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Reduction of spectra exposed by the fiber-fed echelle spectrograph HEROS

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We present a manual for the reduction of data exposed by the fiber-fed echelle spectrograph HEROS. As the reduction process is really not trivial in fiber echelle spectrography (mainly due to instabilities leading to wave-like patterns in merged spectrum), we remind and discuss the most important influences (if they are known) evoking cited instabilities. Nevertheless, the main accent is put on the reduction process description, list of MIDAS commands, and finally on the description of HEROS arrangement of some MIDAS routines.

Keywords: Astrophysical Data – Echelle Reduction – Echelle Spectrographs

1 Introduction

We present a short description of the reduction of spectra secured by the fiber echelle spectrograph HEROS (**H**eidelberg **E**xtended **R**ange **O**ptical **S**pectrograph) installed in the Cassegrain focus of the Ondřejov 2-meter Telescope.

We use the package `HEROS` written by O. Stahl and A. Kaufer as an extension of the standard MIDAS distribution (Stahl et al. (1995)).

2 The reduction of the HEROS data: general comment

The reduction of the HEROS data is quite complicated process as the HEROS is not a very standard device: it is a fiber fed echelle spectrograph with two channels, which must be reduced individually. The optical fiber as a feed of the light to the spectrograph leads to quite narrow orders on CCD chips: typical width is bellow 10 pixels. It can evoke problems in the definition of orders and, consequently, in the determination of width of trace which will be read out (along each order): orders are sloped (the tangent is about 0.05 in both channels) and, if orders are too narrow, the signal in the path along pixel-defined columns has "jumps" (in the figure Fig. 1 we have marked them by "+"):

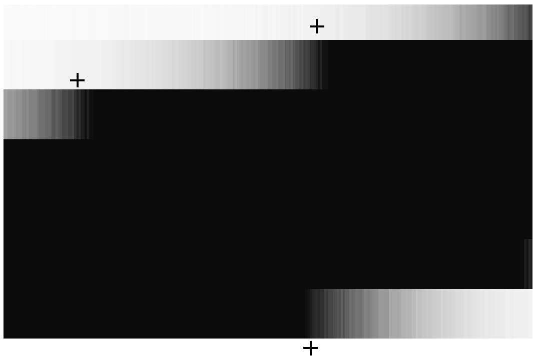


Fig. 1: Discontinuity in the narrow trace of the flat field (the situation in case where the stellar spectrum is quite similar).

Also, the number of orders (typical for echelle spectrographs) can evoke problems during the merging process: despite all efforts we were not able to eliminate wave-like patterns in the continuum of reduced spectra. The behavior of the spectrograph seems to be "chaotic" or "pseudo-chaotically"; wave-like patterns change the amplitude from star to star, it does not depend considerably on the strength of the spectrum, spectral type of the star, horizontal angle or azimuth of the telescope etc. Sometimes the continuum is quite flat and the next stellar spectrum shows the typical wave-like structure. The scale of this structure just corresponds to the length of the order.

It is a serious problem since we are interested mainly in Be stars in Ondřejov. They show wide lines which can spread over more than one order (e.g. H_α is spread over 3 orders). Therefore the wave-like continuum (which is, of course, not seen inside the wide line) modifies the spectral line profile, changes the equivalent width etc. It is thus a problem to estimate continuum inside wide lines – it is not solved correctly yet and it is a field for the future effort.

3 Short overview of the reduction process

In this paper we describe reduction as a transformation of raw data (set of 2D images) to the 1D graph of the stellar spectrum (intensity as a function of the wavelength). For this process we expose, except for stellar image, also comparison spectrum of the Thorium Argon lamp in order to wavelength calibrate and flat field lamp in order to eliminate the high-frequency noise. Examples of images mentioned are given in Fig. 2 and 4.

The process of reduction contains a number of individual steps: First of all we average all flats (in order to eliminate possible shifts of cross-order profiles).

Then we find traces of all orders (to determine them we can use either averaged flat or some strong stellar spectrum as it is discussed bellow); we suppose that these paths are stable in all files in the current directory.

Then we read out the signal (of averaged flat, comparison lights, stars) along traces which follow orders as they are determined above and which have predefined width. We use the empty space between orders to find the background; at first we find background between orders only and then, in the second step, we fit 2D function to this and thus estimate background under orders. We find the background in every image and subtract it.

Next, we look for the dispersion function. For every star we select two nearest ThArs (one ThAr nearest before the star and one ThAr after the star) and average them. We thus obtain comparison spectrum which corresponds to a virtual ThAr which would be exposed in the half-time of the stellar exposure. To this virtual ThAr we fit 2D dispersion relation (as the first approximation). We correct this global dispersion by a number of individual 1D dispersions which are defined in each order individually (it is a useful process since some orders are without comparison lines and the global dispersion is the only way to define the dispersion everywhere).

Next, we transform (averaged) flat and stellar spectra relative coordinates (in pixels) to absolute wavelengths (in Å).

Next, we divide stellar spectrum by averaged flat in order to eliminate high-frequency noise (e.g. different sensitivity of pixels). We do this in 1D spectra (not in 2D images, as it is recommended in general CCD processing). We divide each order by flat individually.

The final step is the merging of orders.

4 Reduction of the red channel: explanation and comments

In this section we give an explanation and/or comments of the reduction process or its individual commands. For the comparison, we have included as an example the reduction log (see Appendix A) where we have reduced red channel spectra exposed in July 9th, 2002.

We list commands (both standard MIDAS commands and HEROS-package extension as mentioned above) not in the alphabetical order but as they are called during the typical reduction process. The details may be found in `[MIDAS-A]` and `[MIDAS-B]`.

4.1 Input data: spectrograph specifics

The HEROS has two channels, each of them is driven by one PC computer with MS-DOS. A detailed description of observations and data acquisition is described in special paper in this volume. Exposed data are saved on hard disc in each control computer. When the observation is finished, all data may be sent through the net to disc array where they are archived.

Data are saved in the FITS format which has (due to some historical reasons) extension `*.at1` (in fact, in MS-DOS context they are `*.AT1` but the data storing pipe-line renames all files to `*.at1`). The name of each file distinguishes type of the channel: red channel creates file `ra****.at1`, where `****` is the number of the file (files are numbered from `0001`÷... independently on the date, year etc.; control computer increases file number automatically by 1 after each file is saved). Corresponding names in blue channel are `ba****.at1`.

4.2 Preparation of the data-reduction

Some steps must be done before reduction:
(Of course, raw data must be saved to a directory where reduction will be run.)

Observational log One should prepare observational log; in this log the type of each image is determined. As an example of such log we show observational log from July 9th, 2002:

```
4289  ThAr
4290  FF
4291  FF
4292  ThAr
4293  alpCrB
4294  ThAr
4295  FF
  .   .
  .   .
  .   .
4306  FF
4307  ThAr
4308  phiPer
4309  phiPer
4310  ThAr
```

Here the number is name of the file (without extension and letter prefix, for example 4292 means `ra4292.at1` if we reduce the red channel and `ba4292.at1` if we reduce the blue channel). MIDAS reads the type of the device (red/blue) from the header of files automatically. Then must be just two spaces and then the type of the image has to follow. One has to write `FF` for the flat field, `ThAr` for the comparison spectrum and name of the object for the stellar spectrum. The name of the star must correspond to the name in `OBJECT.tbl` (see following point).

We keep the filename of the log with fixed syntax: `YYYYMMDD.log`, where `YYYY` is year, `MM` denotes month and `DD` is day. For example, log presented above is `20020709.log`.

OBJECT.tbl The file[1] contains a list of all stars observed with the instrument (i.e. HEROS in our case).

```
  Table : OBJECTS.tbl
Seq   object        al al al del de de epoch norm
------------------ -- -- -- --- -- -- ----- ----
   1 V639Cas        0  3 26  63 38 26 2000.0 NULL
   2 34Psc          0 10  2  11  8 45 2000.0 NULL
   3 gamPeg         0 13 14  15 11  0 2000.0 NULL
   4 zetCas         0 36 58  53 53 49 2000.0 NULL
   .   .            .  .  .   .  .  .    .      .
   .   .            .  .  .   .  .  .    .      .
   .   .            .  .  .   .  .  .    .      .
 133 ARCas         23 30  2  58 32 56 2000.0 NULL
 134 V373Cas       23 55 34  57 24 44 2000.0 NULL
 135 LQAnd         23 56 13  46  8  5 1950.0 NULL
---------------- -- -- -- --- -- -- ------ ----
```

One should copy the table `OBJECT.tbl` to the current directory – the reduction process will break down without this table. Here `al` denotes the right ascension in `hours, minutes, seconds`; `del` or `de` is the declination, both at epoch defined in the following column; `normtab` determines which type of normalisation will be used to the final reduced spectrum. `NULL` means that the continuum will NOT be re-normalised to 1.0 by any way. Another possibility is, for example, `XYFIT` which will call procedure `yxfit` (improving the merging of orders).

[1] It is in the standard MIDAS binary table format.

lswthar.tbl The binary table `lswthar.tbl` contains the list of laboratory wavelengths of comparison lines of the Thorium Argon lamp:

```
 Table : lswthar.tbl
Sequence  WAVE        ORDER
-------- ------- ------------
       1 3325.12   1.7200e+02
       2 3327.19   1.7100e+02
       3 3330.48   1.7100e+02
       4 3333.13   1.7100e+02
       .   .            .
       .   .            .
       .   .            .
    1146 9224.50   6.2000e+01
    1147 9291.58   6.2000e+01
    1148 9354.22   6.1000e+01
-------- ------- ------------
```

Here `ORDER` is the absolute number of the order where the line should fall into.

SAVELINE.tbl and SAVEORDE.tbl These tables contain saved parameters for the reduction (i.e. path of individual orders, positions of the comparison ThAr lines on the CCD image, thresholds etc. – see also the next subsection 4.3 and appendix A).

