit_cal_NIRLampFlat, SOXS_slit_cal_NIRLampFlatAtt, SOXS_slit_cal_VISLampFlat, SOXS_slit_cal_VISLampFlatAtt	5
FITS Image	A master bias Frame (UV-VIS only)	-	-
FITS Image	A master dark frame or lamp-off frames with identical exposure times to the lamp-on flat frames (NIR only)	-	-
FITS Table	An order location table containing coefficients to the polynomial fit describing the order centre locations.	-	-

Output

Table 23: Output files for the `soxs_mflat` recipe and their respective ESO PRO keywords (NIR and VIS).

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
ORDER LOC	table of coefficients from polynomial fits to order locations	FITS	ORDER_TAB_<ARM>	REDUCED	ECHELLE, SLIT
MFLAT	master spectroscopic flat frame	FITS	MASTER_FLAT_-<ARM>	REDUCED	IMAGE
ORDER LOC RES	visualisation of goodness of order edge fitting	PDF	-	-	-
BKGROUND	Fitted intra-order image background	PDF	-	-	-

Table 24: Output files for the `soxs_mflat` recipe for Xshooter UVB arm.

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
ORDER LOC DLAMP	table of coefficients from polynomial fits to order locations	FITS	ORDER_TAB_<ARM>	REDUCED	ECHELLE, SLIT
MFLAT DLAMP	UVB master spectroscopic flat frame (DLAMP)	FITS	MASTER_FLAT_-<ARM>	REDUCED	IMAGE
ORDER LOC QLAMP	table of coefficients from polynomial fits to order locations	FITS	ORDER_TAB_<ARM>	REDUCED	ECHELLE, SLIT
MFLAT QLAMP	UVB master spectroscopic flat frame (QLAMP)	FITS	MASTER_FLAT_-<ARM>	REDUCED	IMAGE
ORDER LOC	table of coefficients from polynomial fits to order locations	FITS	ORDER_TAB_<ARM>	REDUCED	ECHELLE, SLIT
MFLAT	UVB master spectroscopic flat frame	FITS	MASTER_FLAT_-<ARM>	REDUCED	IMAGE
ORDER LOC RES DLAMP	visualisation of goodness of order edge fitting	PDF	-	-	-
BKGROUND DLAMP	Fitted intra-order image back-ground DLAMP	PDF	-	-	-
ORDER LOC RES QLAMP	visualisation of goodness of order edge fitting	PDF	-	-	-
BKGROUND QLAMP	Fitted intra-order image back-ground QLAMP	PDF	-	-	-
ORDER LOC RES	visualisation of goodness of order edge fitting	PDF	-	-	-

QC Metrics

Table 25: Quality Control metrics calculated in the `soxs_mflat` recipe.

Label	Description	Unit	Acceptable Range
COLDPIX FRAC	Fraction of colf pixels		-
INNER ORDER PIX MEAN	Mean inner-order pixel value	elec- trons	VIS: [0.9,1.1], NIR: [0.9,1.1]
INNER ORDER PIX SUM	Sum of all inner-order pixel values	elec- trons	VIS: [100000,700000], NIR: [1000000,1200000]
COLDPIX NUM	Number of cold pixels		VIS: [0.0,0.01], NIR: [0.0,0.01]
N LOW SENS	Number of low-sensitivity pixels found in master flat	pixels	-
ORDEXP10	10th percentile inter-order flux	elec- trons	-
ORDEXP50	50th percentile inter-order flux	elec- trons	-
ORDEXP90	90th percentile inter-order flux	elec- trons	VIS: [10000,150000], NIR: [30000,60000]
X RES MAX	Maximum residual in order edge fit along x-axis	pixels	-
X RES MIN	Minimum residual in order edge fit along x-axis	pixels	-
X RES SD	Std-dev of residual order edge fit along x-axis	pixels	VIS: [0,0.37], NIR: [0,0.2]

10.2.6 soxs_spatial_solution

The `soxs_spatial_solution` recipe enhances the wavelength solution achieved with `soxs_disp_solution` by expanding the solution into the spatial dimension (along the slit). The resulting 2-dimensional solution accounts for any tilt in the spectral lines relative to the cross-dispersion axis. The recipe is similar in logic to `soxs_disp_solution`, but now samples arc lines along the slit in the cross-dispersion direction using a multi-pinhole slit mask.

Usage

The `soxs_spatial_solution` recipe can be run with the following convention:

```
soxspipe [-Vx] spat_solution <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile> --  
↪poly=<oowwss>]
```

To rerun a previously executed `soxs_spatial_solution` recipe, you can find the execution command at the end of the recipe log file (found in the workspace `products/soxs_spatial_solution` directory). Use the `-x` flag to overwrite the product files if they already exist. For example, from the root of your workspace, you would run a command like:

```
soxspipe spat_solution sof/20260111T095625_NIR_3_SSOL_MULTPIN_15_OS_SOXS.sof -s ./sessions/  
↪base/soxspipe.yaml -x
```

While the default polynomial fitting orders have been carefully tuned to robustly reduce most data, it is possible to execute this recipe while providing the dispersion-solution polynomial fitting orders through the command line, with command line settings overriding those in the YAML settings file. For instance, to attempt a dispersion solution fit using 3rd (x) and 4th-order (y) spectral-order (oo) component, a 5th-order (for both x and y) wavelength (ww) component, and a 2nd (x) and 4th-order (y) slit-position component (ss):

detection of order-edge locations - NIR SLIT1.0" flat-frame
mean res: 0.07 pix, res stdev: 0.06

