DESpeRo: Data reduction software for the Echelle Spectrograph Rozhen

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Abstract. This paper presents a fully automated data reduction software for the high-resolution echelle spectrograph ESpeRo that operates on the 2m-telescope of the Rozhen National Astronomical Observatory, Bulgarian Academy of Sciences. The pipeline applies the standard preprocessing corrections to the observational data, including cosmic ray removal, bias subtraction, and flat-field correction. It further identifies and extracts the echelle orders and calibrates the extracted spectra for wavelength. In addition, it provides the option to normalize the obtained spectra of the individual echelle orders by intensity and to merge them into a continuous one-dimensional spectrum spanning the full spectral range of the instrument.
Key words: spectroscopy, echelle, data-reduction

Introduction

The Echelle Spectrograph Rozhen (ESpeRo) is a cross-dispersed, fiber-fed instrument installed at the 2-meter telescope of the Rozhen National Astronomical Observatory (NAO) in Bulgaria. ESpeRo offers a spectral resolution ranging from 30 000 to 45 000 and covers a wavelength range of 3900 to 9000 Å in a single exposure (see Bonev et al. 2017). The acquired 2D spectrum images are well suited to fully utilize the area of the 2D CCD sensor, allowing the capture of nearly the entire visible light spectrum from the observed object at high spectral resolution. However, the complex structure of raw echelle spectra presents significant challenges in developing a reliable method for their autonomous conversion into scientifically usable data. This complexity has so far prevented the creation of an automated data reduction software (DRS). Such DRS solutions are available for other instruments, for example the data reduction pipelines WARP (Hamano et al. 2024) and ATMOSPHERIX (Klein et al. 2024) that process data obtained with the WINERED spectrograph and the SPIRou spectropolarimeter, respectively.

One of the main challenges of reducing raw echelle spectra lies in the presence of multiple spectral orders, covering different but sometimes partially overlapping wavelength domains, each exhibiting different intensity levels due to the wavelength-dependent efficiency of the instrument. Additionally, these orders show significant curvature, which must be accurately accounted for during the extraction process. Accurate tracing of the positions of the spectral orders on the raw image is the first essential step in the processing routine.

Another crucial step is the wavelength calibration of the extracted spectra. ESpeRo is equipped with a ThAr lamp that provides a wavelength reference. Achieving reliable calibration for each spectral order requires accurately solving the ThAr spectrum obtained during the observation. This task is particularly challenging because the prominence of spectral lines can vary significantly and often does not fully correspond to the expected intensities listed in identification atlases. As a result, matching observed ThAr lines with reference lines in a spectral atlas is a non-trivial task, especially for automated approaches.

To address these challenges and enable the autonomous and reliable reduction and extraction of scientific spectra for ESpeRo, we present DESpeRo (Data reduction software for the Echelle Spectrograph Rozhen), a fully automated data reduction pipeline specifically developed for the echelle spectrograph at the Rozhen NAO. DESpeRo performs the complete sequence of processing steps required to transform raw data into scientifically usable spectra. These steps include cosmic ray removal, bias and flat field correction, order extraction, wavelength calibration, and heliocentric radial velocity correction. Additionally, the software offers an option to normalize the signal of each spectral order to the continuum level and merge the normalized orders into a single 1-dimensional (1D) spectrum that spans the full wavelength range of the instrument.

DESpeRo is publicly available on GitHub[1].

1. Initial data treatment

Loading the observations

The raw *.fits* files stored by the software used by ESpeRo to control the CCD camera originally contain no information about the observatory and the observed object. To add this information to the headers of the files, a specialized software called *FitsMEdit* was written by M. Napetova specifically for ESpeRo shortly after the instrument became operational. *FitsMEdit* is installed on the computer that controls the CCD camera and is started at the very end of the observational night. The program adds important information to the image headers, such as the latitude and longtitude of the Rozhen observatory, the right ascension and declination of the object, along with the epoch of the coordinates, the name of the object and the exposure type (scientific, bias, flat or comparison). The software also creates a *Journal.txt* text file in the observational directory, where information about the file name, time of observation, read time and exposure type is stored.

The DRS relies on this being done before attempting to automatically reduce the data obtained with ESpeRo. Once the directory where the raw observations are located is selected, the first action performed by the DRS is to build its own internal data store containing all the relevant data from the observations. This is done with the help of the *Journal.txt* file created by *FitsMEdit*. The internal data store resides in the random-access memory (RAM) of the computer, where all reductions are done. The original observational files are never modified.

