SOXS Pipeline

SOXS Consortium Science Meeting. 24th-26th Nov 2020.

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Overview

- Raw Data
- Pipeline Products
- Pipeline Architecture
- Automated Data-Reduction
- Development Environment
- Pipeline Usage
- Summary Conclusions

SOXS

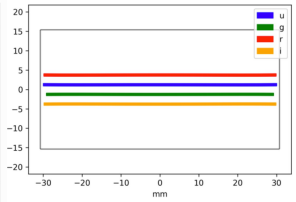
Son Of X-Shooter

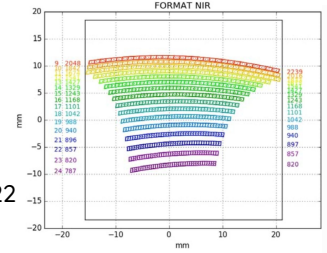
NTT Nasmyth Focus, La Silla, Chile

Science Operations to begin Mid-2022

Parameter	Value
Detector	e2V CCD44–82
Pixel-Size	15 μm
Array-Size	2048 × 4096 px; 30.7 x 61.4 mm
Array-Scale	0.28 arcsec/px
Peak Signal	200,000 e^-/px
Gain	Slow: 0.6 ± 0.1 e^-/ADU Fast: 2 ± 0.2 e^-/ADU
Read noise (rms)	Slow: <3 e^- Fast: <8 e^-
Dark current @ 153K	< 0.00001 e^-/s/px
Resolution (R)	3500–7000 (≃ 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

UV-VIS Spectrograph/CCD Characteristics





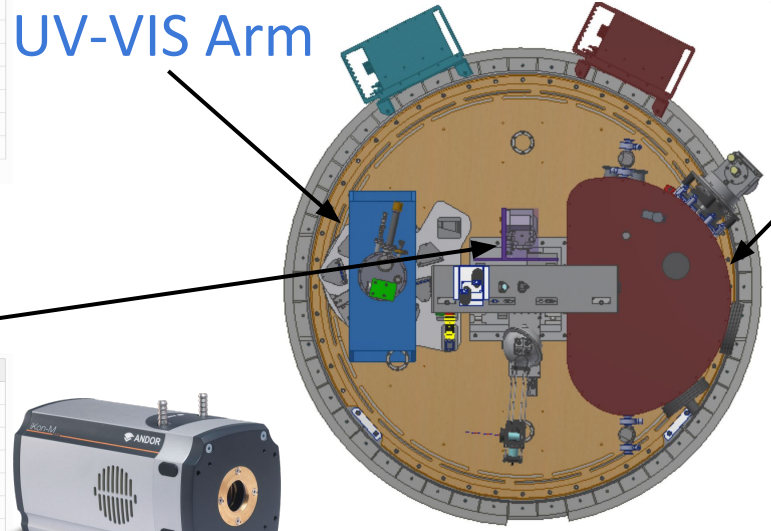
Parameter	Value
Detector	Teledyne H2RG
Pixel-Size	18 μm
Array-Size	2048 × 2048 px
Array-Scale	0.25 arcsec/px
Read noise (rms)	Double correlated: < 20 e^- 16 Fowler pairs < 7 e^-
Dark current @ 40K	< 0.005 e^-/s/px
Resolution (R)	≃ 5000 (1 arcsec slit)
Wavelength Range	800–2000 nm
Slit Widths	0.5, 1.0, 1.5, 5.0 arcsec
Slit Height	11 arcsec
Grating Blaze Angle	44°
Detector Operating Temp	40K
Spectrograph Operating Temp	150K
Orders	15

NIR Spectrograph/Array Characteristics

UV-VIS Arm

NIR Arm

A&G Camera



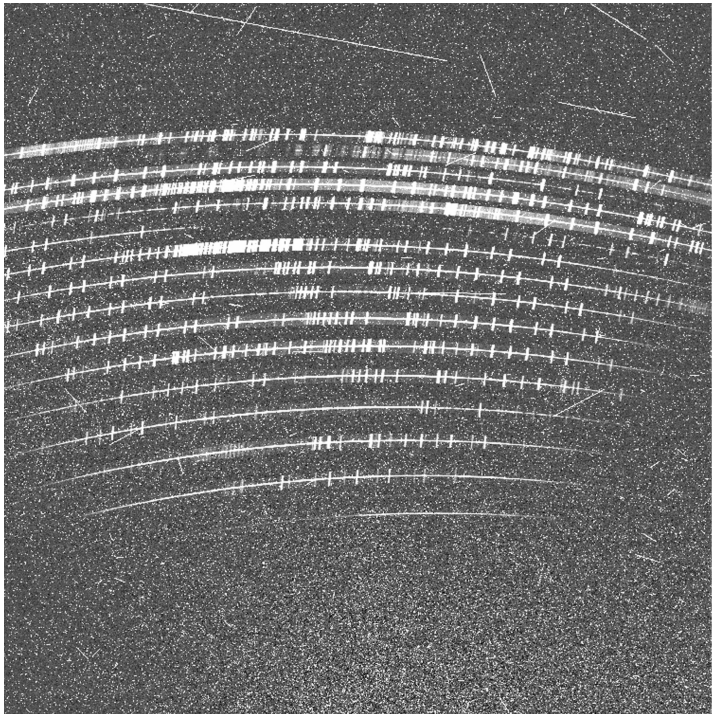
A face-on view of SOXS on the NTT rotator flange.
Figure 2 of Schipani, P. et al. (2018)