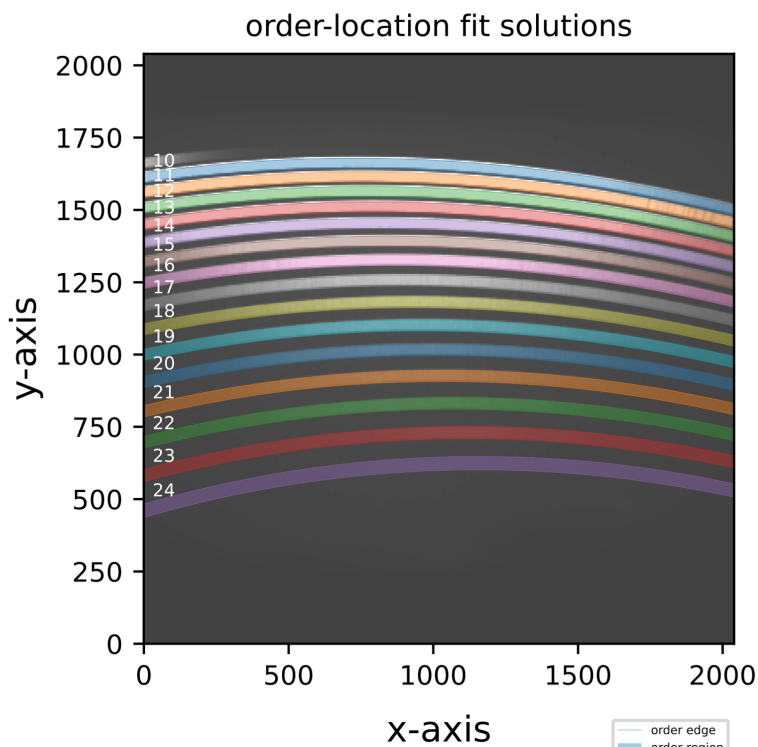
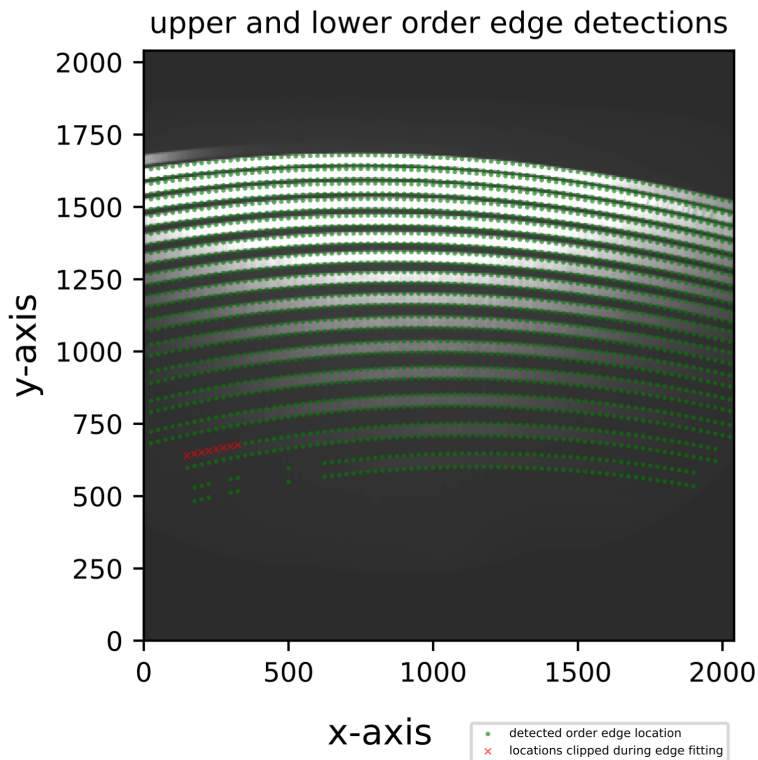


Figure 26: A QC plot resulting from the `soxs_mflat` recipe (SOXS NIR). The top panel shows the upper and lower-order edge detections registered in the individual cross-dispersion slices in a SOXS NIR flat frame. The bottom panel shows the global polynomial fits to the upper and lower-order edges, with the area between the fits filled with different colours to reveal the unique echelle orders across the detector plane.

```
soxspipe spat_solution sof/20260111T095625_NIR_3_SSOL_MULTPIN_15_OS_SOXS.sof -s ./sessions/
↳base/soxspipe.yaml --poly=345524
```

To adjust the default settings for the `soxs_spatial_solution` recipe, open the `soxspipe.yaml` file referenced in the command above in a text editor, navigate to the `soxs_spatial_solution` dictionary, save the file and rerun the recipe command. The settings' descriptions can be found in Table 26.

Product files are written in the `products/soxs_spatial_solution`, and QC plots are in the `qc/soxs_spatial_solution` workspace directory. A report of the product files, QC plots and metrics is also printed to the terminal. The QC metrics calculated for `soxs_spatial_solution` are found in `soxs_spatial_solution_qc` and a typical QC plot in `soxs_spatial_solution_qc_fig`.

Reduction Tips

If this recipe fails because a fit for the dispersion solution is not found, the first parameter to adjust is `poly-fitting-residual-clipping-sigma`. Try setting a value lower than the default value by 0.5 and running the recipe again. If the recipe still fails, repeat the reduction in steps of 0.5 down to 3 sigma.

You can also try adjusting the polynomial fitting orders in `order-deg` and `wavelength-deg`. However, please be advised the pipeline itself will dynamically adjust these values if they fail to fit the default set. It will slowly reduce the orders and refit until it finds a fit or decides a fit can not be found (after five iterations of decreasing the orders).

Parameters

Table 26: The `soxs_spatial_solution` recipe parameters.

Parameter	Description	Type	Entry Point	Related Util
<code>use_flat</code>	divide image by master flat frame	bool	settings	-
<code>subtract_background</code>	fit and subtract the intra-order background light	bool	settings	<code>subtract_background</code>
<code>pixel_window_size</code>	the size of the square window used to search for an arc-lamp emission line, centred on the predicted pixel position of the line	int	settings	<code>create_dispersion_map</code>
<code>pinhole_detection_thresh_sigma</code>	minimum significance required for arc-line to be considered 'detected'	float	settings	<code>create_dispersion_map</code>
<code>order_deg</code>	degree of echelle order number component of global polynomial fit to the dispersion solution [x, y]	int/list	settings file or command-line	<code>create_dispersion_map</code>
<code>wavelength_deg</code>	degree of wavelength component of global polynomial fit to the dispersion solution [x, y]	int/list	settings file or command-line	<code>create_dispersion_map</code>
<code>slit_deg</code>	degree of slit position component of global polynomial fit to the dispersion solution [x, y]	int/list	settings file or command-line	<code>create_dispersion_map</code>

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Table 26 – continued from previous page

Parameter	Description	Type	Entry Point	Related Util
<code>poly_clipping_iteration_limit</code>	number of sigma-clipping iterations to perform before settings on a polynomial fit for the dispersion solution	int	settings	<code>create_dispersion_map</code>
<code>poly_fitting_residual_clipping_sigma</code>	sigma clipping limit when fitting global polynomial to the dispersion solution	float	settings	<code>create_dispersion_map</code>
<code>poly_clipping_pinhole_sets</code>	clipping performed on multi-pinhole sets (true) or individual pinholes (false)	bool	settings	<code>create_dispersion_map</code>
<code>map_to_image_displacement_threshold</code>	maximum distance allowed from the pixel centre when calculating wavelength, order and slit-position for 2d disp-sol image	float	settings	<code>create_dispersion_map</code>
<code>mph_line_set_min</code>	full multi-pinhole sets (same arc line) with fewer than <code>mph_line_set_min</code> lines detected get clipped	int	settings	<code>create_dispersion_map</code>
<code>background_subtraction: bspline_deg</code>	degree of bsplines used to fit the inter-order background (if <code>subtract_background == True</code>)	int	settings file	<code>subtract_background</code>
<code>background_subtraction: gaussian_blur_sigma</code>	Standard deviation of Gaussian kernel used to smooth background image (if <code>subtract_background == True</code>)	int	settings file	<code>subtract_background</code>

Input

Table 27: Input files for the `soxs_spatial_solution` recipe. The files are typically passed to the `soxs_spatial_solution` recipe via a set-of-file (sof) file listing one file per line.