Cosmic ray removal, bias and flat field correction

A cosmic ray is a high-energy particle from space, usually a proton, that strikes the detector and causes a spike of signal in the affected pixels. To remove eventual cosmic ray from the raw images, the *LA-cosmic* algorithm (van Dokkum, 2001) is used. All parameters are kept to their default values, except the **sigclip** parameter (which corresponds to the Laplacian-to-noise

[1] The DESpeRo GitHub repository can be found at the following address: https://github.com/stefangrgv/DESpeRo/.

limit for cosmic ray detection), for which the default value is 4.5, but the DRS uses a more strict value of 3.5 to better filter out cosmic rays.

A bias frame is an image taken with a camera sensor with the shutter closed, so that no light exposure occurs. It measures the electronic noise inherent to the detector, such as readout noise and offset values, which are added during the image capture process. Subtracting the bias frame from raw data ensures that these noise contributions are removed, which improves the accuracy of the final calibrated data.

A flat field is an image taken of a uniformly illuminated source, such as a specialized lamp (a tungsten and/or a LED lamp in the case of ESpeRo). The purpose of a flat field is to measure the pixel-to-pixel sensitivity variations of the detector. It is used to correct uneven illumination, vignetting, and non-uniform pixel response. Dividing the raw data by the flat field ensures consistent brightness and accurate photometric measurements across the image.

Typically in the course of an observational night, several bias and flat field exposures are obtained. In order to correct the raw exposures for bias and flat fields, the individual bias/flat field images are first combined to minimize noise. For both types of images, the combination is done by calculating the median signal in each pixel across all corresponding images. The combined bias image is then subtracted from the combined flat, the ThAr comparison images and the scientific exposures. The combined flat image is normalized to unity, which is done by dividing it by its maximum value. The comparison and scientific images are then divided by the normalized combined flat image.

2. Spectrum extraction

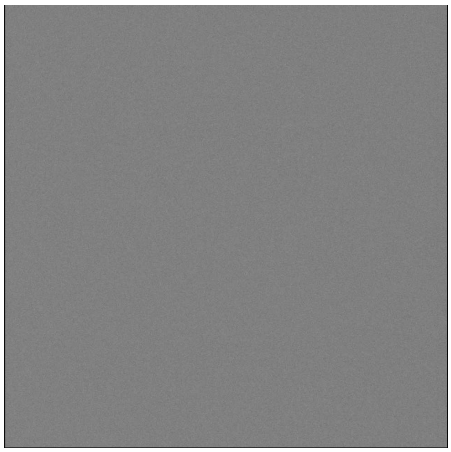
Echelle spectrographs disperse light into multiple (and sometimes overlapping) spectral orders, which are recorded as curved stripes on the detector (the CCD matrix). Example exposures obtained with ESpeRo are shown in Figure 1 for a bias frame (a), a flat field (b), a comparison spectrum (c) and a stellar spectrum (d). In order to reduce the image recorded in the *.fits* to a spectrum, a map of the positions of the spectral orders on the CCD must be extracted.

Identifying order coordinates

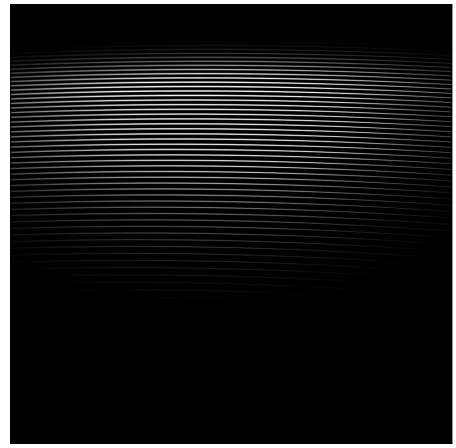
Identifying the coordinates of the echelle orders on the CCD matrix is done using the combined flat image. Flat field exposures are suitable for this task since in them there is sufficient signal over the entire wavelength range of the spectrograph for the order positions to be found with high precision.