4.3 Description and comments of the reduction process

@@ **ECH_PROC:echelle.ctx** The HEROS reduction pipe-line uses the specific context in order to read modified, rewritten or added procedures; they are written down at the level of the standard MIDAS commands or even at the level of FORTRAN codes; then they should be compiled from source codes (see the Appendix D).

CREATE/DISPLAY Open a new window for the presentation of 2D pictures (e.g. raw data).

LOAD/LUT idl4 We download the well-suited color palette. The default is grey scale. Another possible choice is `rainbow`.

CREATE/GRAPHICS Open a new window for the presentation of 1D graphs (e.g. reduced 1D spectra).

CHANGE/DIRECTORY *<path>* It is possible to abbreviate the command to `ch/d` or even to `ch`. MIDAS command is different from standard linux "`cd`"

$ls List the current directory. It is possible to use any linux commands prefixing it with $ (MIDAS environment notation).

INDISK/FITS ra* Call conversion routine which converts input fits file `ra****.at1` to the standard MIDAS format `*.bdf`. The default output filename is `toto*****.bdf`, for each `*.at1` file. For example, input files `ra4289.at1`... will be converted to files `toto0001.bdf`...

CREATE/ICAT all toto* Create a list of files `toto*.bdf` and save it:

into catalogue `all.cat` — do not write extension `cat` in the presented command. For example:

```
 =Image catalog, IDENT
toto0001.bdf                ^2 750,1180
toto0002.bdf                ^2 750,1180
toto0003.bdf                ^2 750,1180
toto0004.bdf                ^2 750,1180
toto0005.bdf                ^2 750,1180
  .                          .  .   .
  .                          .  .   .
  .                          .  .   .
toto0011.bdf                ^2 750,1180
toto0012.bdf                ^2 750,1180
```

Here ˆ2 denotes 2D picture and `750,1180` is size of the CCD image.

@@ **ECH_PROC:preredcat all.cat 200020709** The routine `preredcat.prg` is called. The routine downloads files `toto*.bdf` which are listed in the `all.cat`. Then these files are transformed (rotated to the standard echelle orientation) and their heads are modified. Bad columns on the chip are corrected by a linear interpolation. The output is `b****.bdf`, where `****` is the same number as in log (e.g. `20020709.log`). For example, output files are `b4289.bdf`... Files `toto*` are automatically removed as they are transformed.

The routine also selects all types of images and creates individual (ASCII) catalogs for each of these types; for example `Thar20020709.cat` for all comparison spectra, `FF20020709.cat` for all flats, `Objects20020709.cat` for all stellar spectra. As an example we present just mentioned `Objects20020709.cat`:

```
 =Image catalog, IDENT
b4482.bdf alpCrB        ^2 747,1152
b4486.bdf 4Her          ^2 747,1152
b4490.bdf phiPer        ^2 747,1152
b4491.bdf phiPer        ^2 747,1152
```

As one can see, the x and y size of the image is smaller with respect to the size in the `all.cat` (see upper). The reason is that the border parts of each image are cut off.

Finally, the routine creates file `20020709.tbl` which is just corresponding to the observational log `20020709.log` (created by the user), nevertheless, the new file is in the standard MIDAS binary format.

LOAD/IMAGE b4290 sc=-2 cut=8,140 The command downloads the image `b3359.bdf` to the `display` environment. As the image is too large to be shown, it is convenient to scale it via `sc=-2` which makes the picture smaller 2-times. If necessary, you can scale x and y axes independently by the command `sc=-2,-3` (first number scales x-axis and the second one the y-axis).

The command `cut=8,140` sets the minimum and maximum value in the contrast/intensity scale. If the minimal signal in the picture is about 8 then you should set the minimum near to this value. On the other hand, if the maximal signal is about 8000 then you should set the maximal value much lower (or you will see low signals as almost black). In the red channel of the HEROS we have typically in flat min≈10, max≈8000 and we put `cut=8,140`.

GET/CURSOR activates the cursor in the `display` environment. Clicking on the left button makes a mark in the position of the cursor and reads relative coordinates (with respect to the chip) and intensity of the signal in that position. Clicking on the right button will close this application and the return cursor to the command line.

We use this command mainly to find shifts in flats and/or comps in order to exclude wrong exposures (sometimes can the CCD readout position start jump by one pixel).

In this moment let us assume that we have downloaded a flat field (e.g. file `b4290.bdf` as mentioned above). We choose some region near to the center of the picture and click somewhere on the ridge of some order in that region. We take a coordinate of marked point. Let it be, for example, $(x, y) = (278, 1043)$.

Remark: Another command `GET/GCUR` (or fully `GET/GCURSOR`) opens an active cursor in the 1D

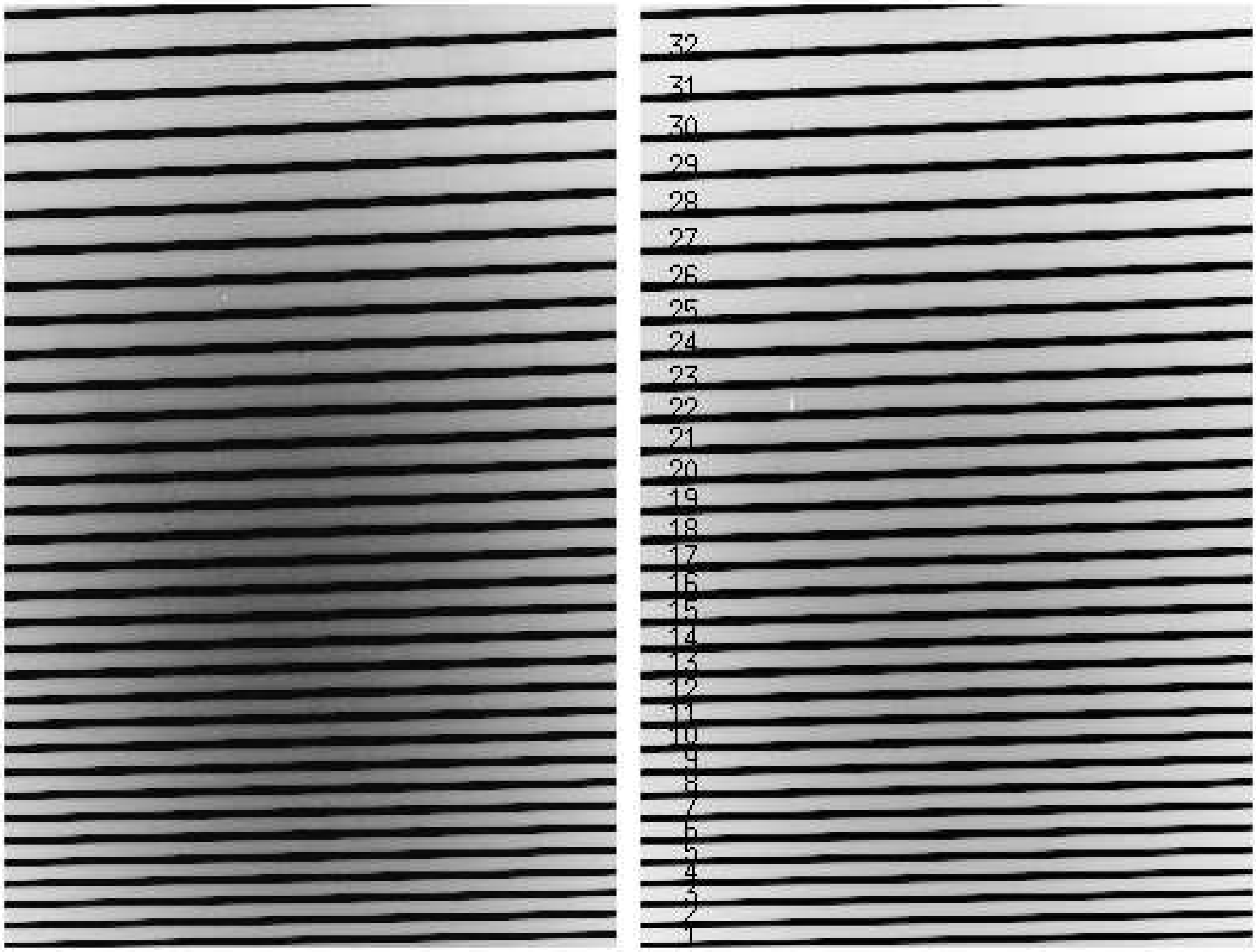


Fig. 2: Flat field (on the left-hand side) and definition of orders (on the right-hand side)

`graphical` application. One can read exact (x, y)-position of any point in 1D graph (for example reduced spectrum).

CHECK/ECHELLE FF20020401 278 1033,1053 We choose catalogue of flat field (`FF20020709.cat`) and put position of the point with some tolerance in the vertical coordinate (since we want to test vertical shifts in flats). Empirical experience shows that optimal tolerance is ± 10 pixels. MIDAS will read all flats in the catalogue `FF20020709.cat`, find position (x, y) in every file, approximate cross-order profile (supposing the Gaussian profile) inside the selected tolerance and find the maximal value in every file. Then it will plot shifts in `graphical` environment - as it is depicted on the figure Fig. 3.

The MIDAS shows position of the ridge of all orders and depicts also errors of its determination. The vertical scale of the picture is driven by the distribution of determined positions, not by the range of their errors. Therefore (sometimes) the range of errors exceeds bounds of the picture, as it is shown on the left-hand-side of the figure Fig. 3. Nevertheless, the typical range of positions exceeds the uncertainties, as it is shown on the right-hand side picture (shifts are determined very accurately as the red channel was re-focused early before this exposure).

Of course, if some flat is exposed incorrectly (for example, the lamp is switched off), then both the position of the order and its error are absurd.