Data Type	Content	Related OB
FITS Image	Arc Lamp through multi-pinhole mask	<code>SOXS_slit_cal_VISArcsMultiplePinhole</code> , <code>SOXS_slit_cal_NIRArcsMultiplePinhole</code>
FITS Image	Master Dark Frame (VIS only, optional)	-
FITS Image	Master Bias Frame (VIS only)	-
FITS Image	Master Flat Frame (optional)	-
FITS Image	Dark frame (Lamp-Off) of equal exposure length as multi-pinhole frame (Lamp-On) (NIR only)	<code>SOXS_slit_cal_NIRArcsMultiplePinhole</code>
FITS Table	First-guess Dispersion map table	

Output

Table 28: Output files for the `soxs_spatial_solution` recipe and their respective ESO PRO keywords.

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
SPAT SOL	Full dispersion-spatial solution	FITS	DISP_TAB_<ARM>	REDUCED	ECHELLE, MULTI-PINHOLE
2D MAP	2D detector map of wavelength, slit position and order	FITS	DISP_IMAGE_<ARM>	REDUCED	ECHELLE, MULTI-PINHOLE
BKGROUND	Fitted intra-order image background	PDF	-	-	-
DISP MAP LINES	Dispersion solution fitted lines	FITS	-	-	-
DISP MAP LINES MISSING	Undetected arc lines	FITS	-	-	-
DISP MAP RES	Dispersion solution QC plots	PDF	-	-	-

QC Metrics

Table 29: Quality Control metrics calculated in the `soxs_spatial_solution` recipe.

Label	Description	Unit	Acceptable Range
DETLINES CLIP NUM	Total number of detected lines clipped during solution fitting	lines	-
DETLINES NUM	Number of lines detected in single pinhole frame	lines	-
DETLINES FRAC	Proportion of input line-list lines detected on single pinhole frame		VIS: [0.95,1.0]
DETLINES TOT	Total number of line in single line-list	lines	-
GOODLINES FRAC	Proportion of good, unclipped lines in single pinhole frame	lines	VIS: [0.55,1.0] NIR: [0.4,1.0]
PINHOLE COUNT MIN	The minimum number of pinholes found across all orders (should be 9)	pinholes	VIS: 9, NIR: 9
X RES MAX	Maximum residual in fitting of pinholes along x-axis (global)	pixels	-
X RES MIN	Minimum residual in fitting of pinholes along x-axis (global)	pixels	-
X RES MEDIAN	Median of absolute residuals in fitting of pinholes along x-axis (global)	pixels	-
X RES SD	Std-dev of residuals in fitting of pinholes along x-axis (global)	pixels	VIS: [0,0.25], NIR: [0,0.42]
Y RES MAX	Maximum residual in fitting of pinholes along y-axis (global)	pixels	-

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Table 29 – continued from previous page

Label	Description	Unit	Acceptable Range
Y RES MIN	Minimum residual in fitting of pinholes along y-axis (global)	pixels	-
Y RES MEDIAN	Median of absolute residuals in fitting of pinholes along y-axis (global)	pixels	-
Y RES SD	Std-dev of residuals in fitting of pinholes along y-axis (global)	pixels	VIS: [0,0.48], NIR: [0,0.12]
XY RES MAX	Maximum residual in fitting of pinholes (global)	pixels	-
XY RES MIN	Minimum residual in fitting of pinholes (global)	pixels	-
XY RES MEDIAN	Median residual in fitting of pinholes (global)	pixels	VIS: [0,0.7], NIR: [0,0.3]
XY RES SD	Std-dev of residuals in fitting of pinholes (global)	pixels	VIS: [0,0.5], NIR: [0,0.4]
X DIFF MEDIAN	Median difference between observed and predicted pinhole detector locations along the x-axis (global)	pixels	-
X DIFF SD	Standard deviation in difference between observed and predicted pinhole detector locations along the x-axis (global)	pixels	-
Y DIFF MEDIAN	SMedian difference between observed and predicted pinhole detector locations along the y-axis (global)	pixels	-
Y DIFF SD	Standard deviation in difference between observed and predicted pinhole detector locations along the y-axis (global)	pixels	-
XY DIFF MEDIAN	Median difference between observed and predicted pinhole detector locations (global)	pixels	-
XY DIFF SD	Standard deviation of difference between observed and predicted pinhole detector locations (global)	pixels	-
FWHM PIN MEDIAN	Median FWHM of detected lines in pinhole frames (global)	pixels	VIS: [1.60,1.72], NIR: [1.55,1.85]
FWHM PIN SD	Standard deviation in FWHM of detected lines in pinhole frames (global)	pixels	VIS: [0.0,0.16], NIR: [0.0,0.145]
R PIN MEDIAN	Median spectral resolution measured from detected lines in pinhole frames (global)		-
X RES MAX 0<N>	Maximum residual in fitting of pinholes along x-axis (order N)	pixels	-
X RES MIN 0<N>	Minimum residual in fitting of pinholes along x-axis (order N)	pixels	-
X RES MEDIAN 0<N>	Median of absolute residuals in fitting of pinholes along x-axis (order N)	pixels	-
X RES SD 0<N>	Std-dev of residuals in fitting of pinholes along x-axis (order N)	pixels	-

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Table 29 – continued from previous page

Label	Description	Unit	Acceptable Range
Y RES MAX O<N>	Maximum residual in fitting of pinholes along y-axis (order N)	pixels	-
Y RES MIN O<N>	Minimum residual in fitting of pinholes along y-axis (order N)	pixels	-
Y RES MEDIAN O<N>	Median of absolute residuals in fitting of pinholes along y-axis (order N)	pixels	-
Y RES SD O<N>	Std-dev of residuals in fitting of pinholes along y-axis (order N)	pixels	-
XY RES MAX O<N>	Maximum residual in fitting of pinholes (order N)	pixels	-
XY RES MIN O<N>	Minimum residual in fitting of pinholes (order N)	pixels	-
XY RES SD O<N>	Std-dev of residuals in fitting of pinholes along (order N)	pixels	-
X DIFF MEDIAN O<N>	Median difference between observed and predicted pinhole detector locations along the x-axis (order N)	pixels	-
X DIFF SD O<N>	Standard deviation in difference between observed and predicted pinhole detector locations along the x-axis (order N)	pixels	-
Y DIFF MEDIAN O<N>	Median difference between observed and predicted pinhole detector locations along the y-axis (order N)	pixels	-
Y DIFF SD O<N>	Standard deviation in difference between observed and predicted pinhole detector locations along the y-axis (order N)	pixels	-
XY DIFF MEDIAN O<N>	Median difference between observed and predicted pinhole detector locations (order N)	pixels	-
FWHM PIN MEDIAN O<N>	Median FWHM of detected lines in pinhole frames (order N)	pixels	-
FWHM PIN SD O<N>	Standard-deviation in FWHM of detected lines in pinhole frames (order N)	pixels	-
R PIN MEDIAN O<N>	Median spectral resolution measured from detected lines in pinhole frames (order N)		-

10.2.7 soxs_stare

The **soxs_stare** recipe reduces object frames taken in stare mode. It models and removes the on-frame sky contribution to the flux. The object trace is then fitted and extracted using an optimal extraction routine.