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

Acquisition Camera Characteristics

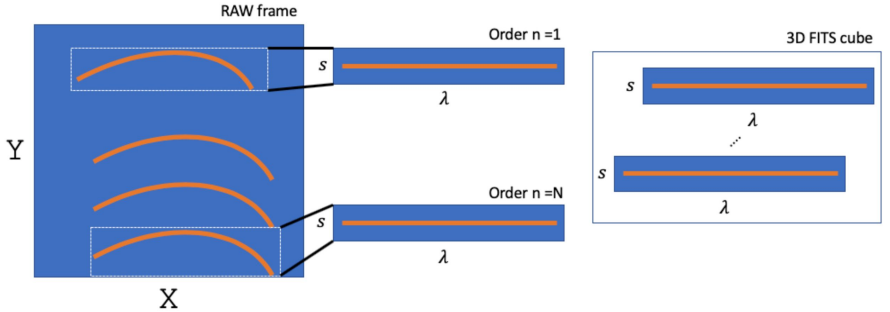
- medium resolution spectrograph (R≃4500) capable of simultaneously observing 350–2000nm (U- to H-band).
- limiting magnitude of R~20 (3600sec, S/N~10).
- primary science objective to study the transient sky; classifying and following transients discovered by all-sky imaging surveys (PanSTARRS, ATLAS, ZTF, LSST).
- Will respond to rapid and long-term Target of Opportunity (ToO) requests.
- SOXS consortium will be allocated 900 NTT nights over 5 years (50% time).
- ESO community can apply for the remaining time.

Raw Data ➔ Final Product

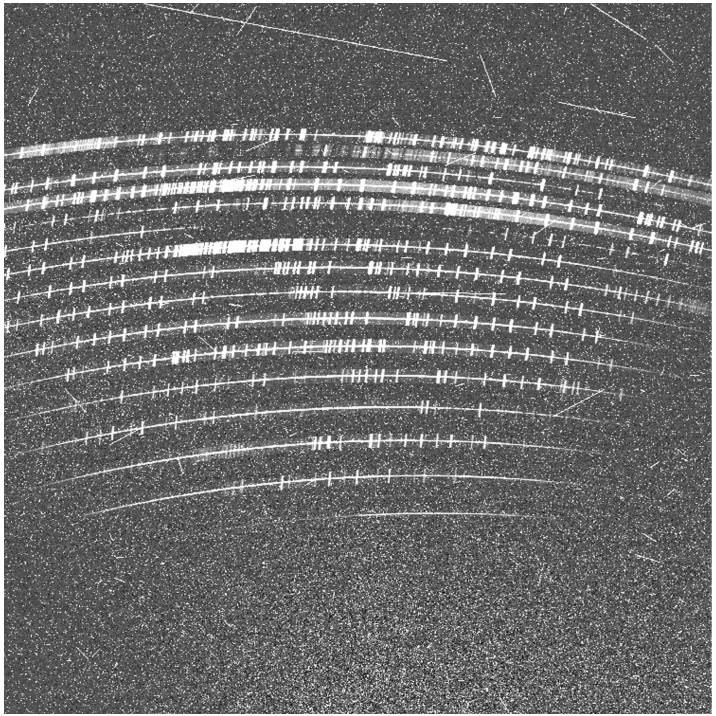


Reduction Stages

- standard detrending stages of calibration needed to remove instrument signatures (bias, dark-removal and flat-field correction).
- calculate and apply accurate wavelength- and flux-calibration solutions to the spectra (curved orders with slit-tilt)
- order rectification (to produce straightened order images)
- sky-background removal
- optimal source extraction