COPY/GRAPHICS postscript The graph presented in the `graphical` window (now it depicts shifts of flats) is saved to the `postscript.ps`

$mv postscript.ps sff1.ps It is possible to run standard linux command through $ – it moves the `postscript.ps` file (which would be rewritten

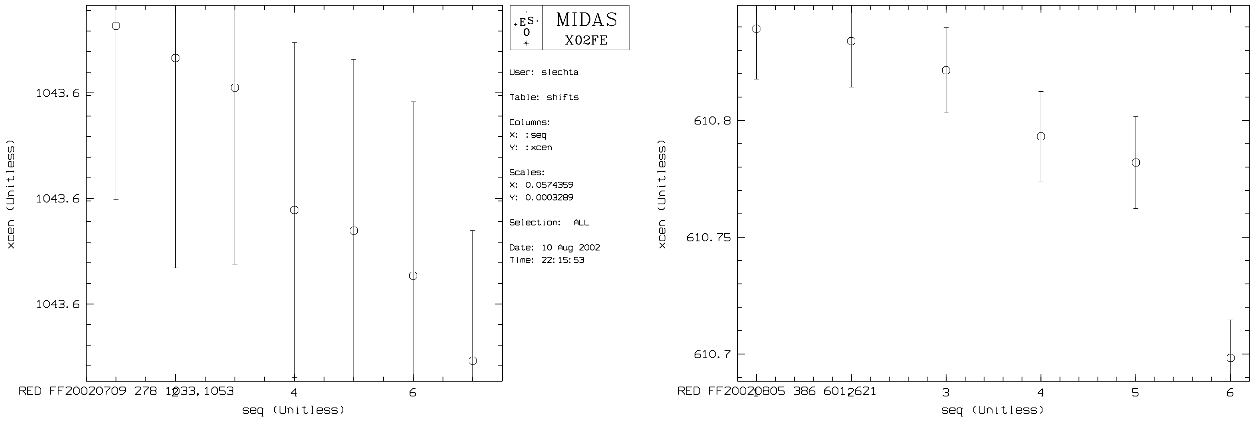


Fig. 3: Shift of flat-fields. The errors of positions is perfectly seen at the right-hand side picture.

after the next `copy/gra postscript`) to the another file `sff1.ps`.

$lpr -Php1 sff1.ps Standard linux command printing the file `sff1.ps` via laser printer `hp1`

AVERAGE/FLAT FF20020709 The command averages the flats and saves the final result to the `c****.bdf`, where **** is number of the first flat which is accounted to the averaging process. For example, we have exposed seven flat fields: `b4290`, `b4291`, `b4295`, `b4296`, `b4299`, `b4302` and `b4306`. Then the averaged flat will be `c4290` (`c*`, in opposite to `b*`).

CLEAR/CHANNEL over erases all marks, lines etc. included in the displayed picture (i.e. in the 2D `display` environment).

LOAD/IMAGE b4292 sc=-2 cut=8,140 It downloads another picture. Now, it is the comparison light - Thorium Argon lamp (see Fig. 4).

GET/CURSOR We recall `get/cursor` again and mark a spectral line somewhere from the central region of the picture. We prefer Thorium line because they usually are not overexposed. Let us suppose that the line is on the position $(x, y) = (318, 575)$.

CHECK/ECHEL ThAr20020709 575 308,328 Now, we look for the shift along the dispersion (i.e. along the horizontal axis). Contrary to all expectation we do NOT write `check/ech ThAr20020709 308,328 575` (i.e. the tolerance in x-axis a y-value) but unexpectedly we write down the fixed value at the first position and the tolerance ALWAYS at the second one. MIDAS reads the name of the catalogue and automatically finds which position should be measured

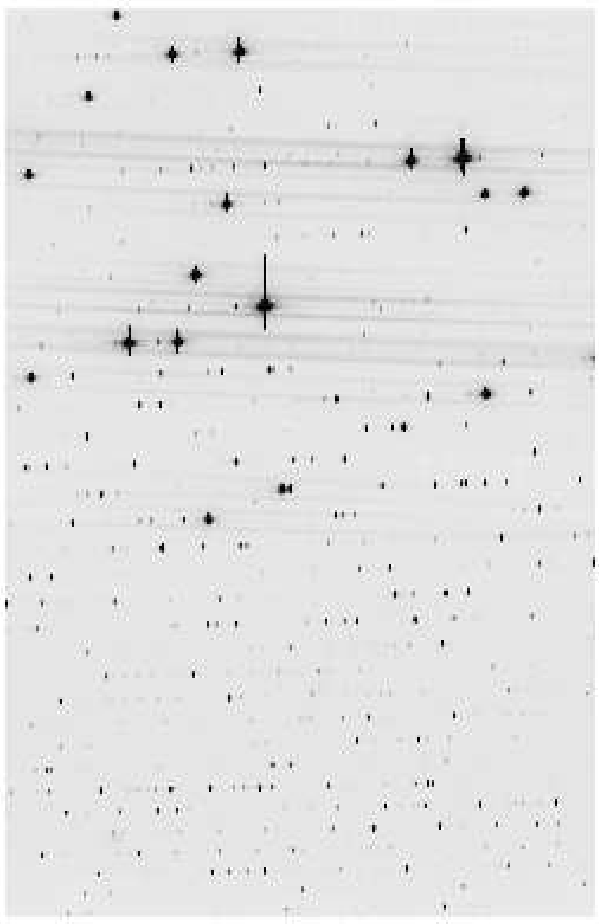


Fig. 4: Thorium Argon comparison spectrum. Strong features belong to Argon infrared lines.

(if the catalogue is `FF****` then MIDAS will check the vertical position, if the catalogue is `ThAr****` then MIDAS will check the horizontal position). Automatically, it depicts a graph of shifts again – see Fig. 5

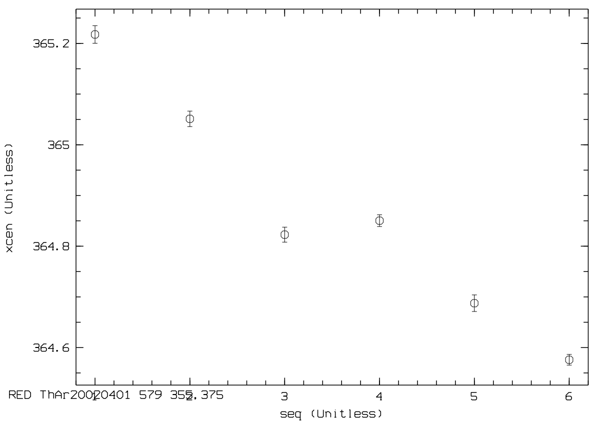


Fig. 5: Shifts in ThAr.

INIT/ECHELLE SAVE The command downloads parameters saved in binary tables `SAVELINE` and `SAVEORDE` – not `SAVEORDE`**R**.

SHOW/ECHELLE The command shows all parameter defined or read in the previous point.

```
CURRENT SESSI
OBJECT    :
FLAT FIELD:  FLAT=c4290     CORRECT=FLATCORR BLAZEFF=BLAZE
WAVE CAL. :   WLC=b4292
AUX.TABLES:LINCAT=lswthar   FLUXTAB=UNITY
------------ PARAMETERS  INSTRUMENT=HEROS     ---------------
METHOD    ECHELLE=31.6    REDUCTION=STANDARD   GUESS=NULL
DEFINE    :WIDTH1=    9.00   THRES1=  400.00   SLOPE=    0.05
           DEFPOL=   3,  4   DEFMTD=STD
SEARCH    :WIDTH2=    5.00   THRES2=    3.00   SEAMTD= GAUS
IDENTIFY  :   TOL=    1.00       DC=       3
BACKGROUND:BACFLA=   2,  3   BACOBJ=   2,  3
           SMFLA=  1000.00   SMOBJ=  1000.00
EXTRACTION:  SLIT=    7.00   OFFSET=    0.00  EXTMTD=AV
REBIN     :SAMPLE=********
MERGE     : DELTA=    3.00
RIPPLE    :RIPMTD=SI        LAMBDA1=    1.00 LAMBDA2=   20.00
                                  K=  568746.0 ALPHA=    0.80
RESPONSE  :   STD=******** RESPONSE=RESPONSE  RESPOL=       1
IMAGE SIZE:  747,1152 PIXELS, NO.ORDERS:  32,SPECTRAL ORDERS: 99 -  68
```

Here:

FLAT=c4290 defines the files which will be used to the order definition and also to the elimination of the high-frequency noise. Usually, it is supposed to be an averaged flat in both cases. Nevertheless, one can use, if necessary, another file for order definition and another file for the elimination of the high-frequency noise. For example, if the flat field lamp does not shine in far blue region of the spectrum, one should expose a hot bright star to define orders. We widely use the typical B star η UMA (HR120315, $\alpha_{2000} = 13^h47^m32^s$; $\delta_{2000} = 49^o19'00"$; $m_{\rm V} = 1.86$; Sp.T.=B3V). Averaged flat must be used to the elimination of the high frequency noise: it is not possible to use a stellar spectrum as in the previous case due to spectral lines.

In the defining `FLAT` one should write name of the file without extension, i.e `c4290` instead of `c4290.bdf`

WLC=b4292 defines the file for the determination of the dispersion relation.

LINCAT=lswthar It gives what table contains a list of laboratory wavelengths of ThAr spectral lines. In HEROS routines it is `lswthar.tbl`.

WIDTH1=9 is supposed width of spectral order (i.e. width of the cross order profile) in pixels.

WIDTH2=5 is supposed width of spectral line

TOL=2 pre-defined tolerance (in σ) for spectral line identification.

If the difference of measured and supposed wavelength of a line exceeds the tolerance, the line is excluded out of list of lines and it is not used in looking for the dispersion.

SLIT=7 Width of the trace which is read out along the path of the every order.

THRES1=400.00 The threshold (level of the signal) for the distinguishing the flat field signal and the noise.

THRES2=3.00 The level of the signal for the distinguishing the level of the comparison lines and the noise.