Usage

The **soxs_stare** recipe can be run with the following convention:

```
soxspipe [-Vx] stare <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
```

To rerun a previously executed **soxs_stare** recipe, you can find the execution command at the end of the recipe log file (found in the workspace **products/soxs_stare** directory). Use the **-x** flag to overwrite the

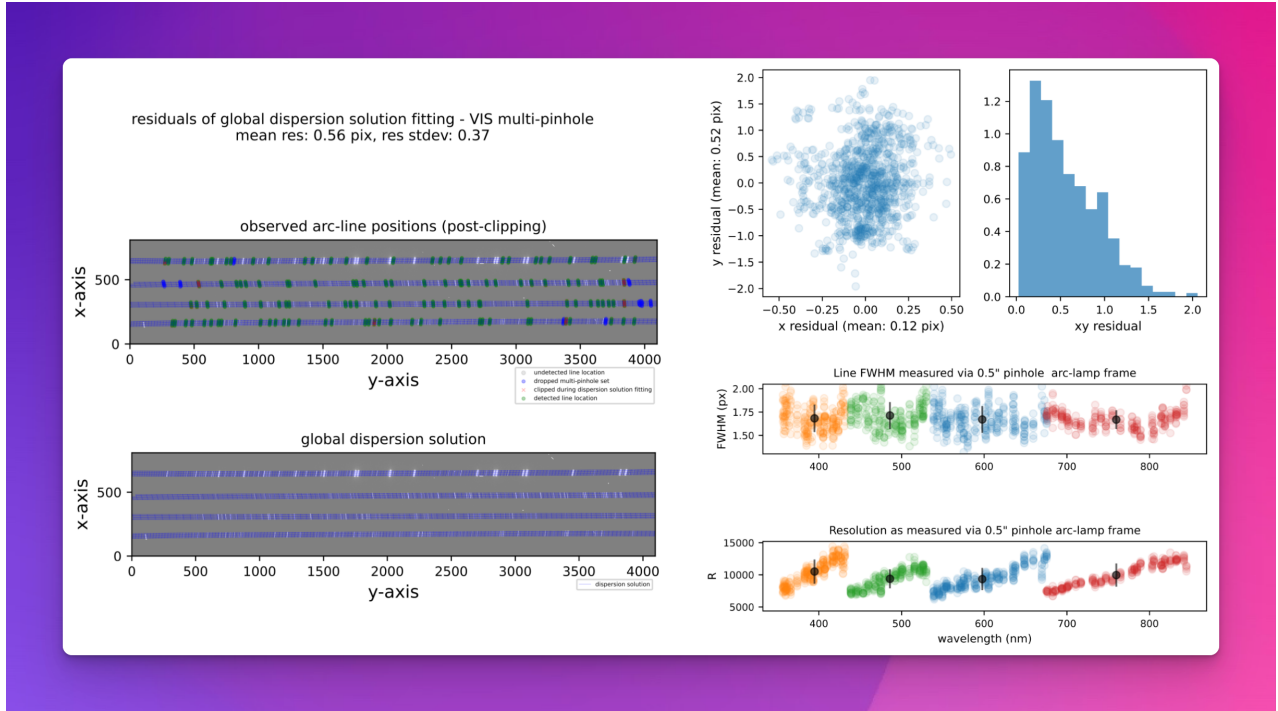


Figure 27: A QC plot resulting from the `soxs_spatial_solution` recipe. The top-left panel shows an SOXS VIS arc-lamp frame, taken with a multi-pinhole mask. The green circles represent arc lines detected in the image, and the blue circles and red crosses are lines that were detected but dropped because other pinholes of the same arc line were not detected, or because the lines were clipped during polynomial fitting. The grey circles represent arc lines reported in the static calibration table that were not detected in the image. The bottom-left panel shows the same arc-lamp frame with the dispersion solution overlaid as a blue grid. Lines travelling along the dispersion axis (left to right) are lines of equal slit position, and lines travelling in the cross-dispersion direction (top to bottom) are lines of equal wavelength. The top-right panel shows the residuals of the dispersion solution fit, and the bottom-right panel shows the resolution measured for each line (projected through the pinhole mask), with different colours for each echelle order and the mean order resolution in black.

product files if they already exist. For example, from the root of your workspace, you would run a command like:

```
soxspipe stare sof/20260111T060038_VIS_1X1_1_STARE_STD_FLUX_SLIT1_0_300_0S_SOXS.sof -s ./
↳sessions/base/soxspipe.yaml -x
```

To adjust the default settings for the `soxs_stare` recipe, open the `soxspipe.yaml` file referenced in the command above in a text editor, navigate to the `soxs_stare` dictionary, save the file and rerun the recipe command. The settings' descriptions can be found in Table 30.

Product files are written in the `products/soxs_stare`, and QC plots are in the `qc/soxs_stare` workspace directory. A report of the product files, QC plots and metrics is also printed to the terminal. The QC metrics calculated for `soxs_stare` are found in Table 33.

Reduction Tips

Typically, this recipe fails because the object trace is not found or fitted correctly. This may simply be because the object is too faint in the data, but a few settings can be adjusted to try and secure a fit. First, increase `slice-length` by a few pixels and try the recipe again. If this does not work, adjust `poly-fitting-residual-clipping-sigma` to both lower and higher levels (by 1 or 2 sigma each time) and rerun the recipe each time.

Parameters

Table 30: The `soxs_stare` recipe parameters.

Parameter	Description	Type	Entry Point	Related Util
<code>use_flat</code>	divide image by master flat frame	bool	settings file	-
<code>subtract_background</code>	fit and subtract the intra-order background light	bool	settings file	-
<code>use_lacosmic</code>	use la cosmic to remove CRHs before extraction	bool	settings file	-
<code>stacked_clipping_sigma</code>	the sigma clipping limit used when stacking frames into a composite frame	float	settings file	<i>clip_and_stack</i>
<code>stacked_clipping_iterations</code>	the maximum sigma-clipping iterations used when stacking frames into a composite frame	int	settings file	<i>clip_and_stack</i>
<code>horne_extraction_slit_length</code>	the length of the 'slit' used to collect object flux (in pixels). Doubles are boxcar extraction aperture size.	int	settings file	<i>horne_extraction</i>
<code>horne_extraction_profile_poly_order</code>	degree of the polynomial used to fit the dispersion-direction profiles of the object.	int	settings file	<i>horne_extraction</i>
<code>horne_extraction_profile_global_clipping_sigma</code>	sigma clipping limit when fitting the object profile (global over the order)	float	settings file	<i>horne_extraction</i>
<code>horne_extraction_profile_clipping_sigma</code>	sigma clipping limit when fitting the dispersion-direction profiles of the object	float	settings file	<i>horne_extraction</i>

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Table 30 – continued from previous page

