ArXSP

Archive Spectrum Processing Tool

User Manual

Version: *1.0*
Draft (not fully polished, but safe to use)

Fesenkov Astrophysical Institute

Authors:

I. Izmailova
A. Umirbayeva
M. Khassanov
L. Aktay
S. Shomshekova

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Contents

Chapter 1

Introduction

ArXSP (Archive Spectrum Processing Tool) is a software package developed at the Fesenkov Astrophysical Institute for processing archival spectral data in FITS format. The program is designed for the reduction, alignment, and calibration of archival spectra obtained during many years of observations at the institute's telescopes.

The purpose of this document is to provide a complete user guide for installing, launching, and operating ArXSP, including:

- system requirements;
- installation on Windows, Linux, and macOS;
- description of the graphical interface;
- structure of the processing modules;
- an example of a full spectral reduction workflow.

Funding

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Legal Information and Authors

ArXSP is registered as an object of copyright:

> *Certificate of registration in the State Register of Copyright-Protected Objects No. 60032 dated June 19, 2025.* Type of object: **computer software**. Title: **ArXSP**. Authors: Khassanov M. K., Izmailova I. M., Umirbayeva A. Zh., Shomshekova S. A.

This documentation accompanies the officially registered version of the software and is intended for a wide range of users: researchers, engineers, educators, students working with spectroscopic data, and anyone interested in processing archival FITS files.

When using the software or materials from this manual, please cite the following works:

- the original publication:
  Izmailova I., Umirbayeva A., Khassanov M., Aktay L., Shomshekova S., *ArxSP: A Python-Based Modular Application for the Reduction of Digitized Archival Spectra*. Available at SSRN: https://ssrn.com/abstract=5494087 or http://dx.doi.org/10.2139/ssrn.5494087;
- the official project repository on GitHub[1].

[1] https://github.com/ill-i/ArXSP

Chapter 2

System Requirements

This manual covers three distribution packages provided with the ArXSP software: installers for **Windows**, **Linux**, and **macOS**. Each package contains a self-contained application that does not require a separate Python installation or any external libraries (all dependencies are bundled into the executable).

Operating Systems

- **Windows:** Windows 10 / 11 (64-bit).
- **Linux:** any modern distribution is expected to work; tested on Ubuntu 20.04+.
- **macOS:** macOS 12 Monterey or newer (Apple Silicon architecture supported).

Processor Architectures

- **Intel x64** — Windows and Linux.
- **Apple Silicon (ARM64)** — macOS (M1/M2/M3/M4), with full testing performed on M1.

Hardware Requirements

- **RAM:** at least 8 GB (16 GB recommended) for stable operation with large spectral files.
- **Disk space:** approximately 1 GB for installation and temporary files.
- **Graphics subsystem:** any GPU supporting OpenGL 3.0+ (required for proper PyQt5 GUI rendering).

Additional Software

All dependencies are bundled with the executable, and no external components are required:

- **Python, and libraries such as NumPy, SciPy, Astropy, OpenCV, PyQt5, and others** are included within the application and do not need to be installed separately.
- No environment configuration is required from the user.

Input and Auxiliary File Formats

- **FITS** — the primary format for spectral input data (reading and writing of processed FITS files is supported).
- **CSV** — a file containing polynomial calibration coefficients; the structure is described in detail in Chapter 5.

Chapter 3

Software Installation

ArXSP is distributed as three standalone installation packages[1], built for the corresponding operating systems:

- **Windows:** `ArXSP_Windows.exe`
- **Linux:** `ArXSP_Linux.AppImage`
- **macOS:** `ArXSP.dmg`

Each installation file contains a fully self-contained executable that includes Python, all required dependencies, and libraries, so no additional environment setup is needed.

3.1 Installation on Windows

Step 1. Download the installer

Download the file:

`ArXSP_Windows.exe`

Step 2. Run the installer

Double-click `ArXSP_Windows.exe`. A standard Windows SmartScreen window will appear:

"Windows protected your PC"

[1] https://vo.fai.kz/software.php

To proceed, click:

1. **More info**
2. **Run anyway**

(This is normal for applications that do not have a digital signature.)

Step 3. Complete the installation

Choose the installation path and click `Install`. After installation, the program will appear in the `Start Menu`.

3.2 Installation on Linux

The Linux version of ArXSP is provided as a `.deb` binary package intended for distributions based on Ubuntu 20.04+.

Step 1. Download the package

Download the file:

`ArXSP_Linux.deb`

Step 2. Installation via graphical package manager

On most distributions, the package can be installed by double-clicking:

1. Open the file `ArXSP_Linux.deb`.
2. In the pop-up window, click `Install`.
3. Enter your administrator password.

Step 3. Installation via terminal

If needed, you can install the package manually:

```
sudo dpkg -i ArXSP_Linux.deb
```

If dependency errors appear, run:

```
sudo apt --fix-broken install
```

This will install the required libraries and complete the installation.

Step 4. Launching the program

After installation, the application will be available in:

```
Applications → ArXSP
```

Notes

- The package includes a bundled Python interpreter and all dependencies (PyQt5, NumPy, SciPy, Astropy, OpenCV), so no additional libraries are required.
- On distributions without `apt` (e.g., Fedora, Arch), the `.deb` file will not work. In such cases, use a Linux build suitable for your distribution or compile the program manually from the GitHub source code[2].

3.3 Installation on macOS

The macOS version is distributed as a `DMG` image.

Step 1. Open the installation file

Open:

```
ArXSP_macOS.dmg
```

Step 2. Installation

Drag `ArXSP.app` into the `Applications` folder.

[2] https://github.com/ill-i/ArXSP

Step 3. First launch (bypassing Gatekeeper)

On the first launch, macOS may display a warning:

> "ArXSP.app cannot be opened because the developer cannot be verified."

or

> "ArXSP.app can't be opened because Apple cannot check it for malicious software."

This is standard for applications that have not passed Apple Notarization. To open the program, use one of the following methods.

Option A. Launch via context menu

1. Open the `Applications` folder.
2. Right-click `ArXSP.app`.
3. Select `Open`.
4. In the pop-up window, click `Open` again.

Option B. Allow the launch in macOS settings

1. Open `System Settings`.
2. Go to `Privacy & Security`.
3. Scroll to the `Security` section.
4. Find the message indicating that `ArXSP.app` was blocked.
5. Click `Open Anyway` (or `Allow`, depending on macOS version).
6. Confirm the launch in the dialog window.

Chapter 4

Program Interface

The graphical interface of ArXSP is organized into three main vertical panels and an additional terminal area:

1. **Left panel** — navigation and processing mode tabs;
2. **Central panel** — the main visualization area for spectra;
3. **Right panel** — processing tools and parameter controls;
4. **Terminal** — system messages and processing logs.

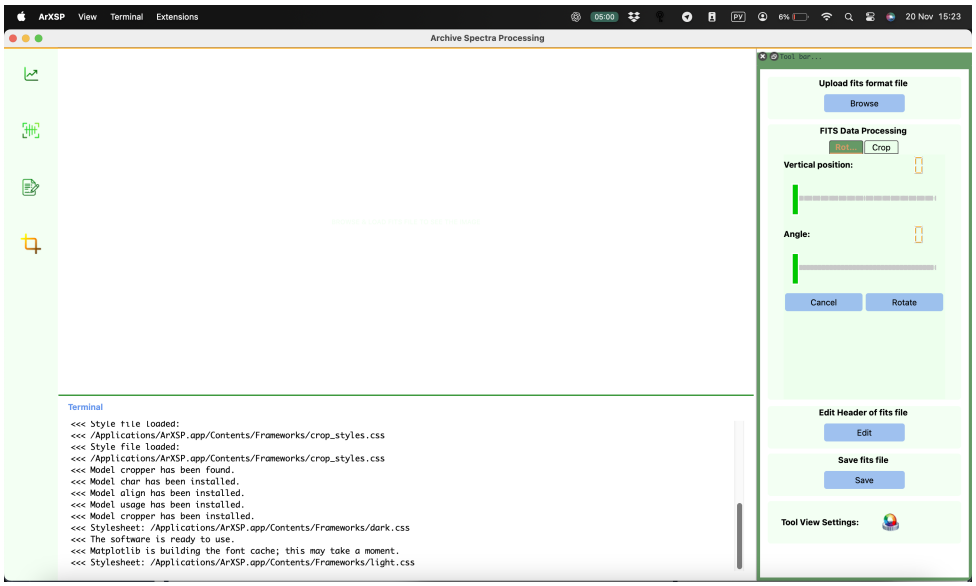


Figure 4.1: Example of the ArXSP main window.

4.1 Left Panel: Tool Tabs

The left panel contains a set of tabs, each corresponding to a separate data processing module.