SLOPE=0.05 The initial slope of the path of the orders. MIDAS assumes the initial value pre-defined in `SLOPE` (then, of course, it modifies automatically the temporal value of the slope along the path of the order (from one edge of the chip to the opposite one).

IMAGE SIZE: 742,1152 The size of the chip (read out of the head of the exposed file) determines the reduction procedure (which is different in blue and red channel. The MIDAS calls different internal procedures).

NO. ORDERS: 32 Supposed number of orders

SPECTRAL ORDERS: 99 - 68 It depicts the absolute numbers of orders (as they are expected in HEROS exposures).

SET/ECHELLE guess=SAVE wlc=b4294 We input parameters to the reduction tables: comparison spectrum (we will look for the dispersion relation on it) will be `b4294.bdf`.

LOAD/IMAGE c4290 sc=-2 We download averaged flat `c4290.bdf`.

DEFINE/ECHELLE It starts looking for the orders (procedure `echdefi`). We define orders on the averaged flat (see also `show/ech`).

LOAD/ECHELLE depicts relative orders on the background of the displayed picture `c3559.bdf` (see figure Fig. 2)

CALIBRATE/ECHELLE We calibrate comparison spectrum (one selected spectrum defined via `show/ech`) to the dispersion.

SAVE/ECHELLE SAVE We save found reduction parameters to tables `SAVELINE` and `SAVEORDE` (not `SAVEORDER` - the name has just 8 letters). In the table `SAVEORDE` we have saved relative positions of spectral orders (defined on `c4290`) on the chip, i.e. values of coordinates are in pixels. In the table `SAVELINE` we have saved positions of ThAr lines (also in relative coordinates with respect to the chip).

REDUCE/ECH 20020401 SAVE It is a core of the reduction pipeline. It contains a lot of subroutines – see Appendix E.

STATISTICS/TABLE LINE :residu The command will show the statistics of the global 2D fit of the dispersion relation.

STATISTICS/TABLE LINE :residual The command will show the same as the previous one but for the local 1D fit.

PLOT/TABLE LINE :order :residu It reads two columns in the `LINE.tbl` and plots them in the graph: variable “order” is on the x-axis and “residu” is on the y-axis.

PLOT f4293 plots 1D reduced spectrum `f4293.bdf` of the star on the `graphical` window

SET/GRAPHICS xa=6500,6600 It depicts detail of the spectrum in the range $6500 \div 6600$Å (neighbourhood of $H_\alpha = 6563$Å - see Fig. 6).

SET/GRAPHICS pmode=0 Change the printing mode: the plot header is not printed.

SET/GRAPHICS ya=0.0,0.04 Rescale vertical axis; it depicts some details of telluric lines.

CREATE/ICAT fits f3* We create a catalogue `fits.cat` where all stellar spectra are included:

```
 =Image catalog, IDENT
f3561.bdf 17Tau        ^1 27851
f3563.bdf 23Tau        ^1 27852
f3564.bdf etaTau       ^1 27852
f3567.bdf kapDra       ^1 27853
f3570.bdf V379Cep      ^1 27854
f3573.bdf V744Her      ^1 27854
```

@@ **ECH_PROC:excatrange fits.cat 5800,8300** We select a region $5800 \div 8300$Å from spectra listed in the catalogue `fits.cat` in order to exclude undefined and/or wrongly defined edges at the start ($<$ 5800Å) and at the end ($>$ 8300Å) of spectra. The output of the procedure `excatrange.prg` is transformed from MIDAS data format `*.bdf` to standard `*.fit` format and saved to files `x****.fit`

$./rename.sh is a standard shell command calling a trivial shell script renaming files `x****.bdf` to `rxn****.bdf` where `r` determines “red” channel, “x” is the range (here $5800 \div 8300$Å) and “n” denotes that the spectrum is not normalised (the continuum is not re-normalized to 1.0 yet).

```
#!/bin/bash

for i in x*.fit;
  do
    fname=`echo $i | sed -e 's/x/rxn/'`
    mv $i $fname
  done
```

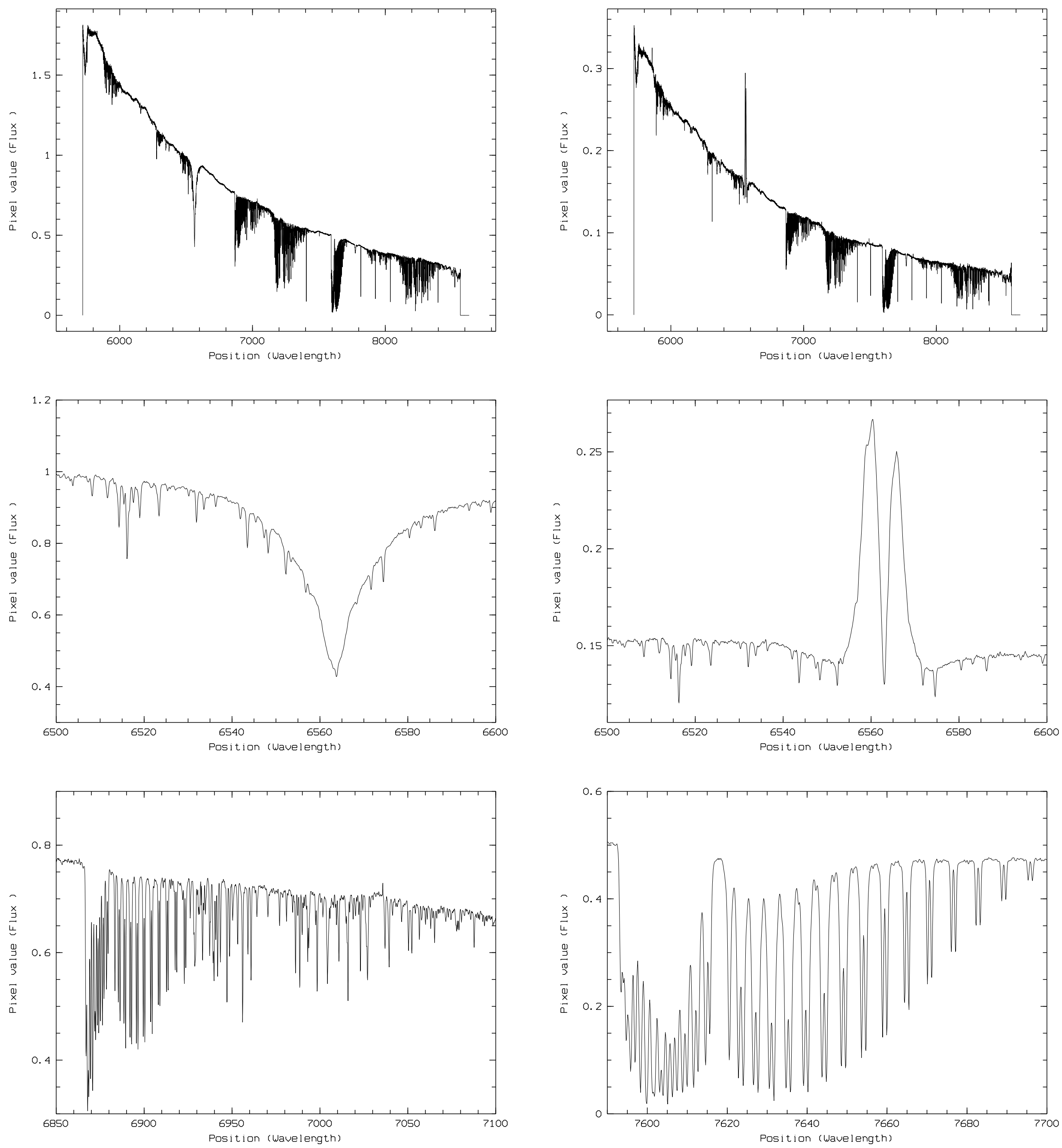


Fig. 6: Stellar spectra (top row); detail in the neighbourhood of $H_\alpha = 6563$Å (on the middle row). Details of telluric lines in the range $6830 \div 7100$Å and $7590 \div 7700$Å (bottom row). We do not plot figure headers here.

5 Non-standard situations: HEROS specifics and possible reduction problems

The reduction manual described above represents standard reduction routines. Nevertheless, HEROS has some specifics which should be explained and commented separately.

5.1 Order definition

As one can see on the Fig. (2), there is a mess in the first and the last orders as they are lying just on the edge of the chip: the first order (bottom) is cut off along almost full width of the chip, while the last order (top) is missing at its half-width. Therefore it is not possible either define the position of these order or positions of ThAr lines in corresponding orders of the comparison spectrum. It is necessary to erase these two orders and define orders on new "cleaned" averaged flat. We put both spectra, for comparison, in the figure Fig. 7:

One can use following way to modify averaged flat `c****.bdf`:

```
Midas ***> copy/ii c4290 orgc4290
Midas ***> @@ ECH_PROC:rows c4290 15 35
Midas ***> @@ ECH_PROC:delrows c4290 1119 1151 35
Midas ***> load/ima c4290 sc=-2 cut=8,140
Midas ***> def/ech
```

5.2 The reduction pipeline in the blue channel

The reduction pipeline in the blue channel is, in principle, quite similar to the red channel. Therefore we do not include individual description of the "blue" pipe-line, as it is presented in sections A and 4 for the red channel. Nevertheless, some differences should be mentioned and explained.