Parameter	Description	Type	Entry Point	Related Util
horne_extraction_- profile_clipping_- iteration_count	maximum number of clipping iterations when fitting dispersion-direction profiles	int	settings file	<i>horne_- extraction</i>
order_sample_count	number of cross-order slices per order	int	settings file	<i>detect_- continuum</i>
slice_length	length of each slice (pixels)	int	settings file	<i>detect_- continuum</i>
slice_width	width of each slice (pixels)	int	settings file	<i>detect_- continuum</i>
peak_sigma_limit	height gaussian peak must be above median flux to be “detected” by code (std via median absolute deviation)	float	settings file	<i>detect_- continuum</i>
order_deg	degree of order-component of global polynomial fit to object trace	int	settings file	<i>detect_- continuum</i>
disp_axis_deg	degree of y-component of global polynomial fit to object trace	int	settings file	<i>detect_- continuum</i>
poly_fitting_- residual_clipping_- sigma	clipping limit (median and mad) when fitting global polynomial to object trace	float	settings file	<i>detect_- continuum</i>
poly_clipping_- iteration_limit	maximum number of clipping iterations when fitting global polynomial to object trace	int	settings file	<i>detect_- continuum</i>
background_- subtraction: bspline_deg	degree of bsplines used to fit the inter-order background (if <code>subtract_background == True</code>)	int	settings file	<i>subtract_- background</i>
background_- subtraction: gaussian_blur_sigma	Standard deviation of Gaussian kernel used to smooth background image (if <code>subtract_background == True</code>)	int	settings file	<i>subtract_- background</i>
response: max_- iteration	maximum number of iterations used to fit the polynomial to the response function	int	settings file	<i>response_- function</i>
response: poly_- order	degree of the polynomial used to fit the response function	int	settings file	<i>response_- function</i>

Input

Table 31: Input files for the `soxs_stare` recipe. The files are typically passed to the `soxs_stare` recipe via a set-of-file (sof) file listing one file per line.

Data Type	Content	Related OB
FITS Images	Raw science frames of targets observed in stare mode	SOXS_slit_obs_StareSynchro, SOXS_slit_cal_SpecphotStdStare, SOXS_slit_cal_TelluricStdStare
FITS Image	Master bias (UVVIS only)	-
FITS Image	Master dark frame (NIR only)	-
FITS Image	Master flat frame (optional)	-
FITS Table	Order location table containing coefficients to the polynomial fits describing the order locations.	-
FITS Table	Dispersion map table giving coefficients of polynomials describing 2D dispersion/spatial solution	-
FITS Image	Dispersion Map image with 3-extensions (wavelength, slit-position and echelle order number)	-

Output

Table 32: Output files for the `soxs_stare` recipe and their respective ESO PRO keywords. Some output file may not be generated depending on the user's pipeline settings.

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
EXTRACTED ORDERS TABLE	Table of the extracted source in each order	FITS	SCI_SLIT_FLUX_-<ARM>	REDUCED	ECHELLE, SLIT
EXTRACTED MERGED TABLE	Table of the extracted, order-merged	FITS	SCI_SLIT_FLUX_-<ARM>	REDUCED	ECHELLE, SLIT
EXTRACTED FLUXCAL SPECTRUM	Table of the flux calibrated extracted spectrum	FITS	SCI_SLIT_FLUX_-<ARM>	REDUCED	ECHELLE, SLIT
SKY SUBTRACTED OBJECT	The sky-subtracted object	FITS	-	-	-
SKY MODEL	The sky background model	FITS	-	-	-
SKY SUB RESIDUALS	The sky subtraction residuals	FITS	-	-	-

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Table 32 – continued from previous page

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
RESPONSE_- FUNC	Response function coefficients	FITS	RESP_TAB_<ARM>	REDUCED	ECHELLE, SLIT
EFFICIENCY	Efficiency estimate	FITS	EFFICIENCY_- TAB_<ARM>	REDUCED	ECHELLE, SLIT
EXTRACTED MERGED ASCII	Ascii version of extracted source spectrum	TXT	-	-	-
BKGROUND	Fitted intra-order image back-ground	PDF	-	-	-
SKY MODEL QC PLOTS	QC plots for the sky-background modelling	PDF	-	-	-
SKY SUBTRACTION QUICKLOOK	Sky-subtraction quicklook	PDF	-	-	-
OBJECT TRACE RES	Residuals of the object trace polynomial fit	PDF	-	-	-
EXTRACTED ORDERS QC PLOT	QC plot of extracted source	PDF	-	-	-
EXTRACTED MERGED QC PLOT	QC plot of extracted order-merged source	PDF	-	-	-
EXTRACTED MERGED FLUXCALIBRATED QC PLOT	QC plot of extracted order-merged, flux-calibrated source	PDF	-	-	-
RESPONSE QC PLOT	Response curve QC plot.	PDF	-	-	-

QC Metrics

Table 33: Quality Control metrics calculated in the `soxs_stare` recipe. Note that the acceptable ranges are enforced only for standard stars, not for science frames.

Label	Description	Unit	Acceptable Range
BADPIX FRAC	Fraction of bad pixels		VIS: [0.0,0.01], NIR: [0.00,0.01]
INNER ORDER PIX MEAN	Mean inner-order pixel value	electrons	VIS: [-40,60], NIR: [-40,60]
INNER ORDER PIX SUM	Sum of all inner-order pixel values	electrons	-
BADPIX NUM	Number of bad pixels		-

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Table 33 – continued from previous page

Label	Description	Unit	Acceptable Range
N ORDERS	Number of orders containing an object trace		VIS: 4, NIR: 15
SAMPLES DET NUM	Number of samples where a continuum is de- tected		-
SAMPLES DET FRAC	Fraction of samples where a continuum is de- tected		VIS: [0.93,1.0], NIR: [0.7,1.0]
SAMPLES TOT NUM	Total number of samples along orders		-
SAMPLES CLIP NUM	Number of continuum sample clipped during solution fitting		-
SAMPLES CLIP FRAC	Fraction of detected continuum samples clipped during solution fitting		VIS: [0.0,0.2], NIR: [0.0,0.3]
X RES MAX	Maximum residual in continuum fit along x- axis	px	-
X RES MIN	Minimum residual in continuum fit along x-axis	px	-
X RES SD	Std-dev of residual continuum fit along x-axis	px	VIS: [0.0,0.2]
Y RES MAX	Maximum residual in continuum fit along y- axis	px	-
Y RES MIN	Minimum residual in continuum fit along y-axis	px	-
Y RES SD	Std-dev of residual continuum fit along y-axis	px	NIR: [0.0,0.5]
EFF MEDIAN	The median efficiency (global)		VIS: [0.04,0.30], NIR: [0.02,0.2]
SNR MEDIAN	The median signal-to-noise ratio across all or- ders (global)		VIS: [50,1000], NIR: [7,200]
EFF MEDIAN O<N>	The median efficiency (order N)		-
SNR MEDIAN O<N>	The median signal-to-noise ratio across all or- ders (order N)		-

10.2.8 soxs_nod

The `soxs_nod` recipe reduces the science frames produced by the NTT and SOXS from a nodding mode observation block.

