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The overview of spectra reduction process

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The reduction of astrophysical spectra is discussed in general. This article is intended as an introduction to following papers where we describe the reduction of data exposed by particular devices (coudé slit spectrograph and Cassegrain fiber-fed echelle spectrograph HEROS).

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1 Introduction

The reduction of spectroscopic data is quite complicated process which includes many sub-procedures. The consecution of such sub-steps can differ case-to-case, with respect to the device (i.e. slit or fiber-fed spectrograph), its configuration etc.

All articles in this volume are dedicated to the acquisition, reduction and archiving of data exposed with the Ondřejov observatory 2-meter telescope. We used the telescope in two possible configuration: slit spectrograph in the coudé focus and fiber-fed echelle spectrograph in the Cassegrain focus. Of course, reduction processes in both devices are completely different; they are described in more detail in following papers. Nonetheless the general overview of the CCD spectra reduction process will be given here to explain the basic ideas of the whole reduction effort. We are using for the data processing two of the most popular professional astronomical systems — IRAF[1] and MIDAS[2].

2 IRAF – reduction of slit CCD spectra

The CCD spectra exposed in the coudé spectrograph are reduced by the standard IRAF tasks, quite powerful procedures optimized for the reduction of single order slit spectra. The detailed discussion of each step can be found in Massey(1997) and Willmarth(1990).

The reduction process may be summarized to following points:

- bias/zero elimination
- flat fielding
- order detection and extraction
- fitting the dispersion relation
- radial velocity correction (heliocentric correction)

2.1 Bias

The bias reflects the detector electronics influences. Generally, the bias may be variable with respect to time, temperature of the chip, position on the chip etc. It consists of constant electronic bias of the detector preamplifier and time variable bias (different on each frame) caused by dynamic processes during the readout. The part of the bias may remain constant in time but variable over the surface ot the chip.

To eliminate the bias, one should expose so-called `zero` files (and, if necessary, darks – see below).

Zero is the file exposed with closed shutter and zero exposure time – none input signal is thus expected. Therefore the file represents internal features of the detector. One can expose a number of zeros and statistically process them (average or median).

To eliminate time-dependent part of the bias, one should define "overscan" zone on the chip and correct the snap with respect to information found in this zone. The overscan is a part of the chip where none signal is expected; one can watch the behaviour of the chip in each exposed file separately. Usually, the overscan zone is defined as some number of rows

[1] `http://iraf.noao.edu`
[2] `http://www.hq.eso.org/midas`

(or columns) on the edge of the chip[3], following the dispersion. For example, CCD chip in 2-meter telescope coudé spectrograph is spread over 16 collumns (along the longer side of the chip i.e. along the dispersion).

2.2 First reduction steps - elimination of the bias

The signal integrated in the overscan zone is subtracted out of the exposed file. Usually, a constant or linear function is fitted on the overscan zone and this function is then (separately) subtracted from each data column – automatized procedure works along the dispersion.

In following reduction step one has to eliminate the time-independent component of the bias – zero. First of all, all exposed biases are averaged and final "mean" zero (with possible spatial structure) is subtracted from all exposed files (stars, comparison lights, flat fields). Thus one eliminates the spatial bias structure of the chip: for example, our chip in coudé focus presents a moiré (lattice).

2.3 Dark exposure

Sometimes (it depends on CCD chip quality and cooling temperature), one should expose dark frames representing the influence of the detector dark current. The dark frame is (similar to zero) exposed with shutter closed, but the exposure time should be equal to the exposure time of the stellar spectrum. Nevertheless, it is not necessary to expose dark together with each stellar exposition. Many long-exposure frames should be averaged (with the cosmics rejection), linearly scaled to stellar exposure time and then subtracted from the stellar exposure. However the noise in the dark frame should be highly reduced by averaging many tens of frames — otherwise the good data might be spoiled by the noisy darks. In most modern cryogenically cooled detectors, however, the dark current is reduced to a negligible value, so we do not need to bother with dark frames.

2.4 Trimming the picture and flat field correction

In following step we cut off unused parts of the chip in order to reduce the memory requirements and speedup the processing. As the criterion we have put the region which is covered by flat field – see Fig. 1.

[3]Sometimes, the overscan zone may be defined at both sides of the chip. Both overscan zones should follow the dispersion. Thus, the zones are situated on opposite sides of the chip.