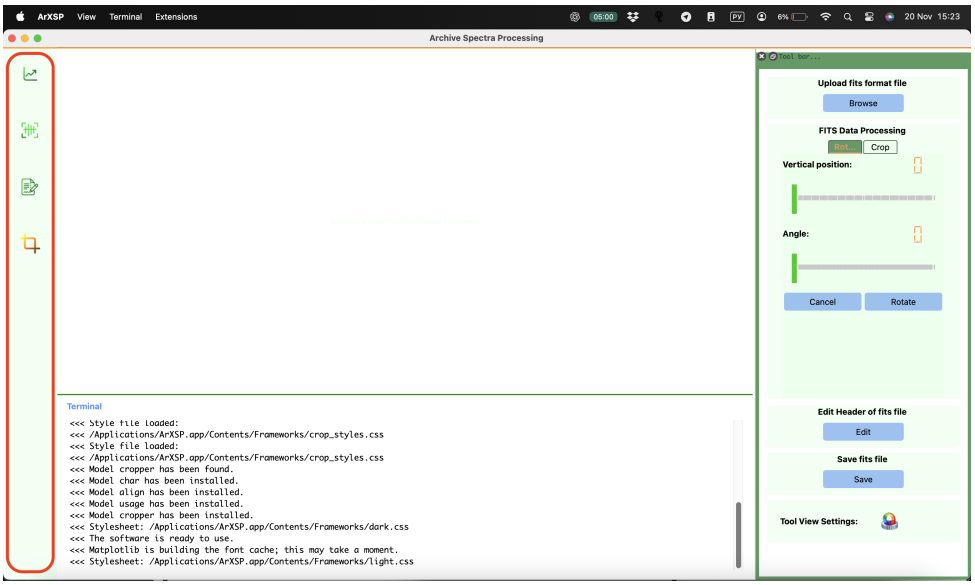


Figure 4.2: Example of the ArXSP window. The left panel is highlighted with a red rectangle.

The current version of the program includes the following modules:

- **Cropper** — initial image preparation: cropping and rotation;
- **Align** — spectrum alignment and correction of geometric distortions;
- **Char** — extraction of the characteristic curve for spectrum calibration;
- **Usage** — auxiliary information (optional).

4.2 Central Panel: Visualization Area

This is the main working area of the program, used for displaying images, plots, and interactive reduction elements. The central panel:

- visualizes the 2D FITS image of the spectrum;
- supports drawing guide lines and auxiliary graphics;
- displays processing results in real time.

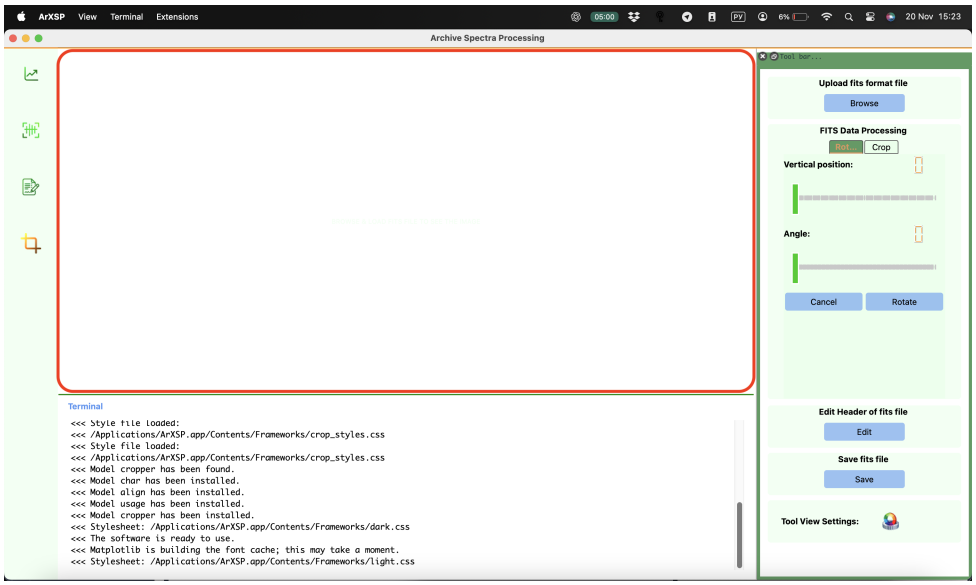


Figure 4.3: Example of the ArXSP window. The central panel is highlighted with a red rectangle.

In every mode, the left and right panels interact with this area, making the central window the core element of the interface.

4.3 Right Panel: Tool Controls

The right panel contains the main controls for the active module and changes depending on the selected tab.

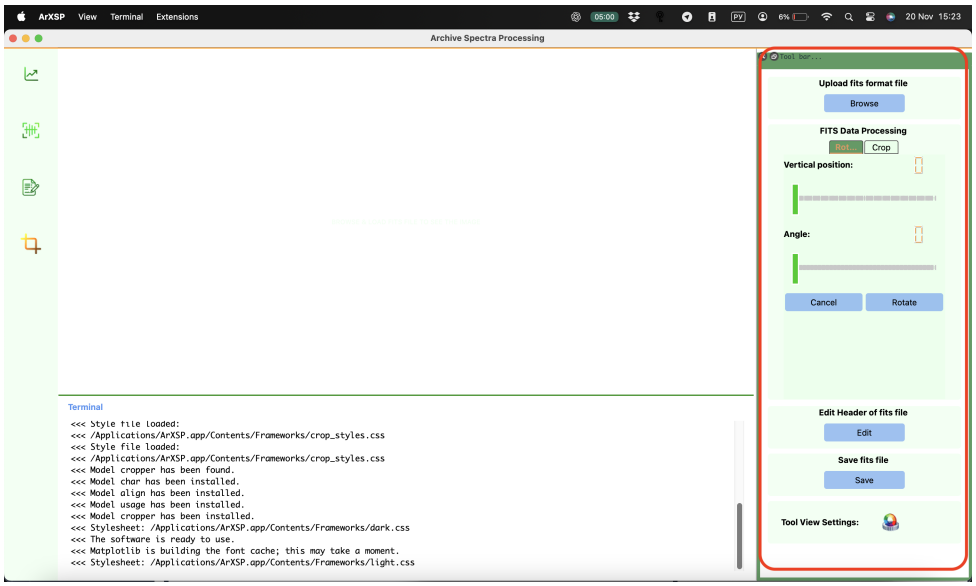


Figure 4.4: Example of the ArXSP window. The right panel is highlighted with a red rectangle.

It includes file loading and saving fields, sliders for interactive tools, and other module-specific controls.

4.4 Terminal

In addition to the three main interface zones, the program includes a built-in terminal panel. It displays system messages, operation logs, and diagnostic information.

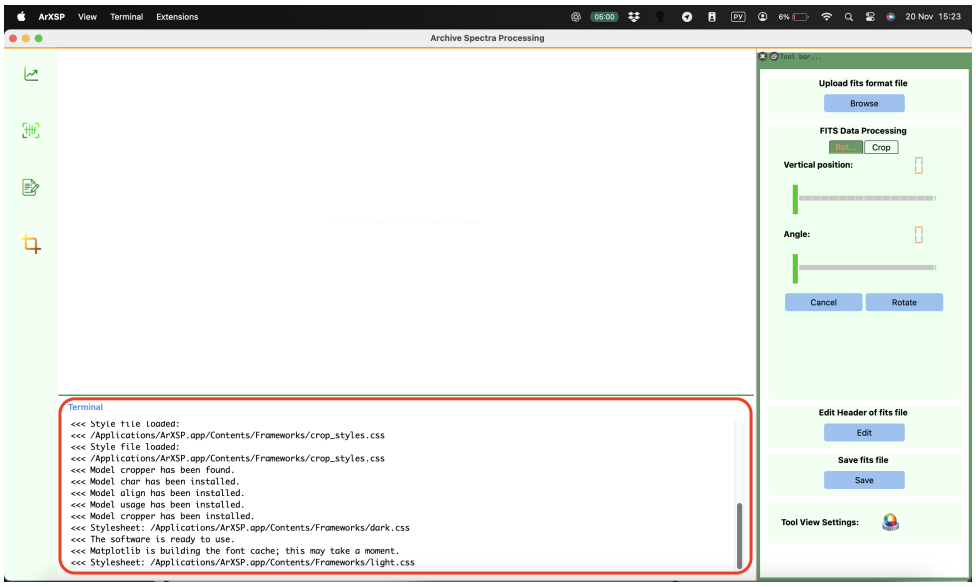


Figure 4.5: Example of the ArXSP window. The terminal is highlighted with a red rectangle.

This panel is used to monitor the processing state and helps track the execution of algorithms.

Chapter 5

Input and Auxiliary Files

Input Data Formats

ArXSP works with two types of files:

- **spectral and raw calibration data** in FITS format;
- **calibration polynomial coefficients** in CSV format.

Each file type serves its specific role in the processing workflow and may appear at different stages of the pipeline.

5.1 Observational Data Files (FITS)

ArXSP supports standard FITS formats:

- `.fits`
- `.fit`

A FITS file contains:

- a 2D spectrum image;
- a header with metadata and all necessary auxiliary information.

These files are the primary input for the entire reduction process. They are loaded through the interface, visualized in the central panel, and used for:

- alignment,

- distortion correction,
- transformation of optical densities,
- intensity calculation.

After processing, results are saved back into a FITS file.

5.2 CSV File with Calibration Polynomial Coefficients

A CSV file is used to store polynomial coefficients required to convert optical density into intensity. It serves as a user-maintained calibration database.

5.2.1 Expected File Structure

The program expects a table with the following columns:

```
id,date_obs,best_poly,extra_poly,root,note
```

Field descriptions:

- **id** — calibration identifier (telescope, object, or code);
- **date_obs** — observation date (DD.MM.YYYY);
- **best_poly** — main polynomial coefficients, listed with semicolons;
- **extra_poly** — additional polynomial coefficients for the low-density range (from the lower limit to zero), also listed with semicolons;
- **root** — transition point from the main polynomial to the additional one;
- **note** — comments related to calibration frames or conditions affecting further processing.