Usage

The `soxs_nod` recipe can be run with the following convention:

```
soxspipe [-Vx] nod <inputFrames> [-o <outputDirectory> -s <pathToSettingsFile>]
```

To rerun a previously executed `soxs_nod` recipe, you can find the execution command at the end of the recipe log file (found in the workspace `products/soxs_nod` directory). Use the `-x` flag to overwrite the product files if they already exist. For example, from the root of your workspace, you would run a command like:

```
soxspipe nod sof/20260111T041914_NIR_3_NOD_STD_FLUX_SLIT1_0_150_OS_SOXS.sof -s ./sessions/  
↪base/soxspipe.yaml -x
```

To adjust the default settings for the `soxs_nod` recipe, open the `soxspipe.yaml` file referenced in the command above in a text editor, navigate to the `soxs_nod` dictionary, save the file and rerun the recipe command. The settings' descriptions can be found in Table 34.

Product files are written in the `products/soxs_nod`, and QC plots are in the `qc/soxs_nod` workspace directory. A report of the product files, QC plots and metrics is also printed to the terminal. The QC metrics calculated for `soxs_nod` are found in Table 37.

Reduction Tips

Typically, this recipe fails because the object trace is not found or fitted correctly. This may simply be because the object is too faint in the data, but a few settings can be adjusted to try and secure a fit. First, increase `slice-length` by a few pixels and try the recipe again. If this does not work, adjust `poly-fitting-residual-clipping-sigma` to both lower and higher levels (by 1 or 2 sigma each time) and rerun the recipe each time.

Parameters

Table 34: The `soxs_nod` recipe parameters.

Parameter	Description	Type	Entry Point	Related Util
<code>use_flat</code>	divide image by master flat frame	bool	settings file	-
<code>subtract_background</code>	fit and subtract the intra-order background light	bool	settings file	-
<code>save_single_frame_extractions</code>	If True, each A and B stacked frame for each offset is saved as 2D image	bool	settings file	-
<code>use_lacosmic</code>	use la cosmic to remove CRHs before extraction	bool	settings file	-
<code>stacked_clipping_sigma</code>	the sigma clipping limit used when stacking frames into a composite frame	float	settings file	<i>clip_and_stack</i>
<code>stacked_clipping_iterations</code>	the maximum sigma-clipping iterations used when stacking frames into a composite frame	int	settings file	<i>clip_and_stack</i>
<code>horne_extraction_slit_length</code>	the length of the ‘slit’ used to collect object flux (in pixels). Doubles are boxcar extraction aperture size.	int	settings file	<i>horne_extraction</i>
<code>horne_extraction_profile_poly_order</code>	degree of the polynomial used to fit the dispersion-direction profiles of the object.	int	settings file	<i>horne_extraction</i>
<code>horne_extraction_profile_global_clipping_sigma</code>	sigma clipping limit when fitting the object profile (global over the order)	float	settings file	<i>horne_extraction</i>
<code>horne_extraction_profile_clipping_sigma</code>	sigma clipping limit when fitting the dispersion-direction profiles of the object	float	settings file	<i>horne_extraction</i>
<code>horne_extraction_profile_clipping_iteration_count</code>	maximum number of clipping iterations when fitting dispersion-direction profiles	int	settings file	<i>horne_extraction</i>
<code>order_sample_count</code>	number of cross-order slices per order	int	settings file	<i>detect_continuum</i>

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Table 34 – continued from previous page

Parameter	Description	Type	Entry Point	Related Util
<code>slice_length</code>	length of each slice (pixels)	int	settings file	<i>detect_ - continuum</i>
<code>slice_width</code>	width of each slice (pixels)	int	settings file	<i>detect_ - continuum</i>
<code>peak_sigma_limit</code>	height gaussian peak must be above median flux to be “detected” by code (std via median absolute deviation)	float	settings file	<i>detect_ - continuum</i>
<code>order_deg</code>	degree of order-component of global polynomial fit to object trace	int	settings file	<i>detect_ - continuum</i>
<code>disp_axis_deg</code>	degree of y-component of global polynomial fit to object trace	int	settings file	<i>detect_ - continuum</i>
<code>poly_fitting_-residual_clipping_-sigma</code>	clipping limit (median and mad) when fitting global polynomial to object trace	float	settings file	<i>detect_ - continuum</i>
<code>poly_clipping_-iteration_limit</code>	maximum number of clipping iterations when fitting global polynomial to object trace	int	settings file	<i>detect_ - continuum</i>
<code>background_-subtraction: bspline_deg</code>	degree of bsplines used to fit the inter-order background (if <code>subtract_background == True</code>)	int	settings file	<i>subtract_- background</i>
<code>background_-subtraction: gaussian_blur_sigma</code>	standard deviation of Gaussian kernel used to smooth background image (if <code>subtract_background == True</code>)	int	settings file	<i>subtract_- background</i>
<code>response: max_-iteration</code>	maximum number of iterations used to fit the polynomial to the response function	int	settings file	<i>response_- function</i>
<code>response: poly_-order</code>	degree of the polynomial used to fit the response function	int	settings file	<i>response_- function</i>

Input

Table 35: Input files for the `soxs_nod` recipe. The files are typically passed to the `soxs_nod` recipe via a set-of-file (sof) file listing one file per line.

Data Type	Content	Related OB
FITS Image	Raw science frames of targets observed in nodding mode	SOXS_slit_obs_AutoNodOnSlit, SOXS_slit_cal_TelluricStdNod, SOXS_slit_cal_SpecphotNod
FITS Image	Master flat frame (optional)	-
FITS Table	order location table containing coefficients to the polynomial fits describing the order locations.	-
FITS Table	Dispersion map table giving coefficients of polynomials describing 2D dispersion/spatial solution	-
FITS Image	Dispersion map FITS image with 3-extensions (wavelength, slit-position and echelle order number)	-

Output

Table 36: Output files for the `soxs_nod` recipe and their respective ESO PRO keywords. Some output file may not be generated depending on the user's pipeline settings.

Label	Content	Data Type	PRO CATG	PRO TYPE	PRO TECH
EXTRACTED ORDERS TABLE	Table of the extracted source in each order	FITS	SCI_SLIT_FLUX_-NIR	REDUCED	ECHELLE, SLIT
EXTRACTED MERGED TABLE	Table of the extracted, order-merged	FITS	SCI_SLIT_FLUX_-NIR	REDUCED	ECHELLE, SLIT
EXTRACTED FLUXCAL SPECTRUM	Table of the flux calibrated extracted spectrum	FITS	SCI_SLIT_FLUX_-<ARM>	REDUCED	ECHELLE, SLIT
RESPONSE_-FUNC	Response function coefficients	FITS	RESP_TAB_-<ARM>	REDUCED	ECHELLE, SLIT
EFFICIENCY	Efficiency estimate	FITS	EFFICIENCY_-TAB_-<ARM>	REDUCED	ECHELLE, SLIT
EXTRACTED MERGED ASCII	Ascii version of extracted source spectrum	TXT	-	-	-
OBJECT TRACE RES	Residuals of the object trace polynomial fit	PDF	-	-	-
BKGROUND	Fitted intra-order image background	PDF	-	-	-
EXTRACTED ORDERS QC PLOT	QC plot of extracted source	PDF	-	-	-
EXTRACTED MERGED QC PLOT	QC plot of extracted order-merged source	PDF	-	-	-
EXTRACTED MERGED FLUXCALIBRATED QC PLOT	QC plot of extracted order-merged, flux-calibrated source	PDF	-	-	-
RESPONSE QC PLOT	Response curve QC plot.	PDF	-	-	-

QC Metrics

Table 37: Quality Control metrics calculated in the `soxs_nod` recipe. Note that the acceptable ranges are enforced only for standard stars, not for science frames.