To find the order positions, the DRS first extracts from the combined flat field its vertical profile P, which is a vector consisting of the sums of the intensity of pixels found in all individual 2048 rows of the CCD matrix at each column position. If $I_{x,y}$ is the intensity of the pixel found in the x column and y row, then the components of P can be expressed as:

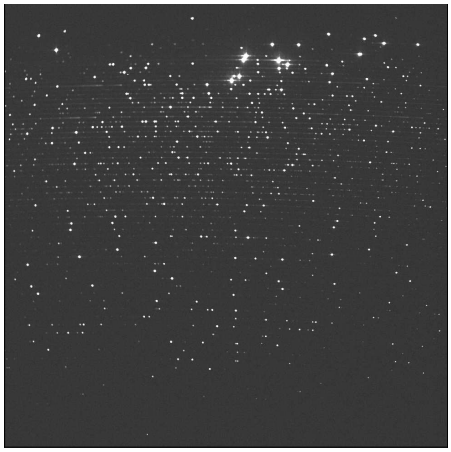
$$P_y = \sum_{x=0}^{2047} I_{x,y} \,. \tag{1}$$



(a) Bias frame



(b) Flat field



(c) Comparison spectrum (ThAr)

(d) Stellar spectrum

Fig. 1: Example raw images obtained with ESpeRo: a bias frame (a), a flat field (b), a comparison spectrum of a ThAr lamp (c) and a stellar spectrum (d). For illustration purposes, the intensity scale is different for each image. The mean order wavelength decreases from top to bottom in each image: the reddest echelle orders are at the top, and the bluest ones are at the bottom.

The vertical profile is then used to find the set of row numbers y_i where the brightest pixel of each order i is found. This is done using the function *signal.find_peaks* of the python library *scipy*. The function returns the peaks of all features in the vertical profile, which consist not only of the echelle orders, but also noise due to scattered light. In order to restrict the results to the echelle orders, only those above a certain intensity threshold are selected from the full array of peak intensity pixels. Once the row number of the brightest pixel in each order is found, its column number is simply

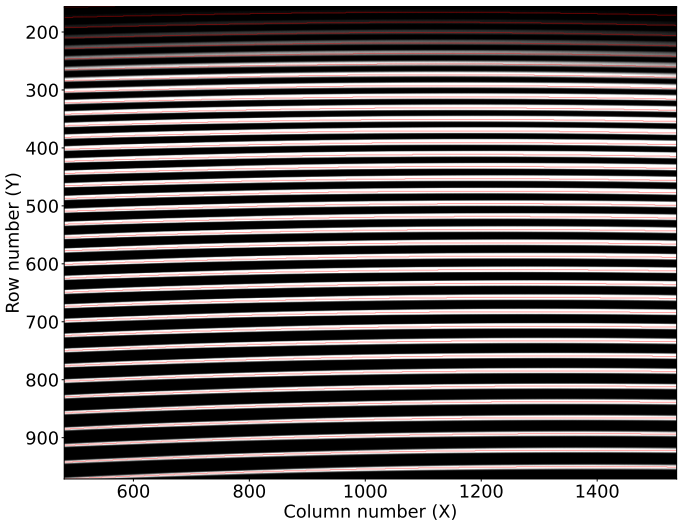
$$x_{\rm peak} = \arg\max_x (I_x, y_{\rm peak})\,. \tag{2}$$

Once the brightest pixel in each order is found, the DRS proceeds to trace the orders across the CCD matrix. This is done using an iterative process. We begin by taking the brightest pixel of the first ($y = y_{\rm min}$) order, whose intensity is $I^0_{x,y}$. We then find the intensities of its three neighboring pixels to the left: $I^0_{x-1,y-1}$, $I^0_{x-1,y}$ and $I^0_{x-1,y+1}$. We select the brightest of these three pixels and add it to the list of brightest pixels in the current order. We repeat this procedure using the brightest neighboring pixel we just found as a starting point in the search of the next brightest neighboring pixel, and the process goes on until the $20^{\rm th}$ pixel from the end of the image is reached. We exclude the last 20 pixels of the image in order to avoid edge effects and increased noise at the edges of the detector, where the response is less reliable. We then once again pick the brightest pixel of the order (obtained from the vertical profile) as our starting position, but this time we look for neighboring pixels to the right, i.e. the procedure is repeated but this time the neighboring pixel is selected as the maximum of $I^0_{x+1,y-1}$, $I^0_{x+1,y}$ and $I^0_{x+1,y+1}$. We perform this search for each of the order peaks extracted from the vertical profile. The end result is an N-dimensional array, where N is the number of echelle orders, where each element consists of a list of (x, y) points that correspond to the column and row of the pixels that trace the respective order. For each order, the DRS then fits the row positions of this array with a $5^{\rm th}$ degree polynomial, resulting in an array of $(x, y_{\rm fit})$ points. It is this resulting fit that is used to trace the positions of the given echelle order. This procedure is repeated for each order. The result is presented in panel (a) of Figure 2, where a section of the combined flat field is displayed with the positions of the echelle orders marked in red.