Example row:

```
BMNY,30.10.1992,1.2e-14;-9.8e-11;...;49413,3.2e-51;...,710.63,"noisy frames"
```

5.2.2 When a CSV File May Be Missing

At the start of working with a new dataset, **the CSV file may be absent completely**. This is normal — no need to worry.

Polynomial coefficients are generated only after processing calibration frames. **Simply proceed to the next step of the instructions.**

5.2.3 Building and Maintaining the Calibration Database

After the first calibration session, the program generates a set of coefficients and prompts you to save them to a CSV file. It is recommended to:

- use a **single** CSV file for all polynomials;
- gradually extend the table with new rows;
- avoid creating a separate CSV file for each observing night.

This creates a unified calibration database.

The program will then automatically:

- read the entire CSV file;
- find the date closest to the `DATE-OBS` of the FITS file;
- select the corresponding polynomial;
- apply it during calibration.

5.2.4 How Polynomial Selection Works

1. The program reads `DATE-OBS` from the FITS header.
2. All dates in the CSV file are converted to a unified time format (`datetime`).
3. The time difference to each calibration entry is computed.
4. The calibration closest in date to `DATE-OBS` is identified.
5. The user is shown a confirmation window with the selected polynomial.

Important Note

The program **does not apply any threshold** to determine whether the difference in dates is "acceptable".

This means:

> Even if the nearest calibration was obtained a year or more before the observation date, it will still be selected as the closest one.

Therefore, users are advised to:

- manually verify that the dates match the observing conditions;
- check whether the calibration night is appropriate for the dataset;
- select another row in the CSV file or create a new calibration if needed.

This approach ensures flexibility and allows the user to build a calibration database tailored to specific telescopes, cameras, and observing modes.

Chapter 6

Example of Data Processing

This section provides a complete example of the spectral preprocessing workflow in the `ArXSP` program. The workflow covers all major stages that both the user and the software follow on the way from a "distorted archival FITS frame" to a clean, calibrated one-dimensional spectrum.

The steps include:

- loading and reading the original FITS file;
- correcting the rotation angle;
- selecting the useful region of the spectrum;
- deriving the characteristic curve for calibration (conversion from optical densities to relative intensities);
- correcting the S-shaped distortion;
- performing the final spectral calibration.

The full preprocessing algorithm is shown in Figure 6.1.

The goal of preprocessing is to bring the image to a state in which the user can reliably inspect the profile, extract the spectrum, and perform subsequent spectral calibration using standard tools (such as IRAF, PyRAF, etc.).

6.1 Input Data

This example uses real archival material: a digitized spectral frame of the object MRK 335 and a set of calibration frames obtained during the night of **29–30 October 1992**.

Below is the list of files used in the example:

Figure 6.1: Flowchart illustrating the preprocessing of archival spectroscopic data. Green — input and output files; yellow — intermediate results; blue — automated processes; purple — manual processes; grey — background operations.

```
MRK335_29-30.10.1992_20m_LXXIV-4-6.fits
Calibrovka_29-30.10.1992_8s_I-3-cal-4.fits
Calibrovka_29-30.10.1992_30s_I-3-cal-4.fits
Calibrovka_29-30.10.1992_1m_I-3-cal-4.fits
Calibrovka_29-30.10.1992_2m_I-3-cal-4.fits
```

`Calibrovka_29-30.10.1992_4m_I-3-cal-4.fits`

The raw spectra were originally obtained with the AZT-8 telescope at the Kamenskoe Plateau Observatory. They were stored in the archive for many years, went through all the typical challenges of photographic plates, and were digitized only decades later as part of an institutional project[1]. More details on the digitization process and the construction of the digital archive can be found in Shomshekova et al. (2022a,b, 2023).

6.2 Geometric Correction and Region Selection

6.2.1 Loading the File

The workflow begins in the `Align` module, which is responsible for geometric correction and removal of the tilt of the spectral trace.

On the left panel, click the tab highlighted in the figure (see illustration `crop_browse`, marked in red). Then, on the right panel, select `Upload FITS format file` (the same illustration, marked in purple), choose the file in the standard dialog, and click `Open` (marked in orange).

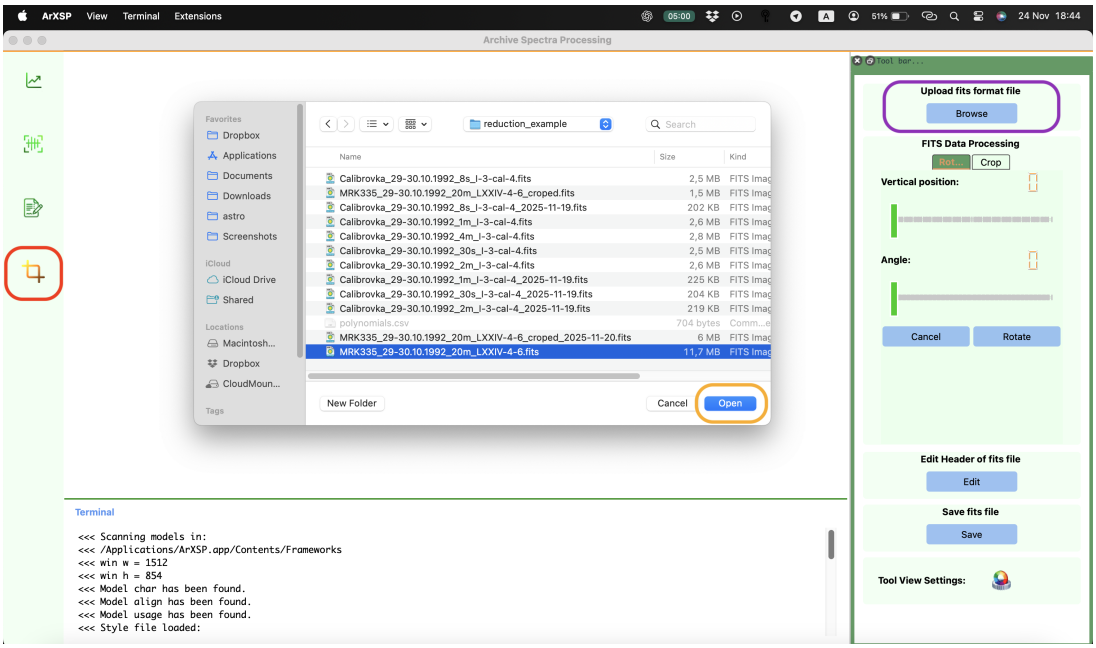


Figure 6.2: File selection window in the `Align` module: tab on the left panel (red outline), `Upload FITS format file` (purple outline), and the `Open` button in the file dialog (orange outline).

The loaded file is automatically converted into an `ArxData` object, which includes:

- a two-dimensional data array;

[1] https://fai.kz/projects/virtobs

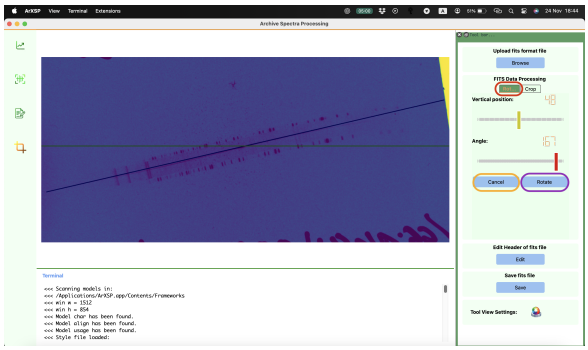
- the FITS header;
- key metadata (filename, exposure time, observation date).

After this, you may proceed to alignment.

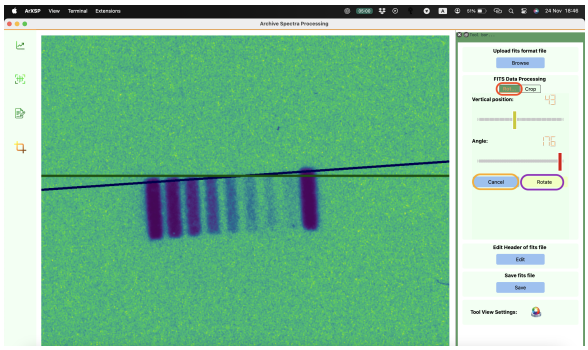
6.2.2 Geometric Correction

It is recommended to perform the rotation *before* cropping. The reason is simple: rotation introduces empty triangular corners, and these areas will need to be cropped later anyway.

To apply the correction, open the tool `Rotate` in the right-panel section `FITS Data Processing` (see figures `crop_rotate_line` and `crop_rotate_line_cal`, red outline; one for the spectrum, the other for the calibration frame). The right panel will show the tilt adjustment controls.



(a) Spectrum: the `Rotate` tool and alignment lines.



(b) Calibration frame: the `Rotate` tool and alignment lines.

Figure 6.3: Example of using the `Rotate` tool for aligning a spectrum (a) and a calibration frame (b). Elements used at this stage are marked with red outlines.