At first, also blue channel must be modified to define orders. The flat field lamp does not shine in the extreme blue region; therefore in the bottom edge of the chip (i.e. at the UV edge) one should cut off 185 rows. The cross-disperser has a low transmissivity limit above 5800Å (upper part of the chip) and therefore we must cut off rows from 1910÷2000 region – see also. Fig. 7.
For example:

```
Midas ***> copy/ii c4290 orgc4290
Midas ***> @@ ECH_PROC:rows c4290 185 1035
Midas ***> @@ ECH_PROC:delrows c4290 1910 2000 1035
Midas ***> load/ima c4290 sc=-2 cut=1000,1400
Midas ***> def/ech
```

We present, as an example, reduced spectrum of ηUMa and V360 Lacertae (see Fig. 8). One can see that the "continuum" (perhaps, quasi-continuum is the better expression) follows the quasi-continuum of the red channel: it increases from right to left. The reason is quite easy. The flat field lamp is too cool (in comparison with the star) and the maximum of its Planck curve is in IR region. Therefore the intensity of the flat field decreases quite rapidly as one runs to the short wavelengths. As we divide (in the reduction process) stellar spectrum by the flat field spectrum, the blue region of the final spectrum diverges as it is shown in Fig. 6 and also Fig. 8.

5.3 Echelle calibration

It is not necessary to repeat manual calibration (via `calib/ech` as it was described in the section 4) each session. One can use `IDTAB` created in some previous reduction session (it is possible to copy `IDTAB` from night to night), if the shift of ThAr lines is not considerable or if the HEROS configuration did not change.
How to get it:
`Midas ***> calib/ech` Standard start of the calibration process. Nevertheless, when the MIDAS waits for the interactive selection of comparison lines (see Fig. (11)), one can press right button of the mouse two times and break the process. The `IDTAB` was created but it is empty yet (because none ThAr lines are marked).
`Midas ***> $cp MYIDTAB.tbl IDTAB.tbl`. Standard linux command (enabled via $) One can copy `MYIDTAB` to the `IDTAB`. In that moment `IDTAB` is not empty and it is the same situation as manual selection of comparison lines.
`Midas ***> @@ ECH_PROC:echiden 2 3 lswthar ? retr` The command for the "re-identification" or "repeating of the identification". The procedure includes lines in `IDTAB` and prepares a global fit of the dispersion relation. The tolerance `tol=2` and the dispersion following the polynomial of the 3rd order (see the command `show/ech` in the sections A and 4) are supposed. The `lswthar.tbl` will be supposed and `retr` is "retry". Then the standard process (as described) follows.

If it is ready, one can save reduction parameters (`save/ech SAVE`) and then it is already standard process as it was discussed before.

5.4 Computing image

From time to time too weak spectrum is exposed, for example due to bad weather conditions (bad seeing etc.). Then it is reasonable to expose two spectra of the star and average them. Of course, we are not able to realise it in case of rapidly variable stars (as δ Sco is). We have an empirical experience that averaging final reduced 1D spectra `f****.bdf` is a bit better than averaging prereduced 2D spectra `b****.bdf`.

We use standard MIDAS command `compu/ima`; for example, if we need to average spectra 4000 and 4001, we use
`compu/ima␣av4000␣=␣(f4000␣+␣f4001)/2`
Here we used the symbol ␣ to mark the obligatory space. As an example we give the comparison of rectified region 4650 ÷ 4750Å of one (individual) spectrum and the region averaged over three spectra – see. Fig. 9:

Acknowledgement

We would like to appreciate the attitude of colleagues Otmar Stahl and Monika Maintz from Landessternwarte Heidelberg-Königstuhl and Thomas Rivinius from ESO for their help and useful discussion concerning the HEROS reduction pipeline.

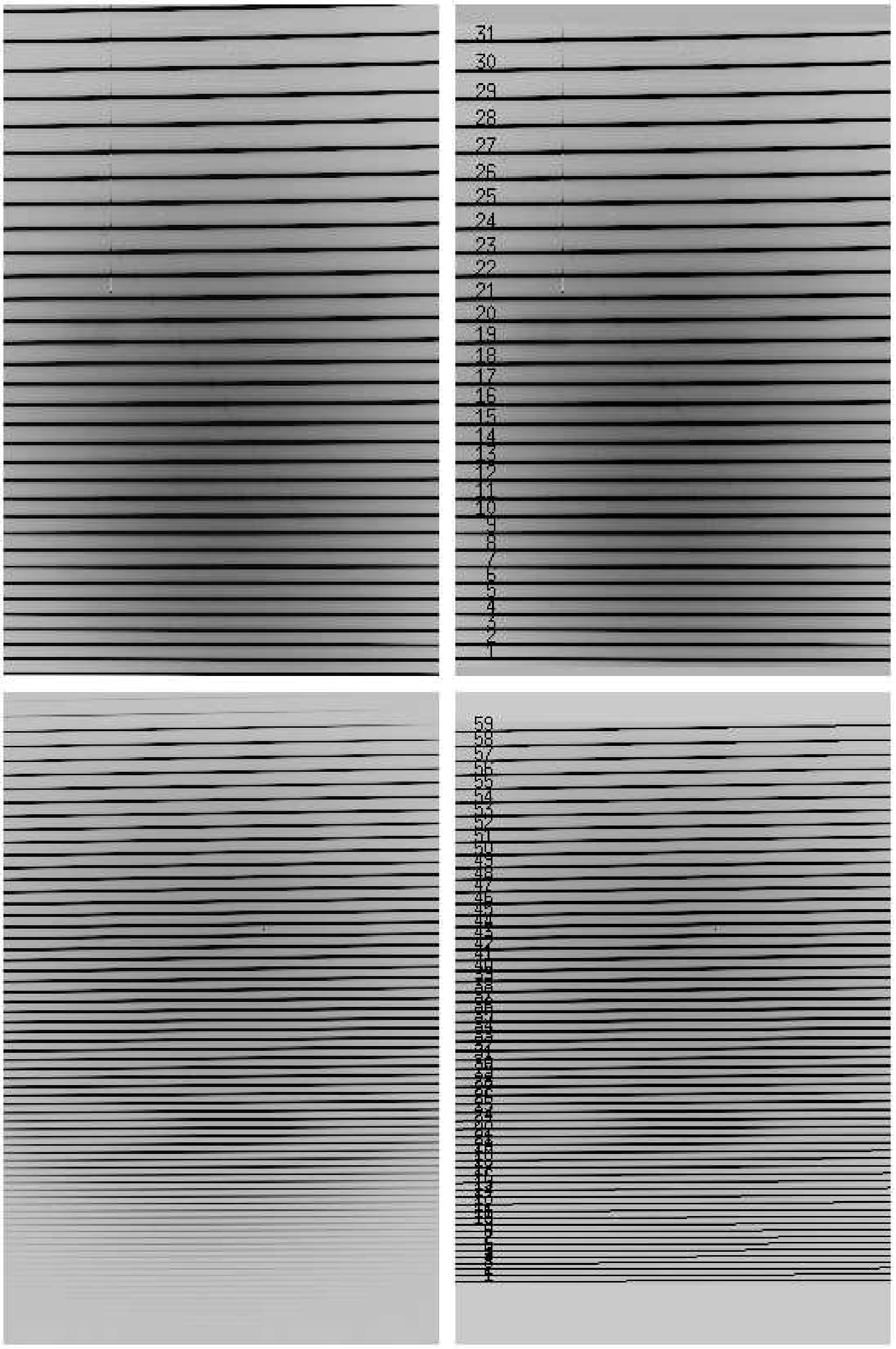


Fig. 7: Original averaged flat field (on the left) and modified (on the right) - with order definition. Top row: red channel situation, bottom row: blue channel situation.

This work was supported by projects AV0 Z1003909 and K2043105 and by grants GA AVČR A3003805 and GAČR 205/02/0445.

References

[MIDAS-A] ESO-MIDAS User Guide, Volume A: System, MIDAS Release 98Nov

[MIDAS-B] ESO-MIDAS User Guide, Volume B: Data reduction, MIDAS Release 98Nov

Stahl O., Kaufer A., Wolf B., Gäng Th., Gummersbach C., Kovács J., Mandel H., Rivinius Th., Szeifert Th., Zhao F., 1995, Journal of Astronomical Data, 1, 3 (published on CDROM)