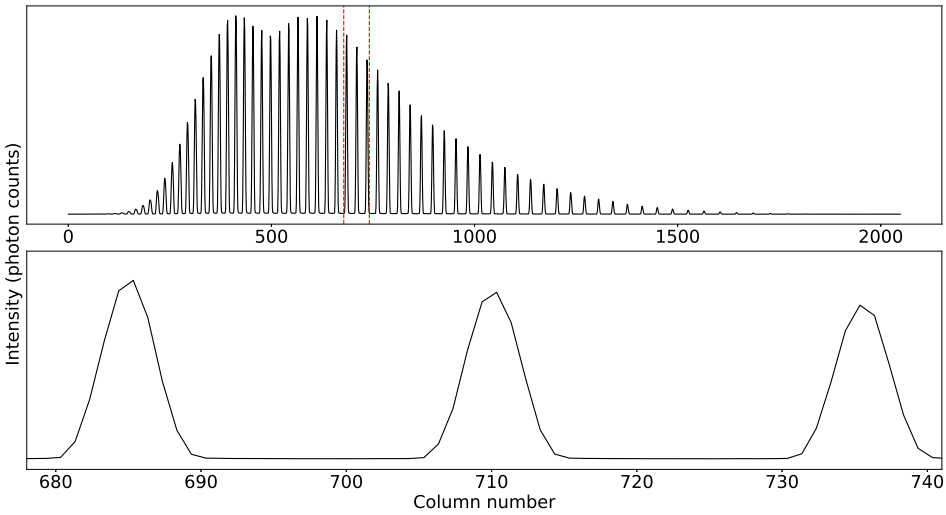
Extracting 2D spectra

Once the order positions on the CCD matrix are found, the DRS proceeds to extracting the 2-dimensional (2D) spectra from the scientific and comparison exposures. The spectra are referred to as 2D because the intensity of each pixel is a function of both the column number and the order number.

When extracting the echelle orders from the scientific and comparison exposures, we need to keep in mind that photons with a given wavelength hit the CCD matrix in not in just one, but several neighboring pixels. This geometric spread of photons defines the aperture of the order. In the case of ESpeRo, we can assume that the order apertures are oriented vertically: in the frame of



(a) Traced apertures from a combined flat field.



(b) Vertical cross-section of a combined flat field.

Fig. 2: Traced echelle orders and evaluation of their heights. Panel (a): a section of a combined flat field with the traced positions of the echelle orders (in red). Panel (b): vertical cross-section of the combined flat-field image taken across the center of the CCD (top) and a zoomed-in view of the region outlined by red dashed lines (bottom).

a single order, photons of the same wavelength hit only pixels that have the same column. The validity of this assumption can be verified with a simple

visual inspection of the raw images.

The height of the order apertures can be measured from the combined flat field image, as it is shown in panel (b) of Figure 2, where a vertical cut across the center of the CCD matrix is displayed for a combined flat image. The profiles in this cut correspond to the order apertures. In the bottom part of the panel, a small part of the cross-section (indicated by the dashed red vertical lines in the top part) is zoomed in, showing three of the orders in detail. From this close look, it can be seen that the typical height of the order apertures of ESpeRo is about 10 pixels. The DRS takes this into account by including five pixels vertically below and five pixels vertically above the trace of the order, effectively extracting the spectrum from 11 pixels for each column within an echelle order.

Were the orders only a single pixel in height, the spectrum $S_i(x)$ of the i^{th} order would simply be

$$S_i(x) = I_{x,y}\,, \tag{3}$$

where x and y are the column and row indexes of the i^{th} order. However, to account for the measured aperture height, we need to change this equation as follows:

$$S_i(x) = I_{x,y} + \sum_{i=1}^{5} (I_{x,y-i} + I_{x,y+i})\,. \tag{4}$$

A visualization of the extraction of a 2D spectrum is shown in Figure 3. There it can also be seen that the absorption lines in the stellar spectrum are clearly oriented vertically along the CCD matrix.

3. Wavelength calibration

Calibrating a 2D echelle spectrum for wavelength involves mapping the pixel positions on the detector to their corresponding wavelengths. Since in the case of ESpeRo the order apertures have a vertical profile, the task is simplified to mapping the column numbers of each order to wavelengths. From the instrument side, a ThAr lamp is used (see Bonev et al. 2017 for details), which provides a comparison spectrum that consists of a very large number of emission lines with well-known wavelength across all the orders of the instrument. The spectrum of this lamp, called a comparison spectrum, is used to identify the pixel positions of a number of spectral lines in each echelle order, after which the measurements are fit with a high-degree function to derive the dispersion solution $D_i(x) = \lambda$, where i is the echelle order, x is the column in the CCD matrix, and λ is the wavelength.