Procedure:

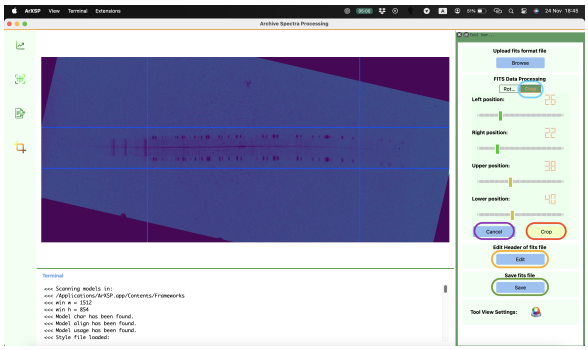
1. Move the upper `Vertical position` slider to raise or lower the green horizontal guide line. For spectra, align it with the object trace; for calibration frames, use the upper or lower boundary of the step pattern.
2. Adjust the tilt using the blue slider. The blue slanted line rotates relative to the fixed horizontal guide. Your task is to match it to the spectral tilt.
3. When satisfied with the result, click `Rotate` (button marked in purple). A `HISTORY` entry will appear in the FITS header.
4. If something went wrong, click `Cancel` (button marked in yellow) to roll back the rotation.

Once the tilt has been corrected, proceed to region selection.

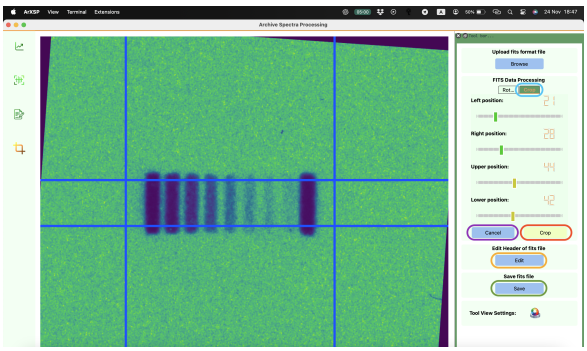
6.2.3 Selecting the Useful Region

The next step is to crop the image so that only the region containing useful information remains. Background, glare, and defects are naturally excluded from further processing.

On the right panel, select `Crop` (see illustrations `crope_line_cal` and `crope_line`, marked in red).



(a) Spectrum: setting the crop boundaries.



(b) Calibration frame: setting the crop boundaries.

Figure 6.4: Example of selecting the useful region for the spectrum (a) and calibration frame (b). Crop boundaries are marked with red lines.

The user specifies:

- upper boundary;
- lower boundary;
- left boundary;
- right boundary.

Recommendations:

- **For spectra:**
  - you may crop closely along the trace, leaving a small margin (2–3 pixels) to avoid cutting the spectrum;
  - leave some space above the trace — later steps include distortion correction and background subtraction.
- **For calibration frames:**
  - crop with a small margin above and below to avoid including background in the step region;
  - leave a thin "veil" of background on the sides — it helps with peak detection.

After positioning the crop lines, click `Crop` (button marked in red). A new `HISTORY` entry will be added to the FITS header.

If the crop was not satisfactory, click `Cancel` (button marked in yellow) to restore the previous image.

6.2.4 Editing the FITS Header

Cropping is the final step in this module, so this is the right moment to open *Edit Header of FITS file* and edit the header if needed (Figure 6.5).

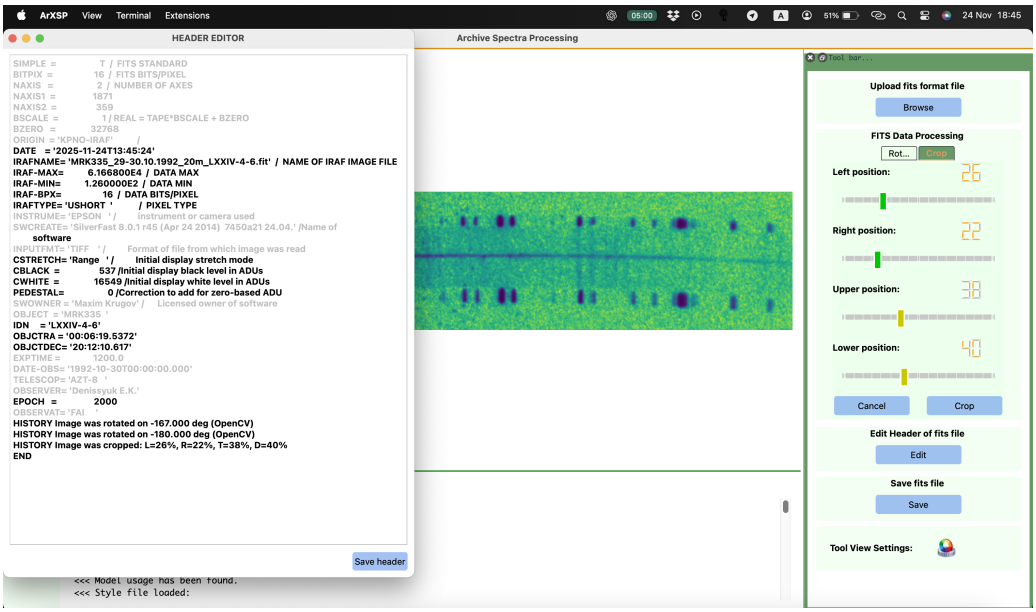


Figure 6.5: FITS header editing window (`Edit Header of FITS file`). Example shown for a spectral frame. The user may modify keys manually, while the program automatically formats them according to the FITS standard.

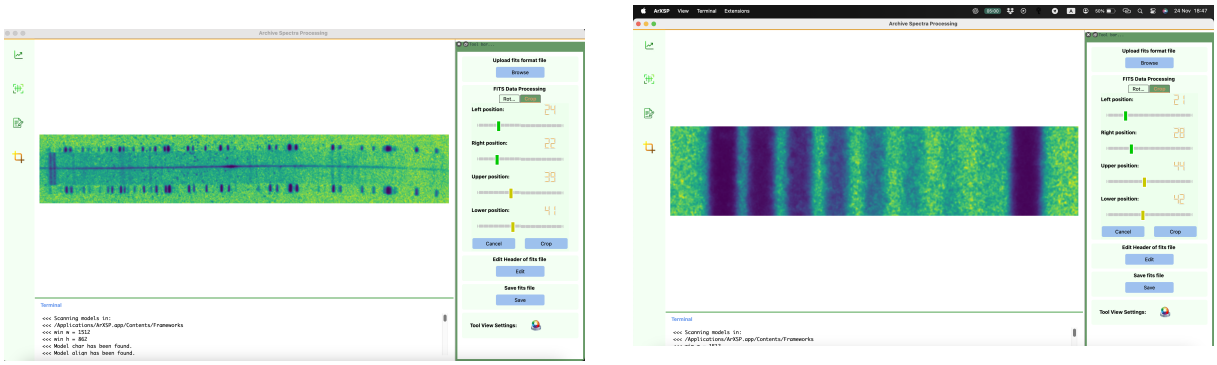
You can edit only those lines displayed in black. System entries that are important for processing and file integrity are shown in grey and cannot be modified. The program automatically corrects the following:

- key capitalization;
- placement of quotation marks and punctuation;
- minor syntax errors.

Nevertheless, it is advisable to enter values carefully.

6.2.5 Saving the Results

If the results look satisfactory—e.g., as in Figure 6.6—go to the `Save FITS file` section and click `Save` (button marked in green). A save dialog will appear. By default, the program appends the current date (the date of the latest reduction) to the filename.



(a) Result of spectrum alignment.

(b) Result of cropping and alignment of a calibration frame.

Figure 6.6: Final state of the images after all steps in the geometric correction module. Left — spectral frame; right — calibration frame. These results are used in the subsequent processing stages.

This completes the work of the geometry module.

6.3 Deriving the Characteristic Curve

The characteristic curve is a central component of processing archival spectra. It describes the transformation from optical densities recorded on the plate to relative intensities, which can be used for physical analysis. Modern CCDs do not require this step, but for digitized photographic plates it is essential.

The curve is derived in the `Char` module, and this is where the accuracy of previous steps becomes immediately visible: incorrect shifts, cropping errors, or residual background will affect the shape of the profile.

The workflow is described below.

6.3.1 Loading the Cropped Calibration Frame

After completing geometric correction and cropping, you may proceed to building the characteristic curve. Open the `Char` module (Figure 6.7, red outline on the left panel).

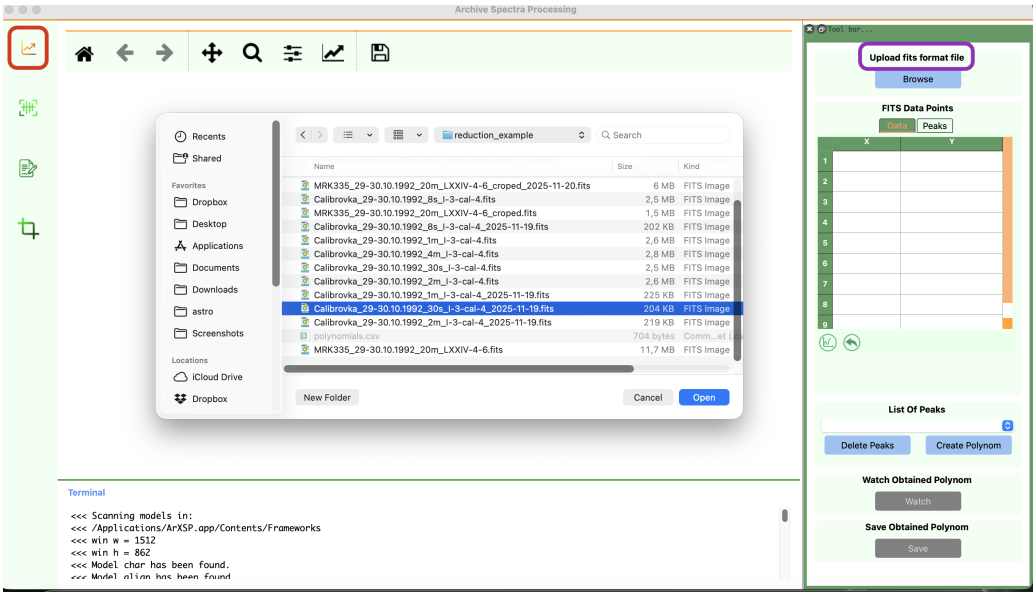


Figure 6.7: Initial view of the `Char` module and loading of the rotated, cropped calibration frame.