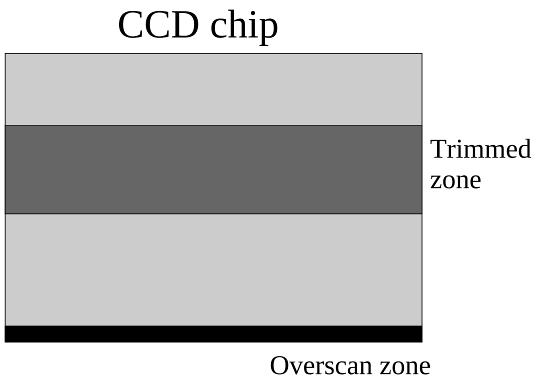

Fig. 1: Position of the overscan zone and trimmed region (covered by flat field).

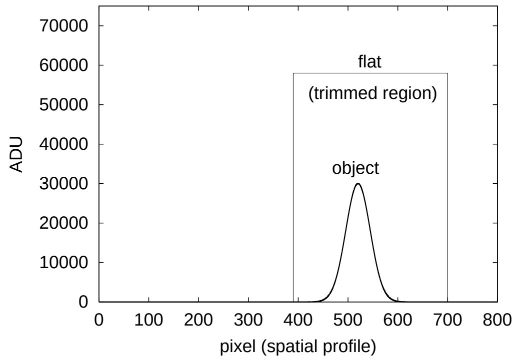

Fig. 2: The supposed spatial profile of the flat field and of the star.

Now, one can flat-field correct the exposed files. The flat field is spectrum of a lamp projected through the same path as the stellar beam runs. The spectrum contains no lines i.e. it consists of the simple continuum. The division of a stellar spectrum by the flat field thus eliminates high frequency noise, for example different efficiency of pixels on the CCD chip.

The flat field correction may be run in 2 dimensions since we suppose the rectangular spatial profile of the flat field – see Fig. 2.

The flat field correction must be done for stellar spectrum and may be also done for comparison light (but it is not necessary).

Bias correction, dark correction (if done) and flat fielding should eliminate any device-dependent effects which could be projected at the stellar exposure.

2.5 The extraction of spectral orders

Now, files are overscan, zero and flat field corrected, trimmed, and sometimes (see above) dark corrected. So, the next reduction step is the extraction of the spectral order; it means, we will do the tracing the spectral order on the chip and read out the signal (see Massey et al. (1990) and Willmarth(1990)).

All these steps (and also many others) are contained in the procedure `doslit`. The procedure `doslit` is the core of the reduction process. It is script calling number of IRAF tasks (i.e. `apfind`, `apedit`, `apresize`, `aptrace`, `apextract`, `setjd`, `setairmass`, `refspec`, `identify`, `reidentify`, and `dispcorr`).

The procedure `doslit` (among others) accomplishes the following :

- It reads file headers, identifies the type of file (star, comparison light...). The extraction of orders is not done on comparisons, of course.

- It finds automatically an extraction aperture in each image. The criterion, which signal should be included to the (supposed) spectrum, is predefined. For example, one can put 5% of the maximal signal as threshold. All pixels with signal above this threshold are included in the definition of spectral order.

  In more details: first of all, the center of (trimmed) snap is found. Then the spatial profile (cross-order profile) is done; center of the profile is found. Then, the aperture is defined, using criteria as mentioned above.

- From this central spatial profile, the procedure runs along profiles to both edges of the picture, keeping the aperture. The positions of centers of profiles are found and hence the order is traced. The ASCII file `ap`<*number*> is created in the current subdirectory `database`. Coefficients of the polynomial, describing the trace is saved in the file. The number is the same as the number of spectrum. For example, stellar spectrum `la230030` is traced, coefficients of the "tracing polynomial" are saved to the file `./database/ap230030`.

- Along the trace, the spectrum is read out. Optimal or "non-optimal" extraction may be applied. In optimal extraction the integration is weighted (i.e. signal in the "wing" of the spatial profile is of low weight). The cosmics may be eliminated here by several statistical methods.

- The center of the exposure time is found (keyword `UT_MIDDLE`). Airmass and JD are computed.

- Two nearest comparison spectra (nearest with respect to time) are found and extracted in the current directory.

- The dispersion (polynomial) relation is found in both comparisons separately.

- Both dispersion polynomials are weighted with respect to the middle time of stellar exposure (see above). Weighted average of these polynomials is done. Final dispersion relation is applied to the stellar spectrum[4].