Comparison standard

To perform the wavelength calibration, the DRS uses a ThAr lamp exposure for which the positions of a large number (531) of emission lines have been

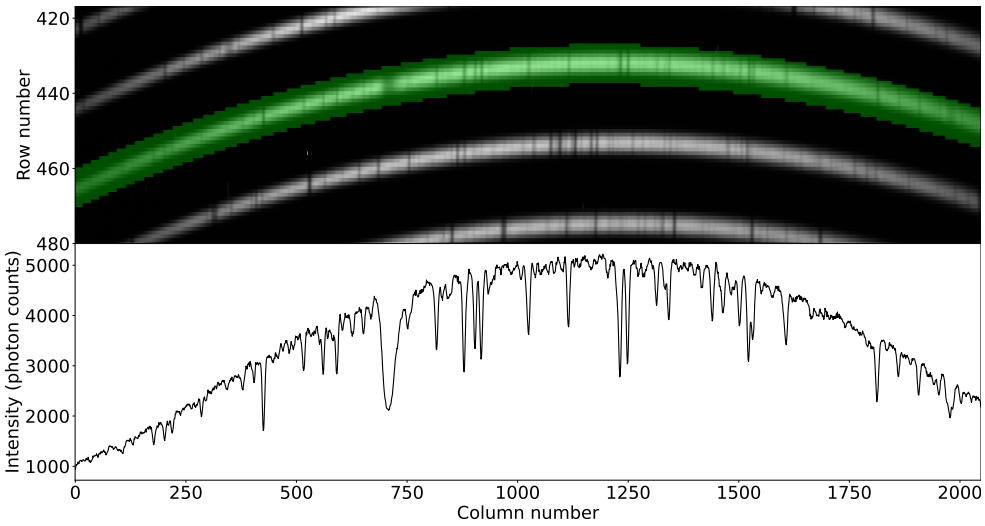


Fig. 3: A visualization of the extraction of an echelle order. Top panel: the raw image after initial corrections (accounting for cosmic rays, bias and flat field), with the green strip indicating the part of the image where the echelle order is located and from which signal will be extracted. Bottom panel: the extracted spectrum.

manually identified beforehand. This solved comparison spectrum will hereafter be referred to as the comparison standard. To identify the emission lines, the atlas provided by the University of Texas at Austin[2] was used as reference. The comparison standard can then be used to calibrate any other ThAr lamp spectrum obtained with ESpeRo. This is possible since all comparison spectra obtained with the intrument are very similar, if not identical. Of course, this approach is valid only as long as no significant changes occur in either the internal geometry of ESpeRo or the ThAr lamp. If at some point a modification is done to the spectrograph, or the calibration lamp gets replaced, a new standard comparison spectrum will be necessary in order to reduce data obtained after this event.

The manual calibration of the comparison standard is done individually for each order. Once the wavelength of a line in a given order is identified using the ThAr atlas, the exact position of the line in the CCD matrix needs to be calculated. This is done by fitting the line profile with a gaussian. The peak position of the gaussian function gives us the position (the column number) x of the line in the CCD matrix. This is done for each identified line in the order. The end result is an array of (x, λ) points that we can use to derive the dispersion function from. An example is shown in Figure 4 for a single echelle order. In the top panel of the figure, the uncalibrated spectrum is shown, along with the gaussian fits (in green) of six spectral lines that have been manually identified in the comparison standard, and their peak positions (as dashed red

[2] http://www.as.utexas.edu/ hebe/2Dcoude/thar/thar.pdf

vertical lines). In the bottom panel, the coordinates of the identified lines are shown as black dots in the column number - wavelength space, and the fitted dispersion function is shown in green. In each individual order i, the dispersion solution is derived using a Chebyshev series of the third degree:

$$D_i(x) = \sum_{k=0}^{3} a_k(i) T_k \,, \tag{5}$$

where T_k is the Chebyshev polynomial of the k^{th} degree and $a_k(i)$ are the parameters derived by the fit. For each echelle order, the comparison standard keeps record of the identified spectral lines – their column number x and wavelength λ – and the fit parameters $a_k(i)$. These values are used to find the dispersion solution for uncalibrated ThAr exposures.