On the right panel, in the `Upload FITS format file` section (purple rectangle in Figure 6.7), click `Browse` and select the calibration frame in the dialog.

Yes, frames must be loaded one at a time — batch processing is not yet implemented.

Observation date is important!

Before loading, make sure that the FITS header contains the `DATE-OBS` key. The characteristic curve is associated with observation dates. If the date is missing, the program cannot select the appropriate calibration.

6.3.2 Building the column profile

The next step is to build a one-dimensional profile that shows how the brightness changes along the dispersion axis.

After loading the file, go to the `FITS Data Points` section on the right panel (purple area) and open the `Data` tab (orange area). Then click the button highlighted in red in Figure 6.8.

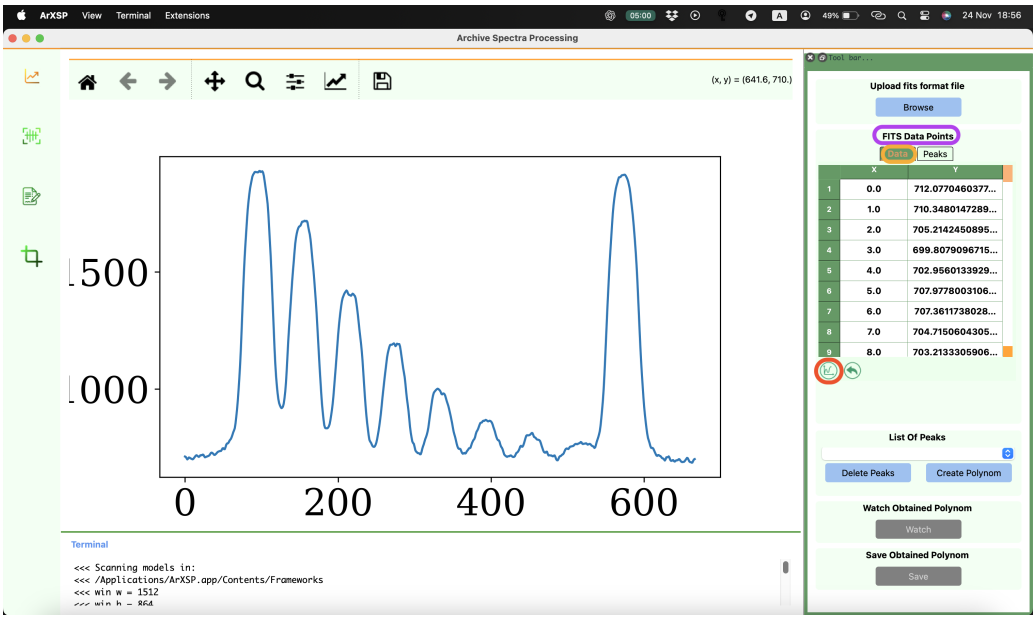


Figure 6.8: One-dimensional profile of the calibration frame built along the columns.

To obtain this plot from the two-dimensional image, the program:

1. integrates values along the vertical direction (taking into account the cropping boundaries);
2. forms a "density–pixel" array;
3. displays the resulting profile in the central panel.

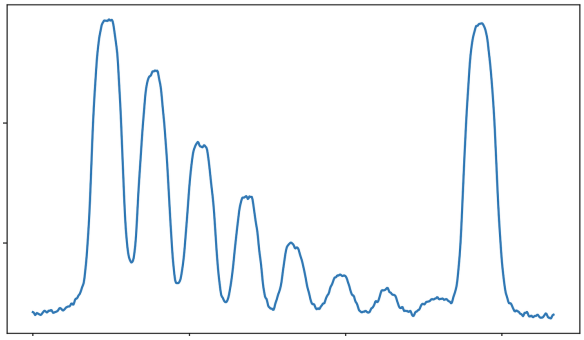
Figure 6.8 shows an example of the resulting profile in the central panel.

At this stage it is important that:

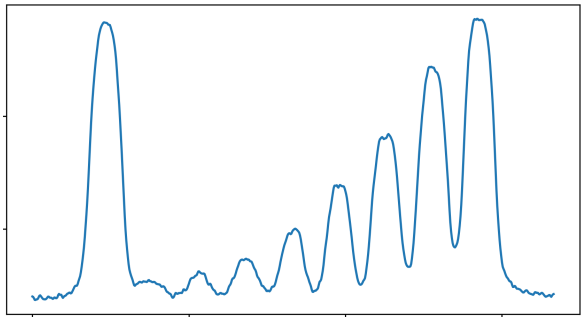
- there is no background inside the selected vertical strip;
- the attenuator steps are fully contained within the selected region;
- a small "veil" of background remains on both sides, which helps to detect the peaks.

Depending on how the calibration frame was scanned, you may see two basic cases (Figure 6.9):

- **normal** calibration: peaks decrease in height, with the last one almost at the level of the first;
- **mirrored** calibration: peaks increase in height in the opposite order.



(a) Normal calibration profile.



(b) Mirrored calibration profile.

Figure 6.9: One-dimensional profiles of normal and mirrored calibration frames. The x-axis shows column numbers in the image, the y-axis shows optical density (blackening).

For mirrored calibration frames it is recommended to use only the automatic mode. The manual mode has limitations in the current version.

The peaks are counted from left to right: the peak that lies almost at the same height as the maximum corresponds to the last (ninth) step.

Now a few words about **what may go wrong**.

Incorrect calibration.

If the second peak in height is equal to or higher than the first one, the calibration is considered overexposed ("burned"). It cannot be used further.

Clipped edge peaks.

If the outer steps were removed during cropping, the algorithm will not be able to determine the levels correctly. You need to repeat the cropping step, this time more carefully.

Example:

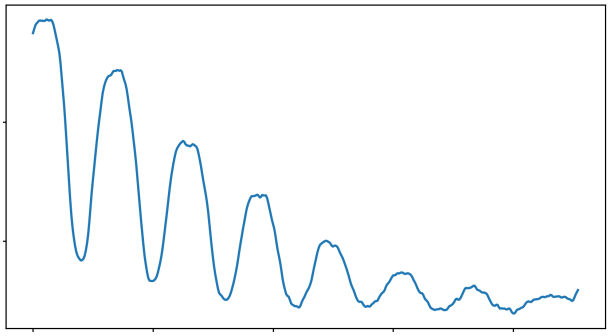


Figure 6.10: Example of incorrect cropping: the edge peaks are missing — the first one is cut in half and the ninth is missing completely. The x-axis shows column numbers in the image, the y-axis shows optical density (blackening).

6.3.3 Peak detection

The next task is to determine the attenuator step levels on the calibration frame.

After building the profile, go to the `FITS Data Points` section on the right panel (purple area) and open the `Peaks` tab (highlighted in orange in Figure 6.11).

Below the table of values, you will find the settings for selecting the peak detection order (orange area in Figure 6.11) and the automatic mode option (blue area in the same figure).

We strongly recommend using the automatic mode — even if the image is not mirrored. It is more stable and avoids many manual-mode issues.

After selecting the mode, click the button highlighted in red in Figure 6.11. The program will then:

1. search for local maxima;
2. display the detected peaks on the plot;
3. generate a table with the peak coordinates.

An example of the output is shown below:

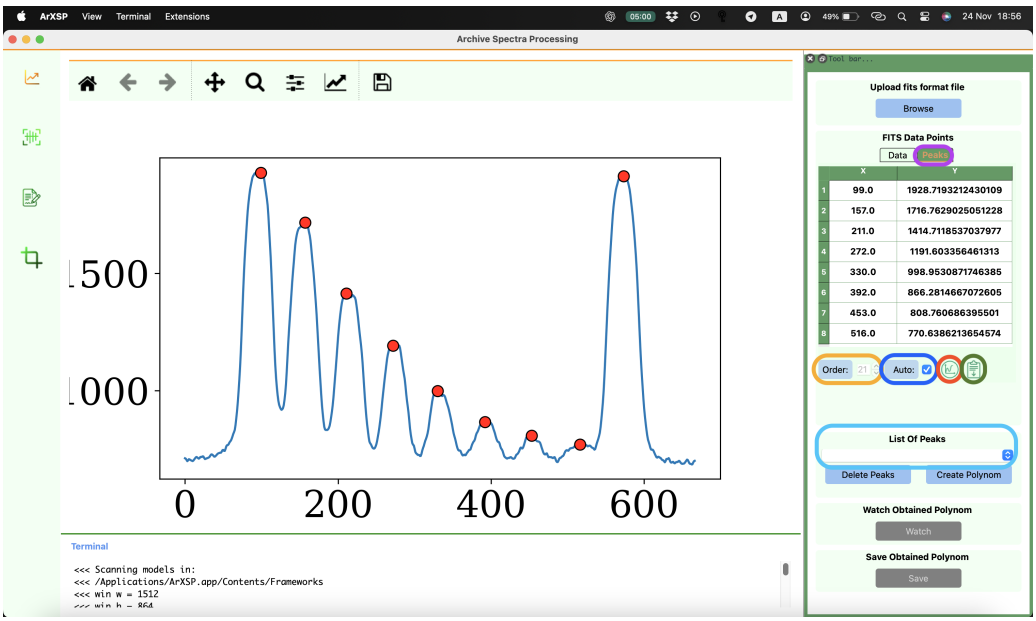


Figure 6.11: Automatically detected attenuator step peaks.