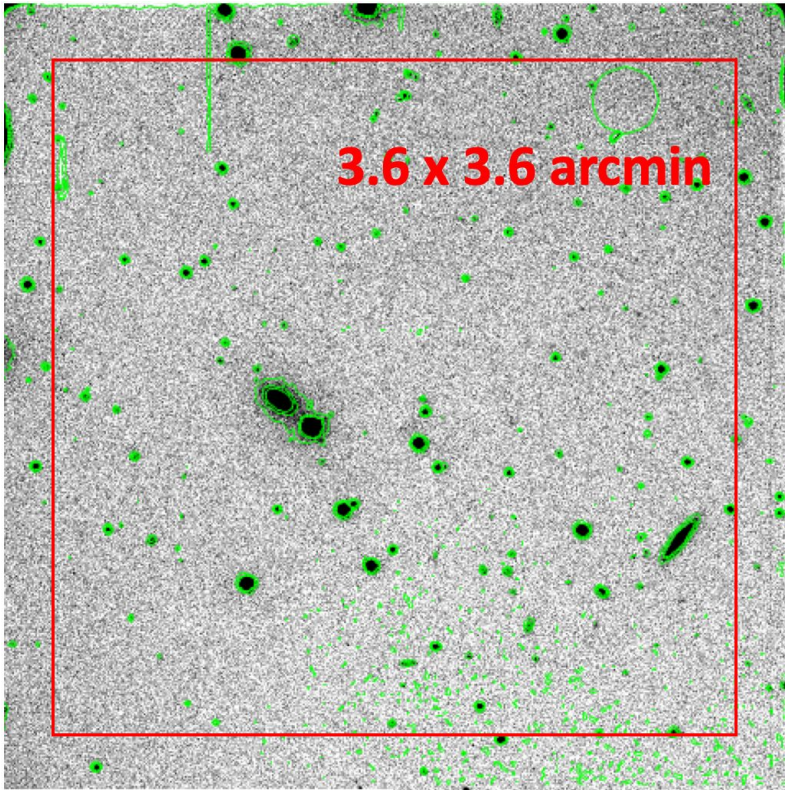
Raw Data ➔ Final Product



6 spectroscopic observation modes

- Stare-mode. Standard 'point-and-shoot' observation.
- Stare-mode, synchronised. Standard 'point-and-shoot' observations where the mid-point of the UV-VISand NIR exposures are matched.
- Nodding-mode. The telescope 'nods' between two-positions along the slit throughout exposure, allowing for on-the-fly sky background removal.
- Fixed sky-offset mode. This mode is for extended objects where not enough uncontaminated sky-background is seen within the 11″slit to allow for measurement and removal.
- Generic sky-offset mode. User defined pattern of telescope offsets.
- Mapping-mode. Used to 'map' an object or location.

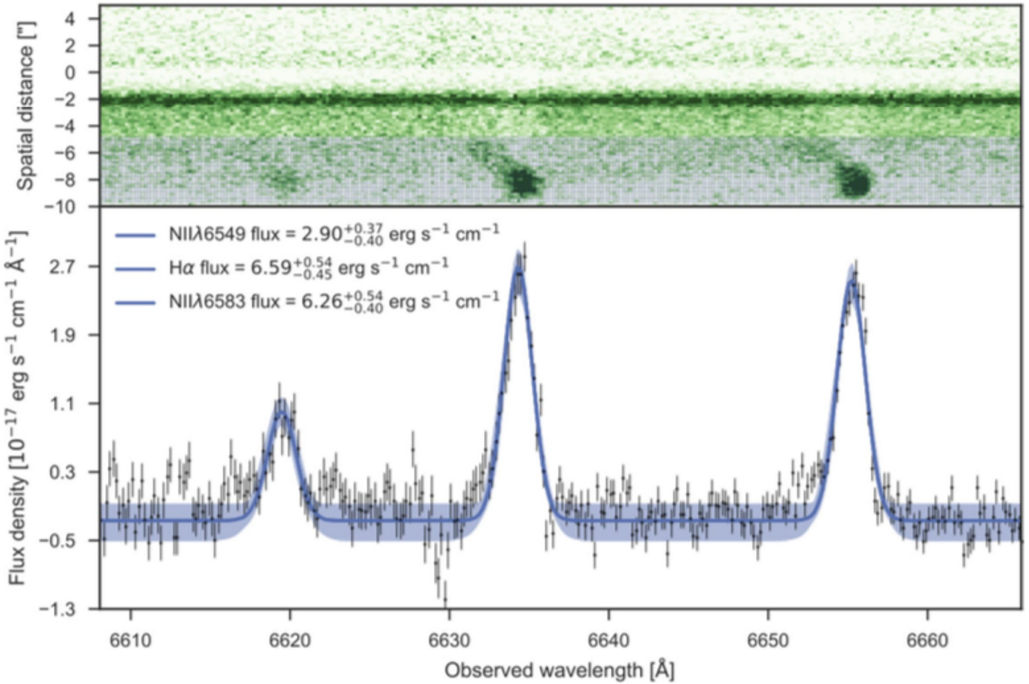
+ imaging observation mode via A&G Camera



- Automated astrometric and photometric calibration using ATLAS RefCat2 (griz all-sky reference catalogue to mag ~19)
- Pipeline can use *g- or r*-band image to scale flux (or allow for *g* + *z* and can then do both VIS + NIR)
- Reliable absolute flux – pipeline should ensure reliable *relative flux calibration*
- Acq camera images – flux calibration to ~ few % (irrespective of photometric conditions)