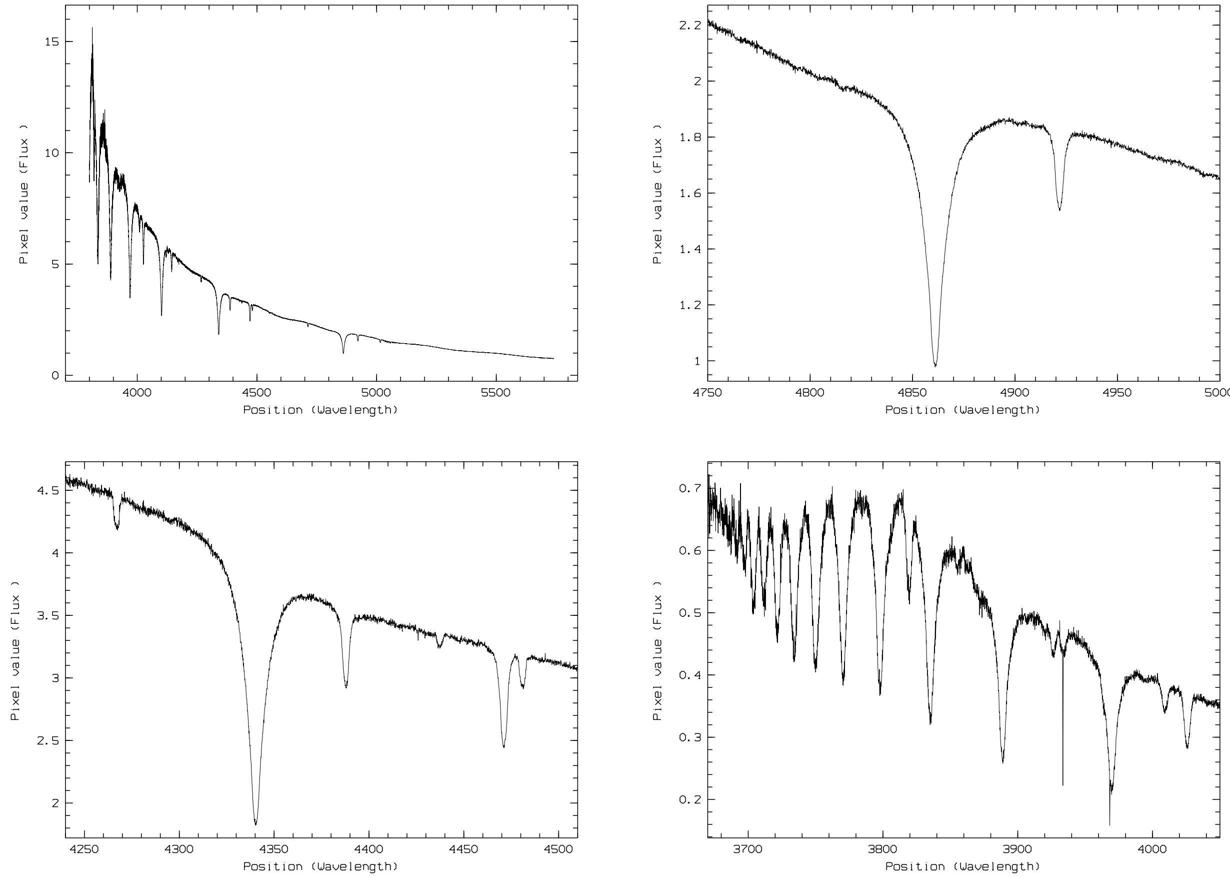


Fig. 8: Final spectrum of the blue channel. Left upper: final spectrum of ηUMa. Right upper: ηUMa; detail of H_β. Left bottom: ηUMa; detail of H_γ. Right bottom: V360Lac; the most blue neighbourhood of Balmer's limit.

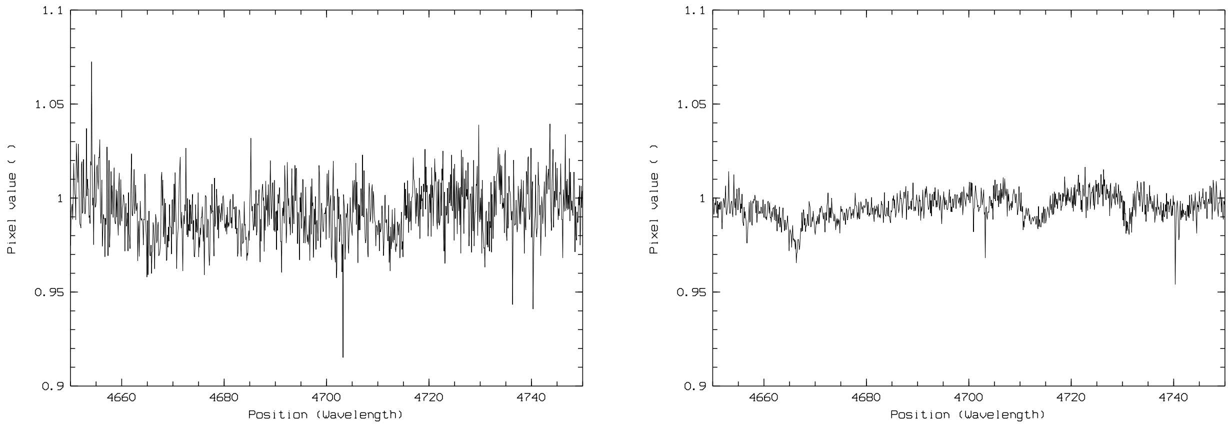


Fig. 9: Comparison of the rectified continuum in the range 4650 $\div$ 4750Å of the individual spectrum (on the left) and the continuum averaged over three spectra (on the right)

A Red-channel pipeline at a glance — reduction log

```
Midas 001> @@ ECH_PROC:echelle.ctx
Midas 002> cre/disp
Midas 003> load/lut idl4
Midas 004> cre/gra
Midas 005> ch /import/raid7/REDUCED2.HER/20020709/red/
Midas 006> $ls
Midas 007> indisk/fit ra*
Midas 008> cre/icat all toto*
Midas 009> @@ ECH_PROC:preredcat all.cat 20020709
Midas 010> load/ima b4290 sc=-2 cut=8,140
Midas 011> get/cur
Midas 012> check/ech FF20020709 278 1033,1053
Midas 013> copy/gra postscript
Midas 014> $mv postscript.ps sff1.ps
Midas 015> $lpr -Php1 sff1.ps
Midas 016> aver/flat FF20020709
Midas 017> cl/ch ov
Midas 018> load/ima b4294 sc=-2 cut=8,140
Midas 019> get/cur
Midas 020> check/ech ThAr20020401 575 308,328
Midas 021> copy/gra postscript
Midas 022> $mv postscript.ps sthar.ps
Midas 023> cl/ch ov
Midas 024> init/ech SAVE
Midas 025> show/ech
Midas 026> set/ech guess=SAVE wlc=b4294
Midas 027> load/ima c3559 sc=-2
Midas 028> def/ech
Midas 029> load/ech
Midas 030> cl/ch ov
Midas 031> calib/ech
Midas 032> copy/gra postscript
Midas 033> $mv postscript.ps calibech.ps
Midas 034> save/ech SAVE
Midas 035> REDUCE/ECHE 20020709 SAVE
Midas 036> stat/tab LINE :residu
Midas 037> stat/tab LINE :residual
Midas 038> plot/tab LINE :order :residu
Midas 039> copy/gra postscript
Midas 040> $mv postscript.ps residu.ps
Midas 041> $lpr -Php residu.ps
Midas 042> plot/tab LINE :order :residual
Midas 043> copy/gra postscript
Midas 044> $lpr -Php residual.ps
Midas 045> $ls f4*
Midas 046> plot f4293
Midas 047> copy/gra postscript
Midas 048> $mv postscript.ps star1.ps
Midas 049> $lpr -Php star1.ps
Midas 050> set/gra pmode=0
Midas 051> plot f4293
Midas 052> copy/gra postscript
Midas 053> $mv postscript.ps star1a.ps
Midas 054> set/gra xa=6500,6600
Midas 055> set/gra ya=0.3,1.2
Midas 056> plot f4293
Midas 057> copy/gra postscript
Midas 058> $mv postscript.ps star1b.ps
Midas 059> set/gra xa=6850,7100
Midas 060> plot f4293.bdf
```

```
Midas 061> copy/gra postscript
Midas 062> $mv postscript.ps lines1.ps
Midas 063> set/gra xa=7590,7700
Midas 064> set/gra ya =0,0.6
Midas 065> plot f4293.bdf
Midas 066> copy/gra postscript
Midas 067> $mv postscript.ps lines2.ps
Midas 068> set/gra
Midas 069> set/gra pmode=0 xa=6500,6600
Midas 070> plot f4298.bdf
Midas 071> copy/gra postscript
Midas 072> $mv postscript.ps star2.ps
Midas 073> cre/icat fits f3*
Midas 074> @@ ECH_PROC:excatrange fits.cat 5800,8300
Midas 075> @@ ECH_PROC:excatrange fits.cat 5800:8300
Midas 076> $ls *.fit
Midas 077> $./rename.sh
Midas 078> $ls *.fit
```

B FITS headers of raw and final data

The file head of the blue camera is:

```
SIMPLE  =                    T
BITPIX  =                   16
NAXIS   =                    2
NAXIS1  =                 2000
NAXIS2  =                  800
CAMGAIN =                    1
ZEROLEV =                   -1
CCD-TEMP=                  140
NFLUSH  =                    1
CORR-TIM=                  221
EXPO-TIM=               7000.0
TIME-BEG=       '23:11.48,660'
TIME-END=        '1:09.58,230'
OBS-DATE=         '25/08/2002'
FILENAME= 'BA4612.AT1'                / Filename
END
```

The file header of the red camera

```
SIMPLE  =                    T        /(logical) file is basic fits format
BITPIX  =                   16        /(integer) number of bits per pixel
NAXIS   =                    2        /(integer) number of axes
NAXIS1  =                  750        /(integer) pixels on fastest varying axes
NAXIS2  =                 1180        /(integer) number of pixels on next axis
FAXIS1  =                   47        /(integer) device origin of first pixel
FAXIS2  =                    1        /(integer) device origin of first pixel
BAXIS1  =                    1        /(integer) binning factor on first axis
BAXIS2  =                    1        /(integer) binning factor on next axis
TIME-BEG=       '00:11.51,000'        /(character) exposure start time
TIME-END=       '02:08.31,000'        /(character) exposure end time
CAMGAIN =                    1        /(integer) camera gain setting
OBS-DATE=         '24/08/2002'        /(character) date of data aquisition
ZEROLEV =                   20        /(integer) Value of true data zero
FILENAME= 'RA4612.AT1'                / Filename
END
```