If the result looks correct, the detected peaks must be added to the internal database. This sounds formal, but in practice it is just a single button press (green area in Figure 6.11).

After clicking, a confirmation window will appear. You can verify the result in the `List Of Peaks` section on the right panel (highlighted in blue), where a new row will be added.

You now need to repeat the steps in Sections 6.3.1, 6.3.2, and 6.3.3 for all calibration frames obtained on the same observation date.

6.3.4 Building the characteristic curve

Once all peaks are detected and saved, you can proceed to constructing the characteristic curve. This is the step where the function relating optical density to relative intensity is obtained. For photographic plates this transformation is essential.

To open the characteristic-curve window, go to the `List Of Peaks` section on the right panel and click `Create Polynom`. A window like the one shown in Figure 6.12 will appear: the plot is on the left, controls and sliders on the right.

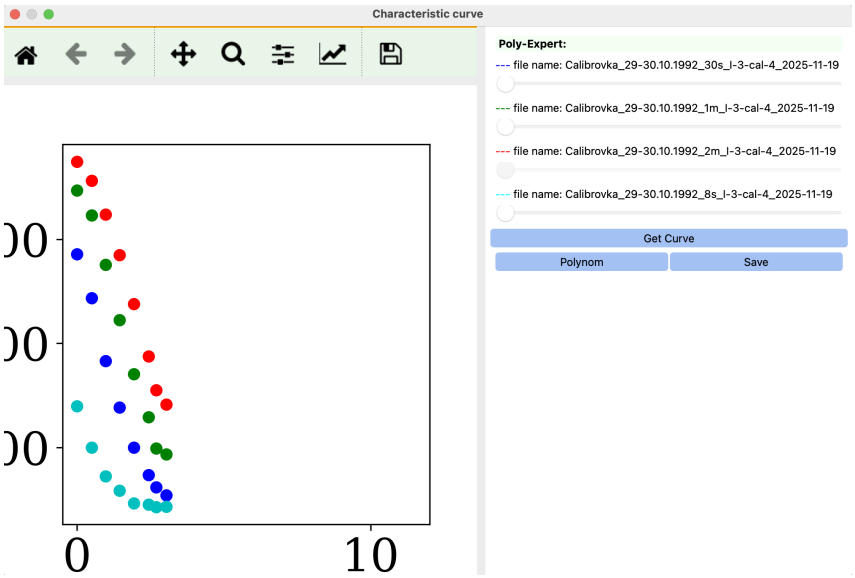


Figure 6.12: Interface for constructing the characteristic curve. The x-axis shows the attenuator step values ("magnitudes"), and the y-axis shows the measured optical density from the plate.

Each attenuator step reduces the light by a fixed amount, expressed in conventional "magnitudes". This is not astronomical photometry — these are laboratory measurements of attenuation. The program contains the required tabulated values and applies them automatically.

Each group of points corresponds to a calibration frame with a given exposure time. The highest set of points belongs to the longest exposure. This set is considered the reference and cannot be shifted; its slider is locked.

Your task is straightforward: **adjust all point sets so that they form a single smooth curve**.

This visual alignment step is acceptable. Many reduction packages — including IRAF — rely on similar procedures at certain stages. Reproducibility is ensured by fitting a polynomial afterwards.

An example of a correctly assembled curve is shown in Figure 6.13.

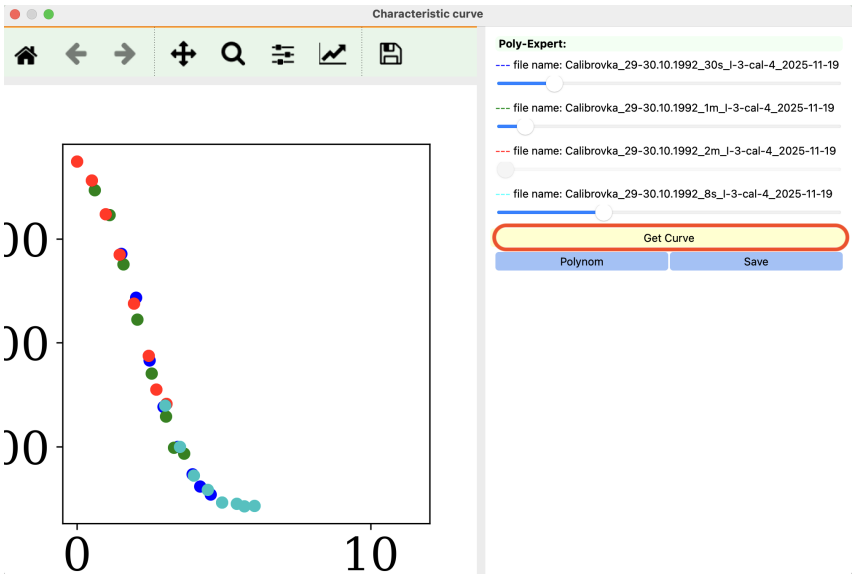


Figure 6.13: Example of a smoothly reconstructed curve combining all calibration exposures.

Once the curve looks smooth and physically reasonable, click `Get curve` (red area in Figure 6.13). The program will automatically convert the logarithmic scale to linear intensity.

The conversion uses the standard relation:

$$I = \frac{I_0}{10^{(m-m_0)/2.5}},$$

where m is the attenuator step value, I is the relative intensity, and I_0 is the chosen zero point (the program uses 10 000 at $m = 0$).

No manual calculation is required — the program performs all operations internally.

The result is shown in Figure 6.14.

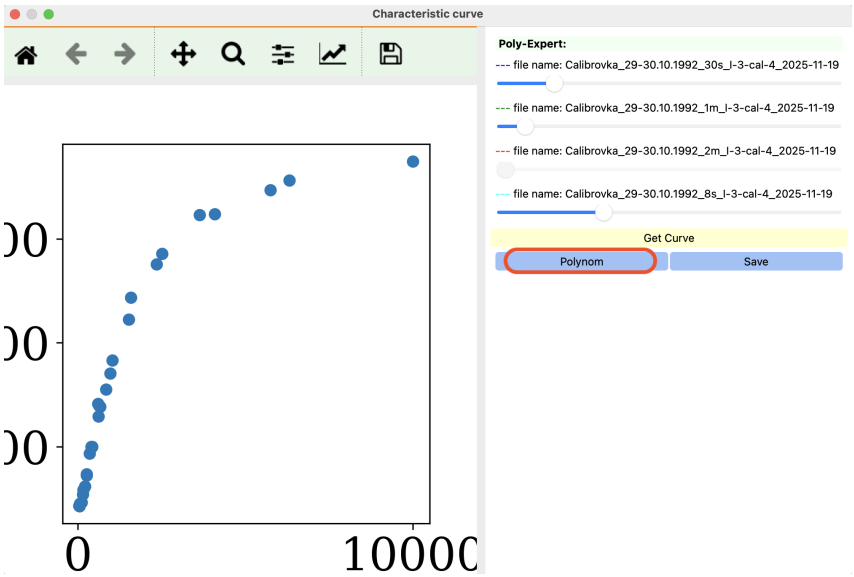


Figure 6.14: Characteristic curve in "optical density — intensity" coordinates.

To turn the curve into a mathematical function, click `Polynom` (red area in Figure 6.14). The program will fit a polynomial and check its monotonicity. The curve must not show any dips, and — most importantly — **each value of optical density must correspond to a unique intensity**.

If the fit is successful, you will see a result like Figure 6.15.

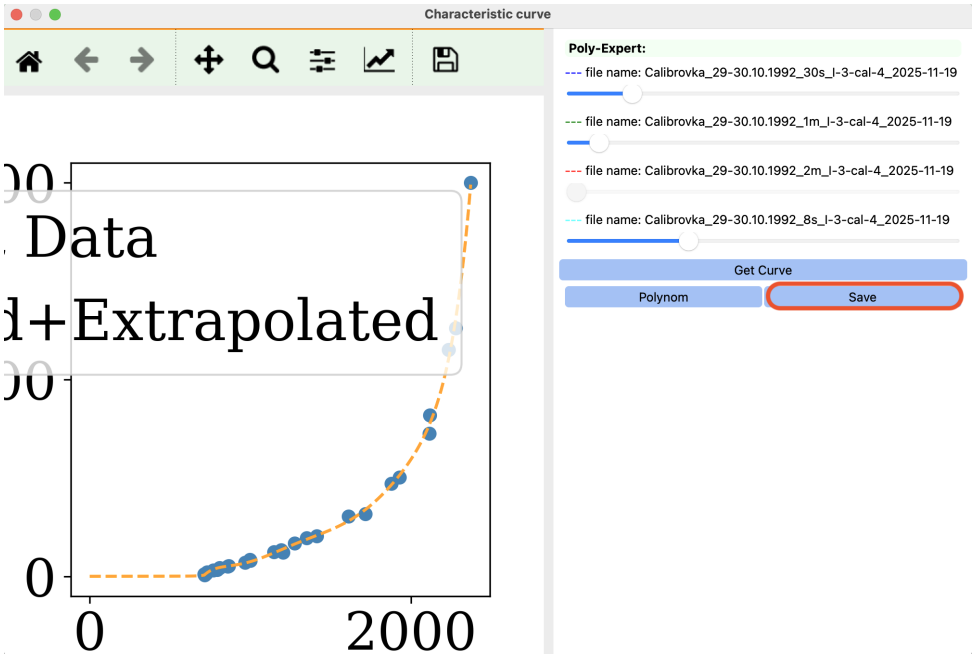


Figure 6.15: Polynomial approximation of the characteristic curve. The screenshot appears cropped because scaling is still unstable in the current version.