Label	Description	Unit	Acceptable Range
BADPIX FRAC	Fraction of bad pixels		VIS: [0.0,0.01], NIR: [-0.001,0.01]

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Table 37 – continued from previous page

Label	Description	Unit	Acceptable Range
INNER ORDER PIX MEAN	Mean inner-order pixel value	elec- trons	VIS: [-40,60], NIR: [-40,60]
INNER ORDER PIX SUM	Sum of all inner-order pixel values	elec- trons	-
BADPIX NUM	Number of bad pixels		-
N ORDERS	Number of orders containing an object trace		VIS: 4 , NIR: 15
SAMPLES DET NUM	Number of samples where a continuum is de- tected		-
SAMPLES DET FRAC	Fraction of samples where a continuum is de- tected		VIS: [0.93,1.0] NIR: [0.7,1.0]
SAMPLES TOT NUM	Total number of samples along orders		-
SAMPLES CLIP NUM	Number of continuum sample clipped during solution fitting		-
SAMPLES CLIP FRAC	Fraction of detected continuum samples clipped during solution fitting		VIS: [0.0,0.2], NIR: [0.0,0.3]
X RES MAX	Maximum residual in continuum fit along x- axis	px	-
X RES MIN	Minimum residual in continuum fit along x-axis	px	-
X RES SD	Std-dev of residual continuum fit along x-axis	px	VIS: [0.0,0.2]
Y RES MAX	Maximum residual in continuum fit along y- axis	px	-
Y RES MIN	Minimum residual in continuum fit along y-axis	px	-
Y RES SD	Std-dev of residual continuum fit along y-axis	px	NIR: [0.0,0.5]
EFF MEDIAN	The median efficiency (global)		VIS: [0.04,0.30], NIR: [0.02,0.2]
SNR MEDIAN	The median signal-to-noise ratio across all or- ders (global)		VIS: [50,1000], NIR: [7,200]
EFF MEDIAN 0<N>	The median efficiency (order N)		-
SNR MEDIAN 0<N>	The median signal-to-noise ratio across all or- ders (order N)		-

10.3 Automatic Reductions Using a Watched Workspace

Warning

A typical user will not need to use the watch command. It is included in the pipeline to allow for automatic/autonomous reductions as data is flowing into a directory. Most users will only need to use the *reduce* command.

With soxspipe, it is possible to create a ‘watched’ workspace. When data is added to a watched workspace, soxspipe will attempt to reduce the data automatically.

First, create the directory you are going to designate as the watched workspace:

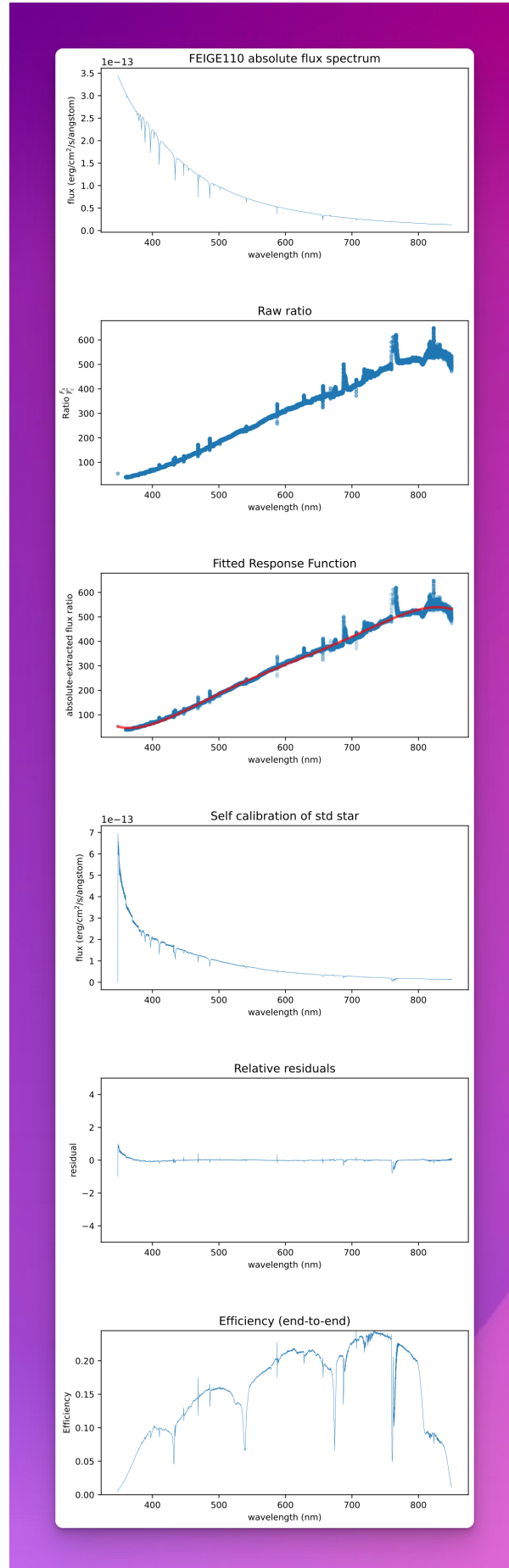


Figure 28: The output of the `reponse_function` utility (used by nodding and stare recipes) used in the reduction of spectroscopic standard star spectra. The third panel shows the fitted response curve, and the final panel shows the overall efficiency of the instrument across the entire wavelength range of the spectrograph arm.


```
mkdir ~/soxs_workspace
```

Now, change into that directory and ask soxspipe to ‘watch’ the directory:

```
cd ~/soxs_workspace
soxspipe watch start
```

The daemon is now running in the background, and you can check its status by running:

```
soxspipe watch status
```

If you start moving FITS files into this workspace, soxspipe will attempt to reduce the data automatically. Note that the pipeline is running in daemon mode, so nothing will be output to the terminal. However, the daemon log file can be found at `~/config/soxspipe/daemon.log`, and individual recipe logs can be found in their usual location beside the products in the workspace products directory.

The daemon will continue running even if you close the terminal with which you initiated it. To stop the daemon, run:

```
soxspipe watch stop
```

11 Logging

When running a recipe, **soxspipe** writes informative logs to the terminal (stdout), allowing the user to keep track of the reduction progress in real-time. For provenance, this information is also written to a log file adjacent to the recipe’s product file(s).