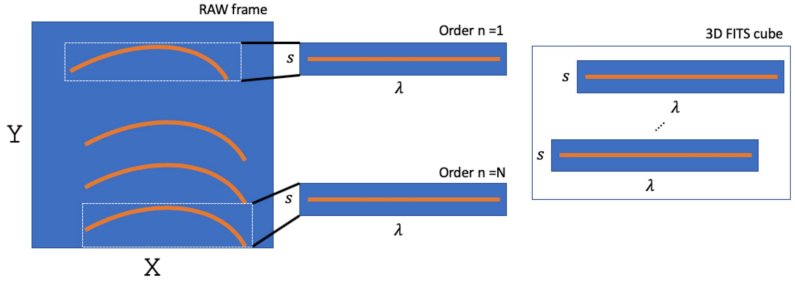
Product	Description
1D Source Spectra	1D spectra in FITS binary table format, one for each arm. Each FITS spectrum file will contain 4 extensions: 1. Wavelength- and flux-calibrated spectra with absolute flux correction via scaling to acquisition image source photometry, 2. an additional spectrum with correction for telluric absorption via MOLECFIT, 3. the variance array and 4. the sky-background spectra.
1D Merged Source Spectrum	1D UV-VIS & NIR merged spectrum in FITS binary table format with PDF visualisation. This spectrum will be rebinned to a common pixel scale foreach arm. This spectrum file will also have the same 4 extensions described above.
2D Source Spectra	A 2D FITS image for each spectral arm containing wavelength and flux calibrated spectra (no other corrections applied) allowing users to perform source extraction with their tool of choice. Note that rectification of the curved orders in the NIR introduces a source of correlated noise not present in extractions performed on the un-straightened orders as done by the pipeline.
Acquisition Camera Images	*ugrizy* astrometrically and photometrically (*griz* only) calibrated to Refcat2 (Tonry et al. 2018).

RESEARCH LETTER



AT2017gfo (GW170817)
XShooter, Pian et al. 2017

Produce 2D distortion corrected, orders merged pre-extraction spectrum for each arm (rectification)