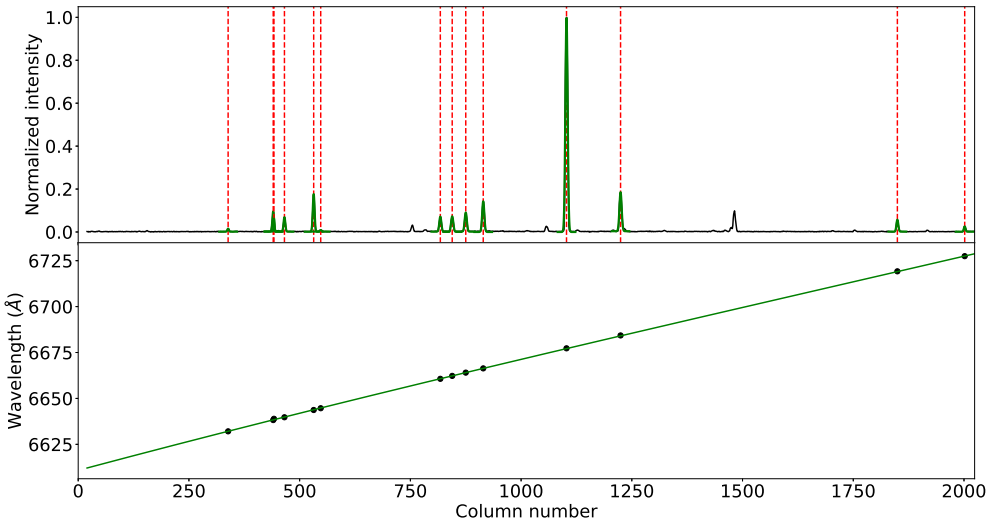


Fig. 4: Dispersion solution of a ThAr comparison spectrum order. Top panel: normalized intensity spectrum (black) of a ThAr exposure with gaussian fits (green) and peak positions (dashed red lines) of identified emission lines. Bottom panel: positions of the identified lines in column number - wavelength space (black points) and the fitted dispersion solution (green).

Solving uncalibrated ThAr exposures

Emission lines in uncalibrated comparison spectra are identified with the help of the comparison standard. This task consists of two steps: 1. matching the orders of the uncalibrated exposure to those of the standard; 2. finding the exact coordinates of the peaks of the individual emission lines.

The DRS matches the echelle orders of the uncalibrated spectrum with those of the comparison standard on the basis of their coordinates on the CCD matrix, specifically – their row numbers (the column numbers of all orders are the integers in the range of 0 to 2007, i.e. every order crosses the entire width of the CCD matrix except the leftmost and rightmost 20 pixels). For each pair ($i_{\rm comp}$, $i_{\rm stand}$) of orders of the uncalibrated comparison spectrum and of the comparison standard, an array named Δ is calculated which has the following components:

$$\Delta_{i_{\rm stand}} = \sum \| Y_{i_{\rm comp}} - Y_{i_{\rm stand}} \| \,, \tag{6}$$

where Y_i and Y_j are the 1D arrays of size 2008 (2048 rows excluding the leftmost and rightmost 20) of the row numbers of $i_{\rm comp}$ and $i_{\rm stand}$ and the sum is calculated by iterating over all orders of the comparison standard. The elements of Δ represent simply how close the orders $i_{\rm comp}$ and $i_{\rm stand}$ are located on the CCD matrix: lower values represent closer orders, with a value of zero meaning that the positions of the two orders match perfectly. (In reality, the order positions of a given echelle order in the uncalibrated comparison exposure and the comparison standard will likely not match perfectly because of minor differences in the flat fields that the order positions were extracted from.) The DRS then finds the index of the element of Δ which has the lowest value ($argmin(\Delta)$). This index is equal to the number of the order $i_{\rm stand}$ of the comparison standard that corresponds to the given order $i_{\rm comp}$ of the uncalibrated comparison spectrum. In this way, the matching order of the standard is found for each order of the uncalibrated spectrum.