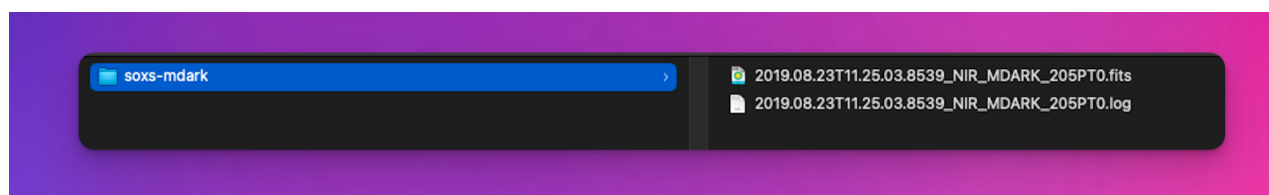


Figure 29: A log file for each recipe is written beside the recipe product.

If the recipe fails, a separate error log is written to the directory the product file should have been written to had the recipe succeeded. Error logs are named with a `*“_ERROR.log”` suffix.

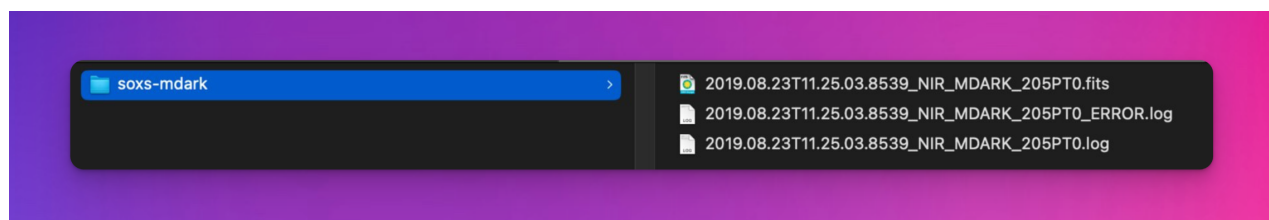


Figure 30: An error log is written to the recipe’s product directory if the recipe fails to complete.

Here is an example log file from one of the simpler recipes (mdark):

```
Recipe Command: soxspipe mdark sof/20260111T083044_NIR_3_MDARK_10_OS_SOXS.sof -s ./
↳ soxspipe.yaml
# VERIFYING INPUT FRAMES

Gain is being read from the detector parameter file (not the FITS header)
```

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```

# VERIFYING INPUT FRAMES - ALL GOOD

# PREPARING 5 RAW FRAMES - TRIMMING OVERSCAN, CONVERTING TO ELECTRON COUNTS, GENERATING
↳UNCERTAINTY MAPS AND APPENDING DEFAULT BAD-PIXEL MASK
# PREPARED FRAMES - SUMMARY
      filename                INSTRUME    MJD-OBS      TYPE  CATG  TECH  ARM  EXPTIME
↳ESO PRO TYPE ESO PRO CATG ESO PRO TECH  SLIT LAMP
-----
↳-----
SOXS.2026-01-11T08:30:44.542_pre.fits    SOXS    61051.3546822  DARK  CALIB  IMAGE  NIR    10.0
↳      --                --      -- BLANK  --
SOXS.2026-01-11T08:31:03.437_pre.fits    SOXS    61051.35490089  DARK  CALIB  IMAGE  NIR    10.0
↳      --                --      -- BLANK  --
SOXS.2026-01-11T08:31:23.438_pre.fits    SOXS    61051.35513238  DARK  CALIB  IMAGE  NIR    10.0
↳      --                --      -- BLANK  --
SOXS.2026-01-11T08:31:43.438_pre.fits    SOXS    61051.35536387  DARK  CALIB  IMAGE  NIR    10.0
↳      --                --      -- BLANK  --
SOXS.2026-01-11T08:32:03.443_pre.fits    SOXS    61051.35559541  DARK  CALIB  IMAGE  NIR    10.0
↳      --                --      -- BLANK  --

# MEAN COMBINING 5 NIR CALIB IMAGE DARK FRAMES
      The basic bad-pixel mask for the NIR detector DARK frames contains 0 pixels (0.0%
↳of all pixels)
      0 new pixels made it into the combined bad-pixel map (bad pixels now account for 0.
↳00% of all pixels)

# SOXS-MDARK QC METRICS
+-----+-----+-----+-----+-----+
↳--+
|      qc_name |  qc_value |  qc_unit |               qc_comment |  qc_
↳flag |
+-----+-----+-----+-----+
↳--+
|  CPATH TEMP |    16    | celsius | [C] temp of common path |
↳pass |
| DETECTOR TEMP |    45    | kelvin | [K] temp of detector |
↳pass |
|  HOTPIX FRAC |    0     |         | Fraction of hot pixels |
↳pass |
|  HOTPIX NUM |    0     |         | Number of hot pixels |
↳pass |
|  MDARK MEDIAN | -1.179 | electrons | [e-] Median flux level of master dark |
↳pass |
|    RAW RON |  14.858 | electrons | [e-] RON in single DARK |
↳pass |
+-----+-----+-----+-----+
↳--+

# SOXS-MDARK RECIPE PRODUCTS & QC OUTPUTS
+-----+-----+-----+-----+
↳--+
|  product_label |               file_name |  file_type |
↳obs_date_utc |  label |  product_desc |
+-----+-----+-----+-----+

```

(continues on next page)

```
→-----+-----+-----|  
|          MDARK | 20260111T083044_NIR_3_MDARK_10_OS_SOXS.fits |      FITS | 2026-01-  
→11T08:30:44.5420 |     PROD | NIR Master dark frame |  
+-----+-----+-----+-----+-----+  
→-----+-----+-----+
```

Informative results from each stage of the recipe’s reduction tasks are written, including a list describing the input files, a table of QC results and a table of the data-reduction products and QC plots generated. At the end of the log file, the user will find the command required to rerun the recipes and a report on the time it took for the recipe to complete.

Abbreviation	Definition
AD	Applicable Document
CP	Common Path
D2	Deuterium
DRD	Document Requirement Description
DFS	Data Flow System
DRS	Data Reduction Software
ETC	Exposure Time Calculator
ESO	European Southern Observatory
FDR	Final Design Review
FITS	Flexible Image Transport System
FF	Flat Field
FOV	Field Of View
HW	HardWare
ICD	Interface Control Document
ICS	Instrument Control Software
MoU	Memorandum of Understanding
NGC	New Generation Controller
NTT	New Technology Telescope
PAC	Provisional Acceptance Chile
PAE	Preliminary Acceptance Europe
PDR	Preliminary Design Review
PDP	Preliminary Design Phase
QSO	Quasi stellar object (quasar)
QTH	Quartz Thorium
RD	Reference Document
RON	Read Out Noise
SNR	Signal-to-noise ratio
SRE	Spectral Resolution Element
SoW	Statement of Work
SOXS	Son Of X-Shooter
SW	SoftWare
TBC	To Be Confirmed
TBD	To Be Defined
TCS	Telescope Control System
TLR	Top Level Requirements
TRS	Technical Requirements Specifications
UT	Unit Telescope (of the VLT)
VIC	VLT Instrument Consortium
VLT	Very Large Telescope
WP	Work Package

Table 38: List of Abbreviations and Definitions

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