Pipeline Architecture

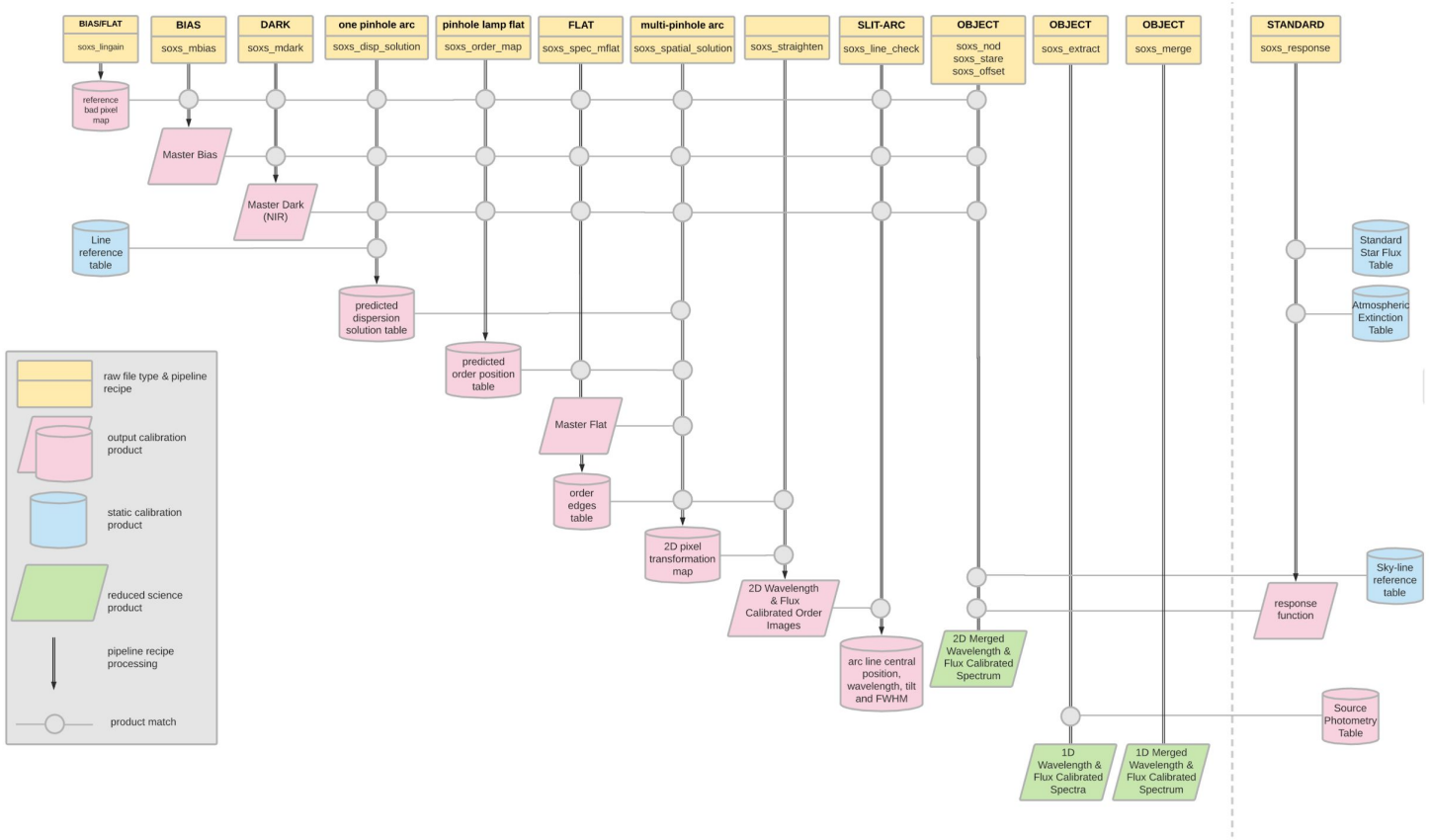
Recipes

Recipe	Reduction Stage
soxs_data_organiser	pre-processing
soxs_lingain	calibration
soxs_img_mflat	calibration
soxs_mbias	calibration
soxs_mdark	calibration
soxs_disp_solution	rectification
soxs_order_centres	rectification
soxs_spatial_solution	rectification
soxs_spec_mflat	rectification
soxs_straighten	rectification
soxs_line_check	rectification
soxs_nod	sky-subtraction
soxs_stare	sky-subtraction
soxs_offset	sky-subtraction
soxs_extract	extraction+
soxs_response	extraction+
soxs_merge	extraction+
soxs_astro_phot	extraction+

Utilities

Utilities	Reduction Stage
detector_lookup	universal
keyword_lookup	universal
set_of_files	universal
prepare_frames	pre-processing
clip_and_stack	calibration
create_dispersion_map	calibration
detect_continuum	calibration
detect_order_edges	calibration
subtract_calibration	calibration

see readthedocs for more details on recipes & utilities: https://soxspipe.readthedocs.io/


BIAS/FLAT
soxs_lingain
BIAS
soxs_mbias
DARK
soxs_mdark
one pinhole arc
soxs_disp_solution
pinhole lamp flat
soxs_order_map
FLAT
soxs_spec_mflat
multi-pinhole arc
soxs_spatial_solution
soxs_straighten
SLIT-ARC
soxs_line_check
OBJECT
soxs_nod
soxs_stare
soxs_offset
OBJECT
soxs_extract
OBJECT
soxs_merge
STANDARD
soxs_response
reference bad pixel map
Master Bias
Master Dark (NIR)
Line reference table
predicted dispersion solution table
predicted order position table
Master Flat
order edges table
2D pixel transformation map
2D Wavelength & Flux Calibrated Order Images
arc line central position, wavelength, tilt and FWHM
2D Merged Wavelength & Flux Calibrated Spectrum
1D Wavelength & Flux Calibrated Spectra
1D Merged Wavelength & Flux Calibrated Spectrum
Standard Star Flux Table
Atmospheric Extinction Table
Sky-line reference table
response function
Source Photometry Table
raw file type & pipeline recipe
output calibration product
static calibration product
reduced science product
pipeline recipe processing
product match

Pipeline Architecture

Recipe	Reduction Stage
soxs_data_organiser	pre-processing
~~soxs_lingain~~	~~calibration~~
~~soxs_img_mflat~~	~~calibration~~
~~soxs_mbias~~	~~calibration~~
~~soxs_mdark~~	~~calibration~~
~~soxs_disp_solution~~	~~rectification~~
~~soxs_order_centres~~	~~rectification~~
~~soxs_spatial_solution~~	~~rectification~~
~~soxs_spec_mflat~~	~~rectification~~
soxs_straighten	rectification
~~soxs_line_check~~	~~rectification~~
soxs_nod	sky-subtraction
soxs_stare	sky-subtraction
soxs_offset	sky-subtraction
soxs_extract	extraction+
~~soxs_response~~	~~extraction+~~
soxs_merge	extraction+
~~soxs_astro_phot~~	~~extraction+~~