Once the orders of the uncalibrated comparison spectrum are matched to those of the comparison standard, the next step is to find in the uncalibrated spectrum the peaks of the lines which will later be used for the wavelength calibration. For each individual order i, this is done as follows. For each line (defined by its column number $x_{\rm line}$ [px] within the given order and wavelength $\lambda_{\rm line}$ [Å]) identified in the comparison standard, a narrow window (20 pixels in width) around the column number in the comparison standard of the spectrum of the uncalibrated ThAr spectrum is fit with a gaussian. This is done in order to find the exact position $x_{\rm line}^{\rm uncal}$ of the peak of the line in the uncalibrated spectrum. The value $x_{\rm line}$ is used as an initial guess for the gaussian fit. Once the positions of all lines are identified, the value pairs ($x_{\rm line}^{\rm uncal}$, $\lambda_{\rm line}$) are used to fine-tune the parameters $a_k(i)$ of the dispersion solution (see Equation 5) of the comparison standard for the current order. Fine-tuning is the process of iteratively adjusting model parameters to achieve better agreement with empirical data. It involves refining an initial fit using an additional dataset, often through optimization techniques such as least squares minimization or Bayesian inference. The DRS performs the fine-tuning of the dispersion solution by using the function *optimize.curve_fit* of the *scipy* python library, which applies the least squares method.

Since the comparison standard has been obtained by summing a number of long ThAr lamp exposures, it is possible that lines present in it may not be present in the uncalibrated comparison spectra usually obtained during an observational run. To take this into account, spectral lines for which the gaussian fit to the uncalibrated spectrum does not converge well are excluded

from the fine-tuning process, so as not to introduce noise to the dispersion solution.

Calibrating scientific spectra and heliocentric velocity correction

Once the ThAr comparison spectra are calibrated for wavelength, the DRS finds the comparison spectrum obtained closest in time to each individual scientific spectrum using the journal of observations. The scientific spectra then simply use the same dispersion solution as their corresponding comparison spectrum.

A last correction done to the calibrated spectra is related to the heliocentric velocity of the observed celestial object. The heliocentric velocity refers to an object's velocity relative to the center of the Sun and accounts for the orbital motion of the Earth. If left uncorrected, this effect would result in a shift in the radial velocity of the observed spectra throughout the year. The calculation of the heliocentric velocity is done using the *astropy* library on the basis of the object and observatory coordinates and the time of observation. The spectra are then corrected for this velocity using the doppler formula.

4. Continuum normalization

A normalization to the continuum level is next performed for each echelle order. This normalization is done with the goal of removing the influence of the overall shape of the continuum and consists of dividing the observed spectrum by an approximation of this continuum, which flattens the continuum to a value of unity. This ensures that the spectral features can be analyzed independently of instrumental effects and variations in the intrinsic brightness of the source.

In order to normalize the signal with respect to the continuum for each echelle order, first an approximation of the continuum must be derived from the signal in that order. To do so, we will select some points in the spectrum that we consider at the level of the continuum, then fit a function through these points and then use this fit as the approximation of the continuum, dividing the spectrum by it to obtain the normalized spectrum.

In most stellar spectra, absorption lines are significantly more numerous than emission lines. To estimate the continuum level in such cases, we identify points situated between absorption features. The DRS does this via the *find_peaks* function of the *scipy* library, which was previously used to locate echelle aperture peaks in Section 2. The function returns the indices of local maxima, which are then interpreted as candidate continuum points. A fifth-degree Chebyshev polynomial is then fitted to these points to model the continuum. Figure 5 illustrates this process: the top panel displays the original, non-normalized spectrum alongside the selected continuum points and the fitted continuum curve, while the bottom panel shows the resulting continuum-normalized spectrum.

While this approach is acceptable for the majority of stellar spectra, it may be suboptimal in certain cases - for instance, in the spectra of hot stars, where very few absorption lines are present. To address such cases, additional normalization strategies will be included in future versions of the DRS.