The header of the final file `*fit` is:

```
SIMPLE  =                    T / Standard FITS format: NOST 100-2.0
BITPIX  =                  -32 / No. of bits per pixel
```

```
NAXIS   =                    1 / No. of axes in image
NAXIS1  =                25101 / No. of pixels
EXTEND  =                    T / FITS extension may be present
BLOCKED =                    T / FITS file may be blocked
COMMENT NOST 100-2.0: Hanisch,R. et al. 2001, Astron. & Astrophys. 376, 559
CRPIX1  =                   1. / Reference pixel
CRVAL1  =        5840.00008702 / Coordinate at reference pixel
CDELT1  =        0.10000000149 / Coordinate increment per pixel
CTYPE1  = 'Wavelength      '   / Units of coordinate
BUNIT   = 'Flux            '   / Units of data values
DATAMAX =       0.280263602734 / Maximum data value
DATAMIN =     0.00313822715543 / Minimum data value

ORIGIN  = 'ESO-MIDAS'          / Written by MIDAS
DATE    = '2002-08-25T21:21:09' /  [UTC] Date of writing
FILENAME= 'x4612.bdf'          / Original file base-name
MIDASFTP= 'IMAGE   '           / MIDAS File Type
OBJECT  = 'V360Lac '           / MIDAS desc.: IDENT(1)
HISTORY COPY/TABL middummz.bdf m4612 5. AVERAGE
\HISTORY          COPY/II m4612 f4612 R4 n,u
\HISTORY                   EXTRACT/IMAG x4612.bdf = f4612.bdf[5840:8350]
\HISTORY
DATE-OBS= '2002-08-24'         / MIDAS desc.: O_TIME(1)
MJD-OBS =        52510.0487383 / MIDAS desc.: O_TIME(4)
TM-START=             4210.992 / MIDAS desc.: O_TIME(5)
AIRMASS =              1.04594 / MIDAS desc.: AIRMASS(1)
HELVEL  =              11.5162

HISTORY  ESO-DESCRIPTORS START   ......................
HISTORY  'WSTART','R*8',1,31,'3E23.15'
HISTORY    5.780900086142123E+03  5.841000087037683E+03  5.902400087952614E+03
HISTORY    5.965100088886917E+03  6.029100089840591E+03  6.094500090815127E+03
HISTORY    6.161300091810524E+03  6.229600092828274E+03  6.299500093869865E+03
HISTORY    6.370900094933808E+03  6.444000096023083E+03  6.518700097136199E+03
HISTORY    6.595200098276138E+03  6.673600099444389E+03  6.753800100639462E+03
HISTORY    6.836000101864338E+03  6.920200103119016E+03  7.006500104404986E+03
HISTORY    7.095000105723739E+03  7.185700107075274E+03  7.278800108462572E+03
HISTORY    7.374400109887123E+03  7.472500111348927E+03  7.573200112849474E+03
HISTORY    7.676700114391744E+03  7.783000115975738E+03  7.892400117605925E+03
HISTORY    8.004800119280815E+03  8.120500121004879E+03  8.239600122779608E+03
HISTORY    8.362300124607980E+03
HISTORY
HISTORY  'NPTOT','I*4',1,31,'7I10'
HISTORY         982       992      1002      1013      1024      1035      1047
HISTORY        1059      1070      1083      1095      1109      1122      1135
HISTORY        1149      1163      1178      1193      1208      1224      1240
HISTORY        1256      1273      1291      1308      1327      1345      1365
HISTORY        1385      1406      1427
HISTORY
HISTORY  'NORDER','I*4',1,31,'7I10'
HISTORY          98        97        96        95        94        93        92
HISTORY          91        90        89        88        87        86        85
HISTORY          84        83        82        81        80        79        78
HISTORY          77        76        75        74        73        72        71
HISTORY          70        69        68
HISTORY
HISTORY  'DTIME','R*8',1,6,'3E23.15'
HISTORY    2.002000000000000E+03  8.000000000000000E+00  2.400000000000000E+01
HISTORY    5.251004873833572E+04  1.169720000000000E+00  1.859764101664225E+01
HISTORY
HISTORY  'ALPHA','I*4',1,3,'7I10'
```

```
HISTORY         22        50        29
HISTORY
HISTORY  'DELTA','I*4',1,3,'7I10'
HISTORY         41        57        50
HISTORY
HISTORY  'LHCUTS','R*4',1,4,'5E14.7'
HISTORY   0.0000000E+00 2.9334977E-01 3.1382272E-03 2.8026360E-01
HISTORY
HISTORY  ESO-DESCRIPTORS END     ................
END
```

C The template for identification of comparison lines

No.	Wavelength (Å)	Order No. (Abs. No.)
1	8332.21	*
2	8178.84	*
3	8046.07	71
4	7916.45	*
5	7891.07	73
6	7372.12	*
7	7353.32	*
8	7146.99	*
9	6871.32	*
10	6666.36	*
11	6416.30	*
12	6215.44	*
13	6134.49	*
14	5987.29	*
15	5928.81	*
16	5928.81	*
17	5912.08	*
18	5912.08	*
19	5888.58	*
20	5882.62	*
21	5802.09	*

Table 1: List of comparison lines for interactive identification in the red channel. See also Fig. 10.

No.	Wavelength (Å)	Order No. (Abs. No.)
1	5606.73	*
2	5451.65	105
3	5187.74	110
4	5162.28	*
5	5162.28	*
6	4965.08	*
7	4726.87	*
8	4510.74	*
9	4510.74	*
10	4272.00	*
11	4272.00	*
12	4259.86	*
13	4200.67	*
14	4198.32	*
15	4181.88	*
16	4181.88	*
17	4158.54	*
18	3803.20	*
19	3734.60	*
20	3734.60	*
21	3729.30	*
22	3719.40	*
23	3719.40	*
24	3588.44	*

Table 2: List of comparison lines for interactive identification in the blue channel. See Fig. 11.

D Echelle context – explanation

The MIDAS `context` (abbreviated to `*.ctx`) is a general mechanism for inclusion of packages of procedures[2]. One can say that it is quite similar to IRAF where one can find a lot of packages, e.g. `ondespec`, which include new tasks. Thus, it is possible to use new keywords and commands after reading some MIDAS `context`.

The `echelle.ctx` is one of many possible contexts used in MIDAS; among others one can remind `spec.ctx` for the standard 1-dimensional spectroscopy.

The standard MIDAS distribution allows calling any context through the command `set/context` <*context_name*>. It includes groups of specific routines and link keywords or user-commands to these included executive routines; in other words, the context defines some keywords (through `create/com`); for example, the user-command `reduce/echelle` includes executive routine `reduce`. The executive routine may be either a fundamental MIDAS routine (i.e. compiled binary file) or it may be a group of (another) MIDAS routines. For example, one can write some executive routine for plotting data through standard commands, i.e. `plot/row`, with some parameters defined in this user's short routine. Of course, it is possible to include some special routines being outside the standard MIDAS distribution.

To reduce HEROS fiber-fed echelle spectra, we use a specific `echelle.ctx` (which is different from standard MIDAS distribution `echelle.ctx`) in order to optimize the reduction process. The HEROS echelle context also includes, besides standard MIDAS routines, an amount of specific HEROS routines, written or adapted by Otmar Stahl and Andreas Kaufer in FORTRAN and C.

It is necessary to accent that our adapted `echelle.ctx` somewhere links standard keywords to the **adapted** routines. In fact it means that the HEROS `echelle.ctx` re-defines a lot of internal MIDAS commands. For example, the command `define/echelle` is the standard MIDAS keyword, nevertheless in HEROS `echelle.ctx` it includes quite different routines then in standard MIDAS distribution!

D.1 "HEROS" `echelle.ctx`

```
! +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
!
! Procedure ECHELLE.CTX       J.D.Ponz 110286
!                             K. Banse 880105
!
! Purpose  :
!           SET/CONTEXT ECHELLE
!           Define standard ECHELLE commands
!
! -------------------------------------------------------------
!
SET/MIDAS USER=EXPERT
SET/CONTEXT spec
!
CREA/COM  EXTRACT/ECHELLE     @@ ECH_PROC:echextr
CREA/COM  EXTRACT/ORDER       @@ ECH_PROC:echexor
CREA/COM  INITIALIZE/ECHELLE  @@ ECH_PROC:echinit
CREA/COM  MERGE/ECHELLE       @@ ECH_PROC:echmerg
CREA/COM  SET/ECHELLE         @@ ECH_PROC:echset
CREA/COM  SHOW/ECHELLE        @@ ECH_PROC:echshow
CREA/COM  DEFINE/ECHELLE      @@ ECH_PROC:echdefi
CREA/COM  SEARCH/ORDER        @@ ECH_PROC:echsord
CREA/COM  CALIBRATE/ECHELLE   @@ ECH_PROC:cascali
CREA/COM  REGRES/ECHELLE      @@ ECH_PROC:echregr
CREA/COM  SEARCH/ECHELLE      @@ ECH_PROC:echsear
CREA/COM  PLOT/RESIDUAL       @@ ECH_PROC:echpres
CREA/COM  LOAD/ECHELLE        @@ ECH_PROC:echload
CREA/COM  LOAD/IDENT          @@ ECH_PROC:echlide
CREA/COM  IDENTIFY/ECHELLE    @@ ECH_PROC:echiden
CREA/COM  SAVE/ECHELLE        @@ ECH_PROC:echsave
!
CREA/COM  ECHFILT             @@ ECH_PROC:echfilt
CREA/COM  ECHFIT              @@ ECH_PROC:echfit
CREA/COM  SPLBACK             @@ ECH_PROC:splback
```

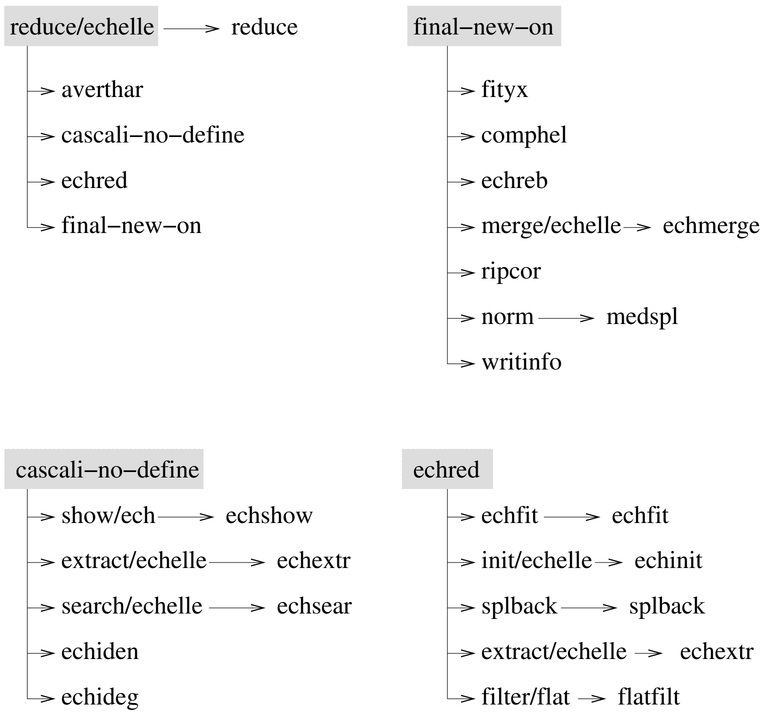
[2]We assume the specific HEROS packages are installed by MIDAS administrator; it requires the recompilation of a part of the MIDAS system.

```
!
! New commands for automatic reduction of HEROS echelle data
! A. Kaufer 13.02.95
!
CREA/COM  TAPELIST/ECHELLE    @@ ECH_PROC:tapelist
CREA/COM  INTAPE/AT1          @@ ECH_PROC:tapeinAT1
!
CREA/COM  PRERED/ECHELLE      @@ ECH_PROC:prered
CREA/COM  REDUCE/ECHELLE      @@ ECH_PROC:reduce
CREA/COM  ECHREB              @@ ECH_PROC:echreb
CREA/COM  FINAL               @@ ECH_PROC:final
!
CREA/COM  CHECK/ECHELLE       @@ ECH_PROC:shifts
CREA/COM  AVERAGE/FLAT        @@ ECH_PROC:averflat
CREA/COM  FILTER/FLAT         @@ ECH_PROC:flatfilt
CREA/COM  AVERAGE/THAR        @@ ECH_PROC:averthar
!
INIT/ECHELLE
```