10 sec

1 min

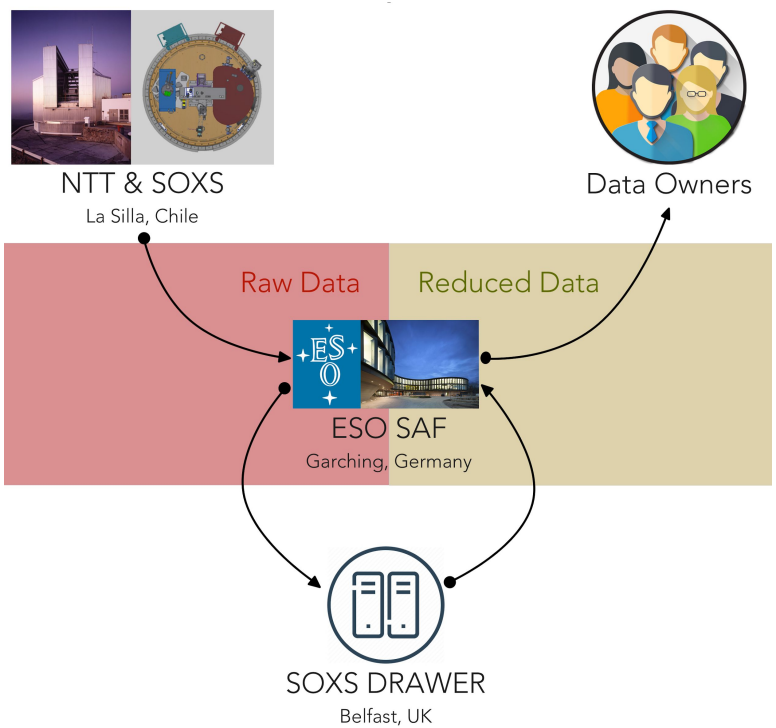
5 min

5 min

1 min

Total Reduction Time for Single Observation ≈ 12 min

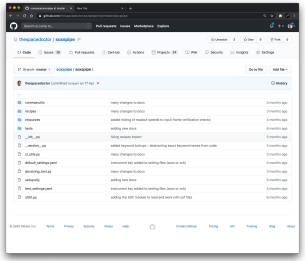
Automated Data-Reduction



- SOXS Data Reduction And WEllness Reporter (DRAWER).
- Automated reduction of data with access to history of calibration frames.
- Monitor health of instruments.

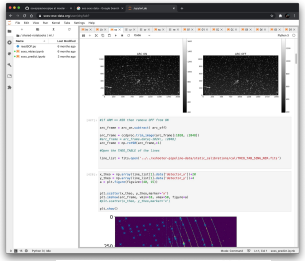
GOAL: populate the ESO SAF with the fully reduced data products within 30 mins of raw data appearing in the SAF (15 min stretch goal)

Development Environment & Infrastructure



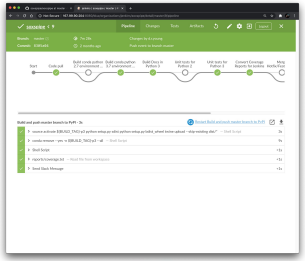
GitHub

Version Control via git and Github as a 'centralised' remote repository (also for project planning and issue tracking).



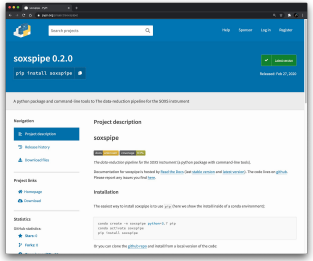
jupyter

Jupyter notebooks for development, investigation, prototyping, visualisation …



Jenkins

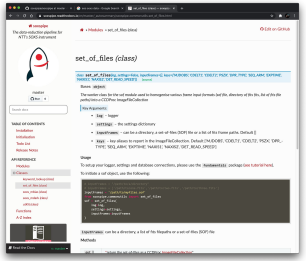
Code testing and continuous integrate via Jenkins server and declarative pipeline.



python Package Index

PyPi for production code distribution …

pip install soxspipe



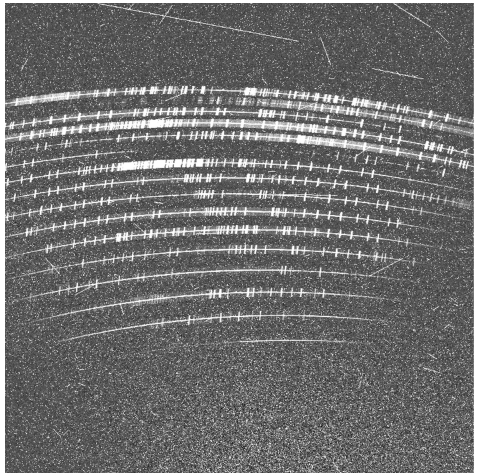
SPHINX

Read the Docs

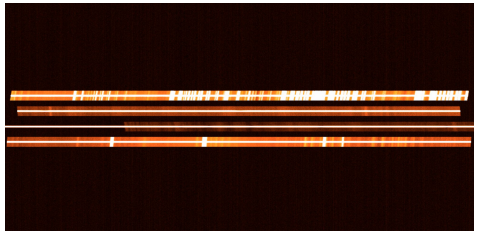
Docs written in docstrings and markdown files that live beside the code.

https://github.com/thespacedoctor/soxspipe
https://soxspipe.readthedocs.io/

Test Driven Development



Full NIR arm displaying a 300 second exposure of a V=16 mag point-source. Seeing 1", slit 1"



Full UV-VIS arm with a bright (V=8) object and different tilts on the slit for each pseudo-order