- One can use tasks `rv, rvcorr` in order to compute the heliocentric correction.

- Finally, procedure `dopcorr` should be run in order to apply heliocentric correction to the dispersion relation[5]

3 MIDAS – reduction of echelle spectra

The reduction process of the echelle spectra is, in principle, similar to the described slit spectra reduction; therefore we do not give full description of the reduction process and instead of this we put main accent to differences of both methods. The very detailed description of echelle spectra reduction (however in IRAF) is given by Churchill (1994).

We use the MIDAS packages for the reductions since it is optimized for echelle spectra (see `MIDAS-B`, Chapter 7). We also have to use HEROS-specific routines adopted by A. Kaufer and O. Stahl from Landessternwarte Heidelberg.

3.1 Pre-reduction process

First of all, it is necessary to translate the spectrum to the MIDAS internal binary format (called `*.bdf`).

Then one must transform the spectrum to the orientation expected by MIDAS: the dispersion should run from left to right and from bottom to top – see Fig. 3.

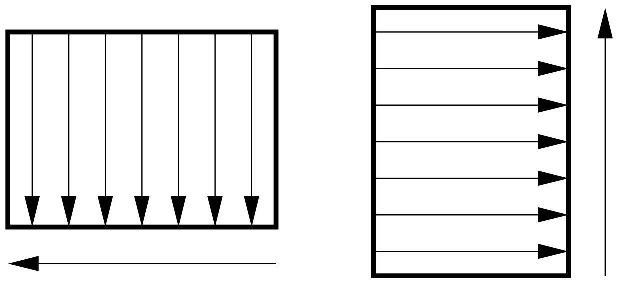

Fig. 3: The transformation of the exposed spectrum.

Then we average flat fields.

[4]It is not necessary to fit dispersion on each stellar spectrum again and again. Also different way is allowed: one can use any previous dispersion polynomial and suppose some offset with same polynomial coefficients. It corresponds, for example, to the shift of Dewar bottle due to nitrogen evaporation.

[5]It is necessary to point out that the application of dispersion and heliocentric correction is written to file headers only (keywords, coefficients of dispersion polynomials etc.). Raw data are not changed

3.2 Reduction of echelle data

- Orders definition (procedure `cascali`). It works independently on each spectral order. The cross-section in the center of the picture is done. Then the procedure finds the maximum of the cross-section (profile) and runs along the order to both sides of the chip, looking for maximum in each profile. Finally, the spectral order is approximated as a polynomial function.

  It is possible to define spectral orders on averaged flat field or on strong stellar spectrum. We usually use averaged flats.

- Looking for background. We do not expose offsets and biases as a special files. The background is looked for in between-orders space on flats and stars. Therefore the distance of order should be (minimally) three times greater than the width of orders (then the scattered light is negligible in between-orders space).

- Optimal extraction. It runs along orders with pre-defined aperture. Weighted integration of the signal (i.e. weighted extraction) is used.

  The comparison spectrum is not traced, of course, it is extracted along orders defined on averaged flat (or star).

- Dispersion relation. The dispersion relation is found on one (reference) spectrum. It consists of two fitting methods, global and individual. First of all, the global 2-dimensional dispersion relation is found as a first approximation. Then "local" dispersion relation are found on each spectral order individually. Global 2-dimensional relation is re-iterated again: the global dispersion relation may be used in orders, where "local" dispersion is not found (for example due to lack of comparison lines).

- Averaging of comparison spectra. Two comparison spectra (before and after star) are averaged. The dispersion relation is re-fitted on this reference spectrum.

- Rebinning. Flat field and stellar spectra are transformed to wavelength using the dispersion relation to the so called λ-order space[6]

- Flat field correction. The stellar spectrum is divided by averaged flat field (each order individually).

- Merging of orders. It is the final process. Sometimes it is not necessary to merge order (for example if we study narrow lines of late stars) but we have to merge them because we deal mainly with Be (i.e. early) stars with wide spectral lines (for example H_α is spread over 3 orders in HEROS spectrum).

  There are many methods how to merge spectral orders but only the most precise ones may give good results (see Škoda and Hensberge (2003))

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[6]All orders have the same length in pixels (from one side of the chip to the opposite side) but different length in wavelengths.

[7]All IRAF's documents may be found on URL `http://iraf.noao.edu/docs/docmain.html`

[8]`http://www.eso.org/projects/esomidas/doc/`