E Appendix: On the command `reduce/echelle`

The keyword `reduce/echelle` is a link calling the procedure `reduce.prg`

The structure of called routines and final binary files is quite complicated and it is not easy to describe it intelligibly. Therefore we prefer to explain the structure of `reduce/echelle` through a schematic picture



In the presented scheme we show how some command/procedure calls other MIDAS commands/procedures up to final routines. For example: the command `reduce/echelle` (left-top) calls the procedure `reduce.prg` which calls (among others) the procedure `final-new-on.prg`. This procedure contains (among others) the keyword `merge/echelle` which downloads the procedure `echmerge.prg`.

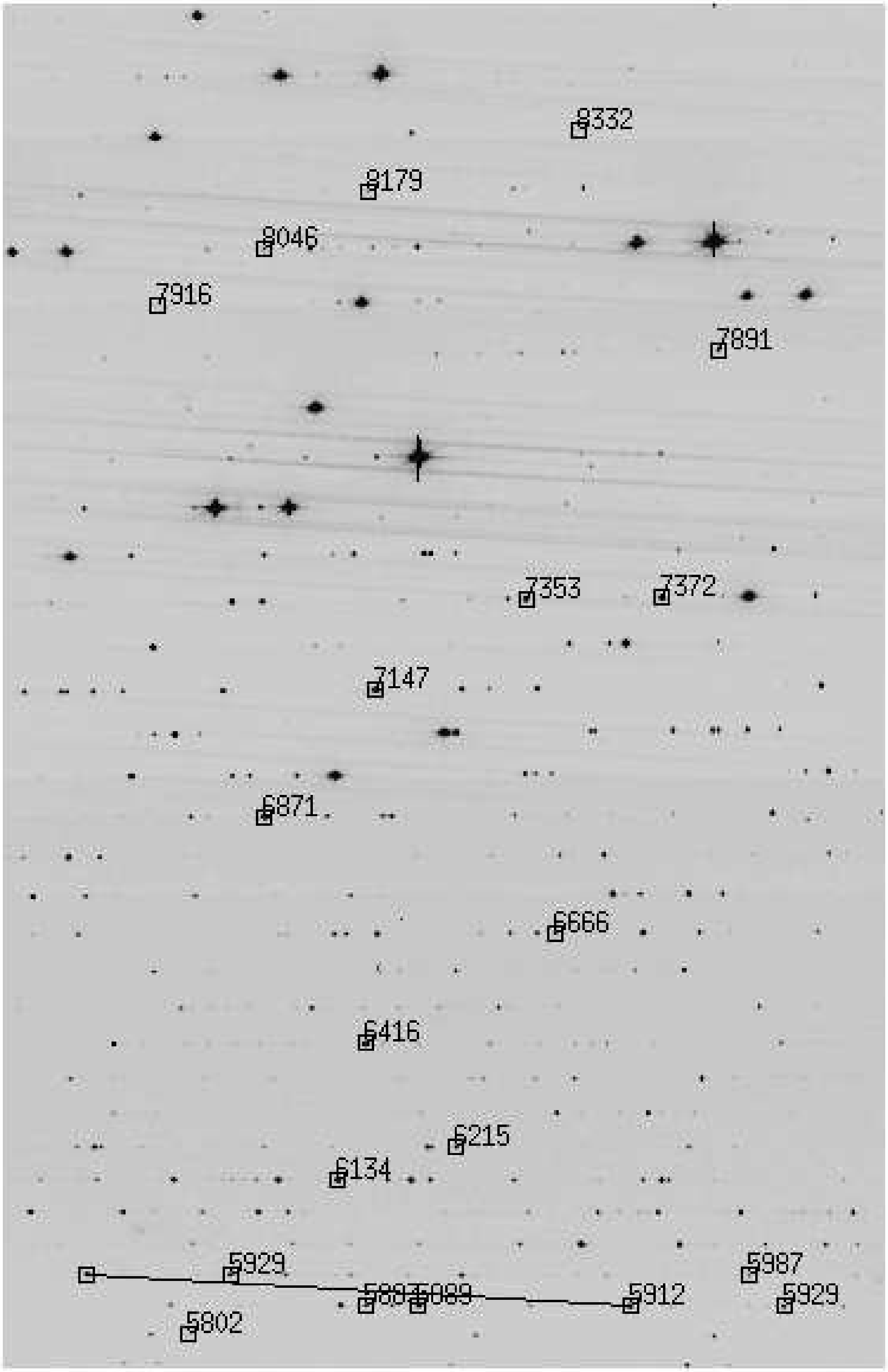


Fig. 10: Identification of ThAr-lines in the red channel

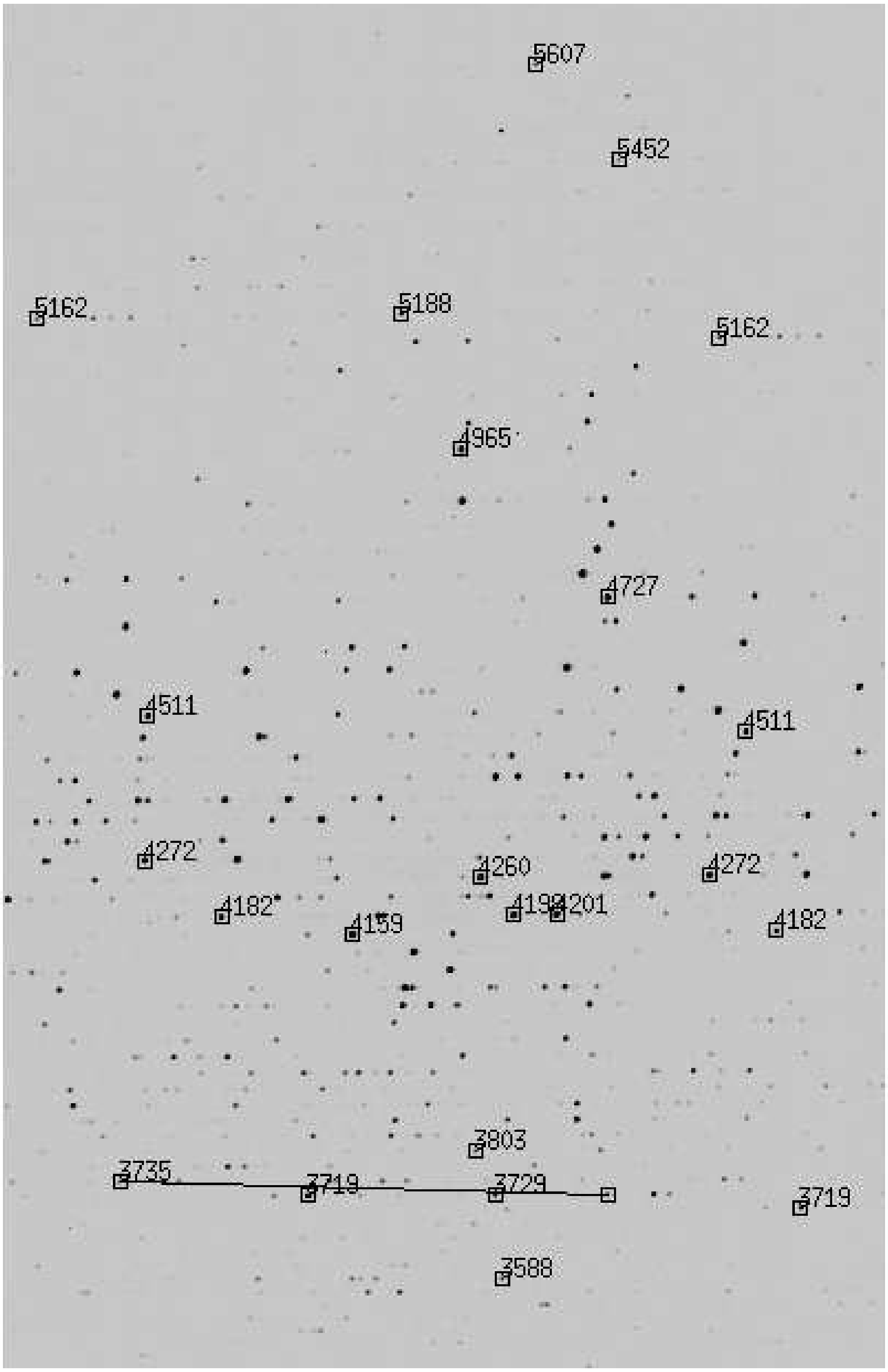


Fig. 11: Identification of ThAr-lines in the blue channel