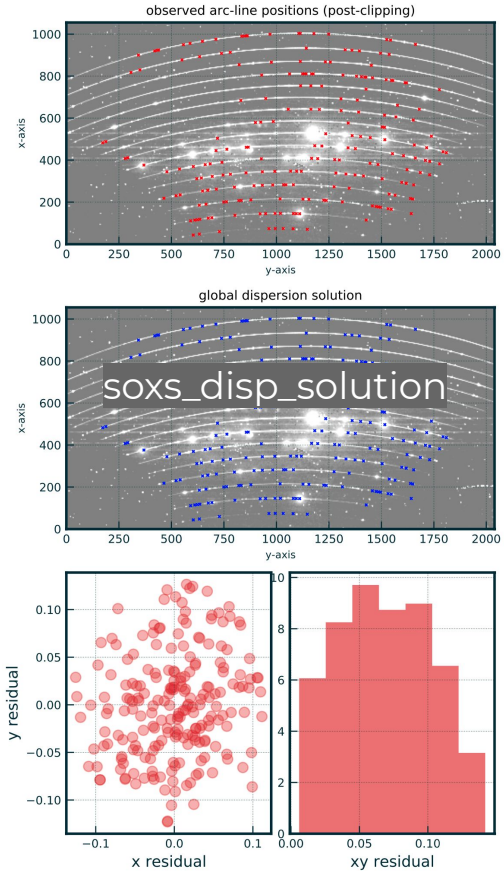
End-to-End (E2E) Simulator designed by Matteo Genoni used to generate mock data-sets for unit-tests.

'Extreme' mock data used to push the pipeline to the limits of its capabilities.

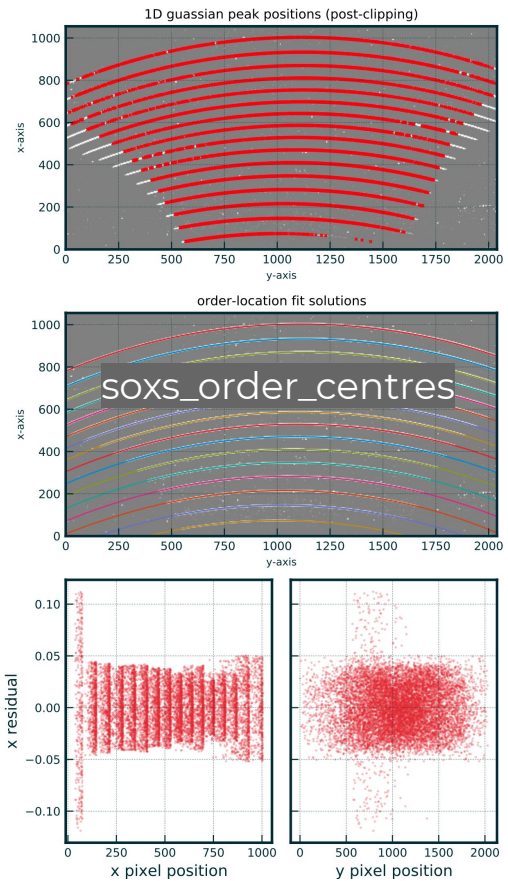
E2E Simulator can take into account the grating dispersion, sampling, PSF, noises and position of various resolution elements coming from full ray-tracing.

SOXS

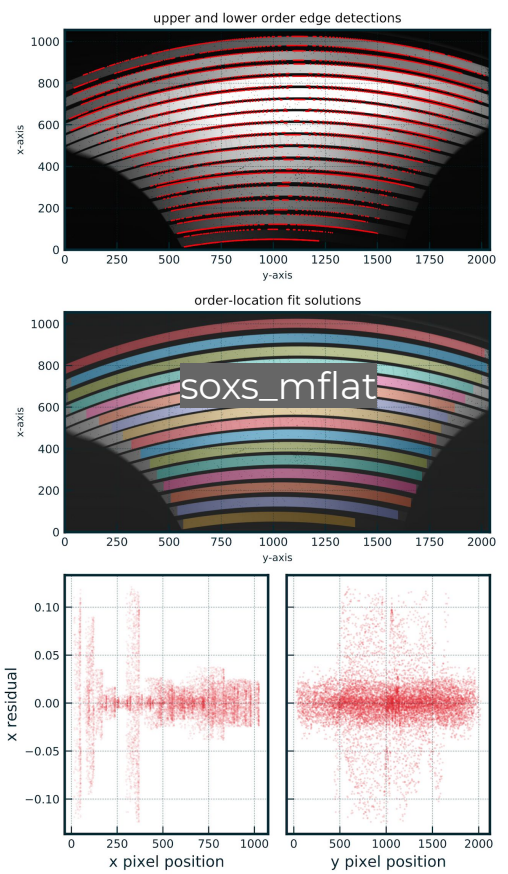
residuals of global dispersion solution fitting - single pinhole
mean res: 0.07 pix, res stdev: 0.03



traces of order-centre locations - pinhole flat-frame
mean res: 0.02 pix, res stdev: 0.01



detection of order-edge locations - flat-frame
mean res: 0.02 pix, res stdev: 0.02



A soxspipe Recipe API

```python
from ._base_recipe_ import _base_recipe_

class soxs_mbias(_base_recipe_):

    def __init__(
            self,
            log,
            settings=False,
            inputFrames=[]
    ):

        ...
```

class **soxs_mbias**(*log, settings=False, inputFrames=[]*) [source]