The program also constructs an additional "tail" polynomial for low densities (extrapolation). This ensures a correct transformation in the region from zero up to the lower limit of the main curve.

After the polynomial is built, click `Save` (red area in Figure 6.15). This saves the result in the program's temporary memory.

However, this does not yet store the polynomial in your calibration archive.

To save it permanently to a CSV file, go to the main window, find the `Save Obtained Polynom` section, and click `Save`. A dialog will appear where you can choose the file location.

The CSV format is described in Section 5. In short, each row contains:

- the calibration date;
- coefficients of the main polynomial;
- coefficients of the auxiliary polynomial;
- the transition point between them;
- optional comments.

After saving, the polynomial is ready for use with any spectra obtained near that observation date.

6.4 Distortion correction and calibration

After obtaining the characteristic curve and saving the results of the previous step, the next task is to bring the spectrum into a form suitable for quantitative analysis: to remove the S-shaped distortion and apply the spectral calibration. A detailed description of the origin of this distortion and the internal correction algorithm can be found in (Shomshekova et al., 2023) and (Izmailova et al., 2024).

This stage is performed using the corresponding tools in the `Char` module (highlighted in blue on the left panel in Figure 6.16). Although the interface remains familiar, the logic of the process is different: here we are working not with the geometric shape of the frame, but with the structure of the spectrum.

The key steps are described below.

6.4.1 S-shaped distortion correction

Archival photographic spectra almost always exhibit a characteristic S-shaped distortion. It is caused by the magnetic field of the electron-optical converter, which bends the trajectories of the electrons. For accurate extraction of the one-dimensional spectrum and for subsequent photometric analysis, this distortion must be removed.

Selecting the region and alignment

Begin by loading the cropped spectrum frame using the `Browse` button in the `Load the spectrum to start aligning` section on the right panel (red highlight in Figure 6.16).

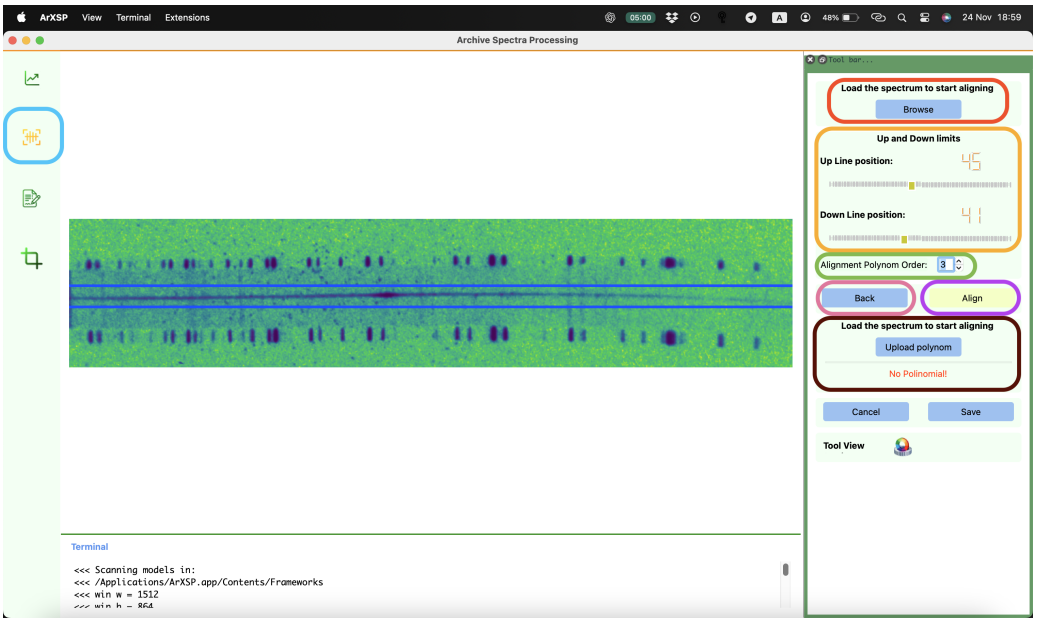


Figure 6.16: Identifying the central line of the spectrum for distortion correction. The plot shows the position of the maximum along the dispersion axis.

Typically, three structures are visible in the frame: two sets of horizontal calibration-lamp lines and a narrower continuous line corresponding to the object's spectrum. In some cases, one set of lamp lines may be missing — this is not critical, as one set is sufficient for wavelength anchoring.

A more problematic situation arises when the object spectrum is barely visible or disappears into the noise. If only faint traces are present, you may try selecting the region manually, but a reliable correction may not be achievable.

Figure 6.16 shows how the object spectrum is placed within an aperture defined by two blue horizontal lines. These boundaries are adjusted using the sliders in the `Up and Down limits` section (orange area). Once the region is selected, choose the polynomial degree for approximating the S-shaped curve (green area), then click `Align` (purple area).

After estimating the S-shape via a polynomial approximation, the program performs:

1. a row-wise shift to place the spectrum maximum along a horizontal line;
2. interpolation of values where required;
3. construction of a new two-dimensional frame without S-shaped distortion.

If the result is unsatisfactory, you can revert one step using the `Back` button (pink highlight in Figure 6.16). After reverting, try adjusting the aperture width or changing the

polynomial degree. It is common for one of the edges of the spectrum to remain imperfectly aligned — this is normal. The outer regions usually do not contain useful spectral features, so focus on obtaining high-quality alignment in the central part.

An example of a corrected frame is shown in Figure 6.17.

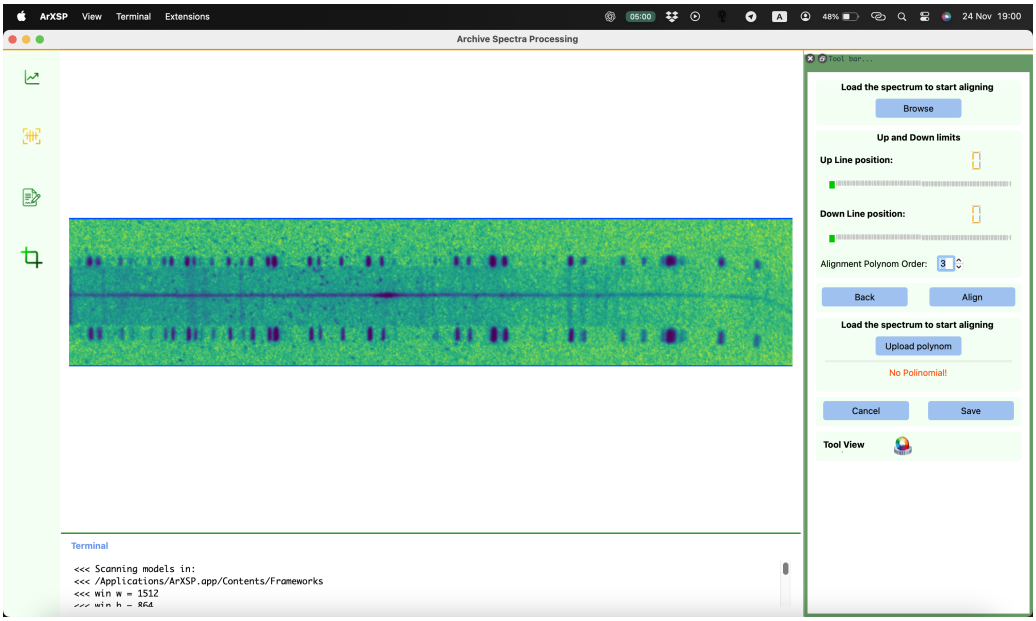


Figure 6.17: Result of the S-shaped distortion correction: the spectrum maximum is aligned horizontally across the frame.

Once the alignment looks satisfactory, proceed to the final step.

6.4.2 Calibration using the characteristic curve

After correcting the distortion, the final step is to convert optical density values into relative intensities. This transformation uses the characteristic curve derived earlier (see Section 6.3).

The characteristic curve describes the relationship between the optical density of the emulsion and the actual photometric flux recorded on the plate. The program applies the polynomial approximation to every pixel in the spectrum to compute intensities in a linear scale. This transformation enables further operations such as measuring spectral line fluxes, building line profiles, comparing with standard spectra, and other spectroscopic analyses.

Loading the characteristic-curve coefficients

To apply the characteristic curve, load the CSV file containing the polynomial coefficients. Proceed as follows:

1. Click `Upload polynom` in the `Load the spectrum to start aligning` section (brown highlight in Figure 6.17).

2. In the file dialog, select the CSV file and click `Open`.

3. A date-selection dialog will appear. The interface is minimalistic, but the program automatically identifies the nearest available calibration date and displays it in the *Selected Date* field.

4. If the suggested date is unsuitable, click `Choose another`. A full list of available dates will appear, allowing manual selection.

5. Click `Put this` to confirm and apply the selected polynomial.

Figure 6.18 shows an example of the calibrated spectrum: optical density has been converted into relative intensity, producing a physically interpretable spectrum.