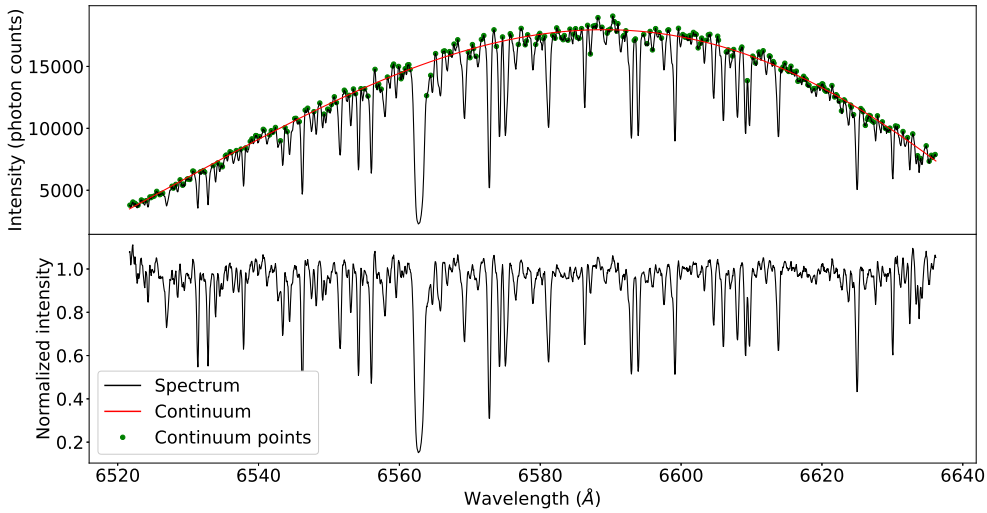


Fig. 5: Continuum normalization of an echelle order. Top panel: non-normalized spectrum (black), points selected for the approximation of the continuum level (green) and the fitted continuum (red). Bottom panel: the resulting continuum-normalized spectrum (black).

5. Merging orders into 1D spectra

Once the spectra of the individual echelle orders of each exposure are normalized, the DRS proceeds to merging them into a single 1D spectrum. This spectrum is simply a table with two columns: one for the wavelength and one for the normalized intensity.

To construct a 1D spectrum from the normalized echelle orders, the DRS merges the signal from individual orders based on a signal-to-noise ratio (S/N) prioritization. In regions where the orders do not overlap in wavelength coverage, the corresponding 1D segments are extracted directly from the individual orders without modification. In overlapping regions, the normalized flux values from the overlapping orders are compared, and the data from the order with the higher S/N is retained in the 1D spectrum.

Since the dispersion solutions for the individual echelle orders are expressed as Chebyshev polynomials (see Section 3), the wavelength sampling of the merged 1D spectrum is non-uniform. This presents a significant challenge when exporting the 1D spectrum in *.fits* format compatible with the *IRAF* software package (Tody 1986), which requires a global, uniformly sampled wavelength solution. Reconstructing such a solution from non-linear segments with different sampling would involve interpolation and resampling over the entire wavelength domain of ESpeRo, which we avoid in order to preserve the fidelity of the original physical measurements. It is for this reason that the DRS only supports exporting the merged 1D spectra as ASCII tables (in plain *.txt* format) and not as *.fits* files.

Summary

The Data reduction software for the Echelle Spectrograph Rozhen (DESpeRo) is presented. It is fully automated and performs reduction of the raw scientific exposures as follows:

1. Cosmic ray removal
2. Bias correction
3. Flat field correction
4. Identification of the echelle orders and extraction of the 2D spectra
5. Wavelength calibration to the heliocentric restframe
6. Approximation of the continuum level and normalization of the 2D spectra
7. Creation of 1D spectra by stitching the normalized echelle orders

DESpeRo provides the reduced spectra in several different formats:

1. Wavelength-calibrated and non-normalized 2D spectra – in *.fits* and ASCII formats;
2. Wavelength-calibrated and normalized with respect to the continuum 2D spectra – in *.fits* and ASCII formats;
3. Wavelength-calibrated and normalized with respect to the continuum merged 1D spectra – in ASCII format.

Applicability to other instruments

As its name implies, DESpeRo was specifically developed to reduce data acquired with the ESpeRo spectrograph. Nonetheless, we expect it to be capable of performing the same task for other instruments, provided the input data adhere to the same format as that used by ESpeRo (i.e., *.fits* files). Some adjustments may, of course, be required. Although we have not attempted to use DESpeRo on data obtained with a different instrument, we anticipate that the following considerations must be addressed:

- An observation log file named *Journal.txt* must be present in the format produced by *FitsMEdit*, or the corresponding metadata must be supplied to the DRS through an alternative method.
- The *.fits* files produced by ESpeRo are atypical in that their *data* attribute includes an additional dimension. Specifically, the shape of the data array is (1, 2048, 2048), rather than the conventional (2048, 2048). If the input data lack this extra dimension, they must either be reshaped accordingly or the function that loads the data must be modified to accommodate the format.
- As discussed in Section 2, the echelle orders in the raw ESpeRo observations are vertically oriented. If the input data have a different orientation, this must be accounted for.
- Most critically, the comparison standard described in Section 3 is strictly instrument-specific. To calibrate data from a different spectrograph, a new comparison standard must be created by identifying the positions of a sufficient number of spectral lines. A python script that allows the creation of such a new standard from a raw comparison spectrum is available in the DESpeRo GitHub repository.

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