Bases: `soxspipe.recipes._base_recipe_._base_recipe_`

The soxs_mbias recipe

Key Arguments

- `log` – logger
- `settings` – the settings dictionary
- `inputFrames` – input fits frames. Can be a directory, a set-of-files (SOF) file or a list of fits frame paths. Default []

Methods

`clean_up` ()	*remove intermediate files once recipe is complete*
`prepare_frames` ([save])	*prepare all frames in the input data*
`prepare_single_frame` (frame[, save])	*prepare a single raw frame by converting to electron counts and adding mask and uncertainty extensions*
`produce_product` ()	*The code to generate the product of the soxs_mbias recipe*
`verify_input_frames` ()	*verify the input frame match those required by the soxs_mbias recipe*

https://www.eso.org/sci/software/pipelines/installation/software_prerequisites.html

ESO Pipelines and EsoReflex Software Prerequisites for Source-based Installations

Home | About | RPM Installation | MacPorts Installation | Source Kits | Support

EsoReflex 2.9.0 and newer supports Python based recipes as long as EsoRex is compiled with one of the following prerequisites:

Pipeline Usage

Installation

```
> pip install soxspipe
```

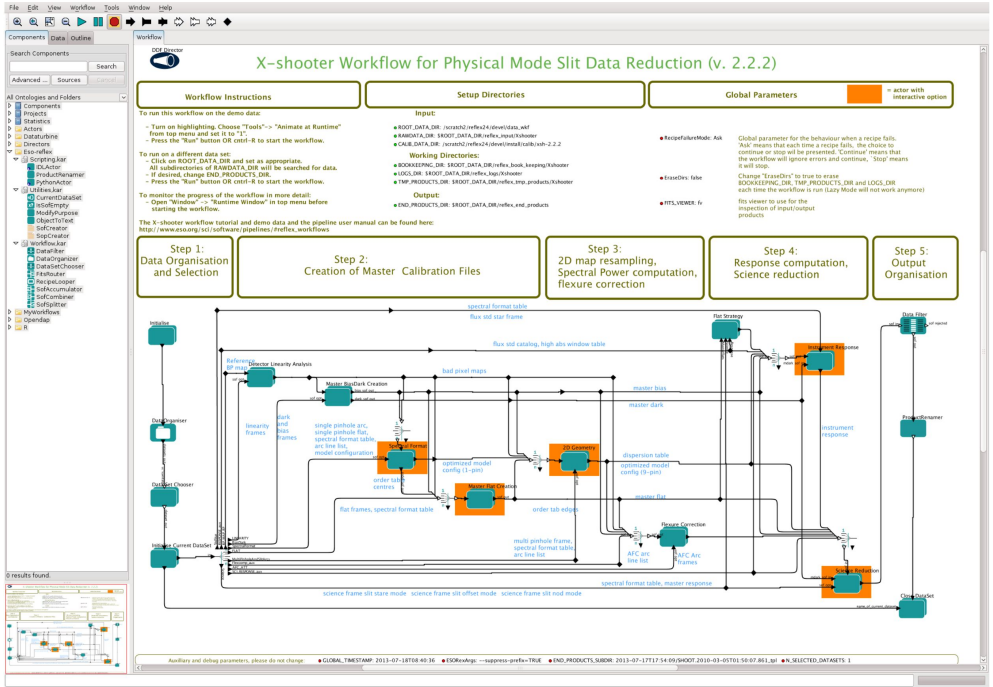
Pipeline Usage

A soxspipe Command-line Interface (ala ESORex)

```
> soxspipe -h

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

Usage:
    soxspipe init
    soxspipe mbias <inputFrames> [-s <pathToSettingsFile>]
    soxspipe mdark <inputFrames> [-s <pathToSettingsFile>]
    soxspipe mflat <inputFrames> [-s <pathToSettingsFile>]
    soxspipe disp_sol <inputFrames> [-s <pathToSettingsFile>]
    soxspipe order_centres <inputFrames> [-s <pathToSettingsFile>]


Options:
    init                                setup the soxspipe settings file for the first time
    mbias                               the master bias recipe
    mdark                               the master dark recipe
    mflat                               the master flat recipe
    disp_sol                            the disp solution recipe
    order_centres                       the order centres recipe

    inputFrames                         path to a directory of frames or a set-of-files fi

    -h, --help                          show this help message
```

Pipeline Usage

ESORelfex GUI



Summary

- Final data products include 1D source spectra, 1D merged source specta, 2D source spectra, acquisition camera images.
- Pipeline will drive automated data reductions for ~90% of data, shipping finally ESO Phase III compliant data to the ESO SAF
- Goal of populating the ESO SAF with reduced data within 30 mins of raw data appearing in archive
- Pipeline will be very easy to install and well documented for those wishing to re-reduce their own data
- Full pipeline version to be released to coincided with PAC.
- On-sky bug fixes followed by public release after commissioning commences