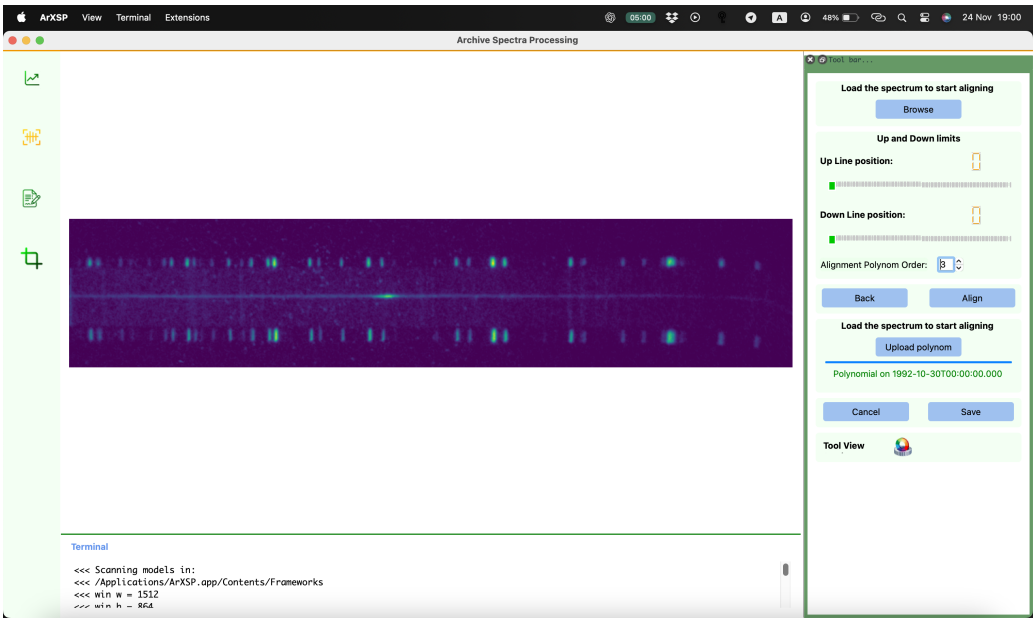


Figure 6.18: Result of spectral calibration. Optical density values have been converted to relative intensities using the characteristic curve.

The final step is to save the resulting spectrum. Click *Save* at the bottom of the left panel. The program automatically generates a filename that includes the date of the last reduction, which helps track processing versions.

An example of a fully preprocessed archival spectrum and its FITS header is shown below:

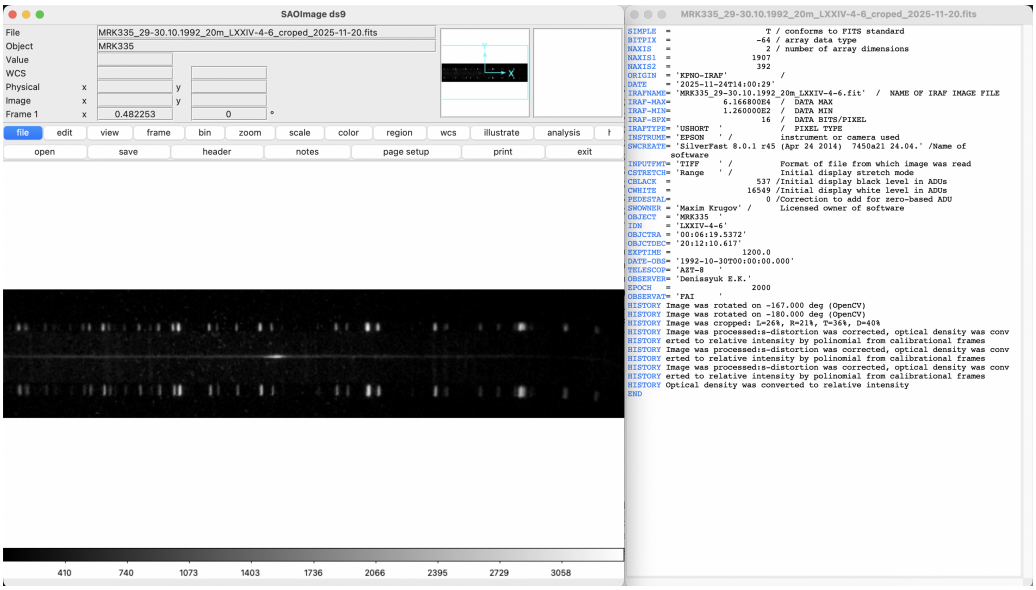


Figure 6.19: Example of a preprocessed archival spectral frame and its FITS header, displayed in `SAOImageDS9`.

This completes the preprocessing stage: the spectrum is now fully prepared for scientific analysis, including line-flux measurements, profile reconstruction, object classification, and other spectroscopic studies.

Chapter 7

Common Issues and Their Solutions

If something goes wrong — do not worry, you are not alone. First, check the terminal: it may not always be polite and can sound slightly passive-aggressive, but it is always honest.

FITS File Without Observation Date

If the `DATE-OBS` keyword is missing from the header, the program will, at certain stages, behave as if it "does not know anything" — and formally this is correct. For example, selecting a calibration polynomial is impossible without a valid date.

The solution is simple: open the Header Editor and add the date manually. Ideally, use the actual date. If the actual date is unknown, specify an approximate observation date so that the program can select an appropriate calibration.

Incorrect CSV File

A common source of problems is a CSV file that is "almost a CSV, but not quite." The program expects commas as column separators. If you insert a list of several numbers inside a cell separated by commas, the parser can no longer determine where columns end and where your internal list begins.

Golden rule:

- columns are separated by commas;
- values inside a single cell are separated by semicolons.

If you swap these — you will get a surrealistic table rather than a valid CSV.

Spectrum Did Not Align as Expected

If during alignment you are convinced that "this time it will definitely work," yet the spectrum still shifts, bends, or behaves as if it does not care — this is normal.

Consider the following:

- Adjust the aperture: too narrow — you will cut the spectrum; too wide — you will include sky background or noise.
- Check that the guiding lines are not placed directly on the frame edges.
- Ensure that you are aligning the spectrum itself, not noise, background, or an accidental photographic defect.

An unpleasant but realistic fact: the edges of the spectrum almost always "wander." This is not a program bug — it is the physical nature of photographic material. (Or perhaps it is a bug — we have not yet found a better universal method.)

Therefore, do not aim for perfect alignment in a single step. Focus on the central part — most important spectral information is located there. Final cosmetic trimming is easier to perform during the cropping stage, once the rest of the frame is already consistent.

In short: **if the spectrum behaves like a stubborn cat — take a breath, make it as straight as reasonably possible, and refine it at later steps.**

Chapter 8

Your Comments and Feedback

Developing the first version of any software is always an adventure: you start from a blank page, build something large and elegant, and then it suddenly begins to fall, break, behave unpredictably — and occasionally delight you. Usually in that order, and then in cycles. At some point you realise: it is not perfect yet, but it already *works*.

The version of `ArXSP` available to you now is exactly that. We learned a great deal along the way, debated, redesigned, rewrote, and eventually produced a tool that can already perform a full preprocessing cycle for archival spectra — a workflow that, to our knowledge, is not implemented in any existing software other than the legacy QC system originally developed at our institute.

Thanks to this work, an entire library of archival spectra — obtained through the effort of our colleagues, over many sleepless and often cold nights at the telescope and later in the darkroom — can now be revived and reused in new scientific research.

We are genuinely proud of this.

But like any first version, the program is still growing, evolving, and may occasionally be a little temperamental. This is why your feedback is incredibly important to us — as users, researchers, observers, and simply curious people working with archival data.

If you have something to say — we are listening. Especially if it is constructive, kind, and expressed with a human touch. Criticism is a valuable tool when it helps improve the software rather than discourage the authors. We truly do our best, and we need to understand what can be made clearer, better, or more convenient for you.

If you encounter unusual behaviour, want to suggest an improvement, or simply wish to share your experience with the program — please write to us (email: `izmailova@aphi.kz`). The experience of real users is irreplaceable; no stress test can substitute for it.

Thank you for using our program. Thank you for reading this manual. And thank you for your patience — we sincerely tried to create a tool that is pleasant to work with.

References

Izmailova, I., Umirbayeva, A., Khassanov, M., Aktay, L., Shomshekova, S., 2024. Arxsp: A python-based modular application for the reduction of digitized archival spectra URL: https://doi.org/10.2139/ssrn.5494087, doi:10.2139/ssrn.5494087. available at SSRN: https://ssrn.com/abstract=5494087.

Shomshekova, S. A.and Izmailova, I., Moshkina, S., Umirbayeva, A., 2022a. Digitization of comet photometric astronegatives of the Fesenkov Astrophysical Institute (in russian). Reports of the National Academy of Sciences of the Republic of Kazakhstan 1, 137–143. doi:10.32014/2022.2518-1483.143.

Shomshekova, S., Izmailova, I., Umirbayeva, A., Omarov, C., 2022b. A method for digitization of archival astroplates of the Fesenkov Astrophysical Institute. New Astronomy 97, 101881. doi:10.1016/j.newast.2022.101881.

Shomshekova, S., Kondratyeva, L., Omarov, C., Izmailova, I., Umirbayeva, A., Moshkina, S., 2023. Digital archival spectral data for Seyfert galaxies and their use in conjunction with modern FAI spectral data. Experimental Astronomy doi:10.1007/s10686-023-09916-6.