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Reduction of spectra exposed by the 700mm CCD camera of the Ondřejov telescope coudé spectrograph

Petr Škoda, Miroslav Šlechta

Astronomical Institute, 251 65 Ondřejov, Czech Republic;
slechta@sunstel.asu.cas.cz; skoda@sunstel.asu.cas.cz

We present a brief cook-book for the reduction of spectra exposed by the Ondřejov 2-meter telescope coudé spectrograph. For the data reduction, we use standard IRAF packages running on Solaris and Linux. The sequence of commands is given for the typical reduction session together with short explanation and detailed list of parameter settings. The reduction progress is illustrated by example plots.

Keywords: Astrophysical Data – CCD Data Reduction – Slit Spectrographs

1 Introduction

We reduce coudé spectrograph data with standard IRAF tasks from the `NOAO imred` and `twodspec` packages.

The data are exposed at the chip SITe005 with 800×2000 effective pixels (its total length including the overscan regions is 2030 pixels). The dispersion runs along the longer side of the chip. The stellar cross-order (spatial) profile is symmetric (see Fig. 3 upper left) with the maximum near to the 474th row. Due to the symmetry of the profile one can easily trace the spectrum (following the maximum in cross-order profile) — we use Chebyshev polynomial up to 5th order – see the section A.5.1 and also Fig. 3);

Before the reduction we eliminate (it is called "trim section") unused regions of the chip (in our case we mean regions not covered by flat field) and reduce the region containing the useful signal only.

The stability of the spectrograph and CCD detector is quite good, so we can usually process the exposures of all night semi-automatically after presetting the correct parameters. The reduction process is straightforward following the basic scheme described in IRAF cookbooks Massey(1997) for general CCD frame preprocessing and Massey et al.(1992) and Willmarth(1990) for spectra extraction and calibration. It is thus not necessary to repeat full details here. Instead of this we put main accent to the customization of parameters of individual IRAF tasks required by the specific setup of our CCD. As we work immediately with the FITS files with extension `*.fit` we have to set up the `login.cl` file by adding the line `set imtype = "fit"` to it.

2 The CCD reduction pipeline at a glance

Here we present a list of all user's inputs to IRAF during the reduction process. All parameters must be set by `epar` to values shown in Appendix A.

```
cd /home/slechta/
xgterm &
>cl
cl>noao
cl>imred
ci>ccdred
cc>cd /data/hd39853/
cc>setinst
cc>ccdlist *.fit ccdtyp=comp
cc>ccdlist *.fit ccdtyp=comp name+ >comps30.25
cc>ccdlist *.fit ccdtyp=object
cc>ccdlist *.fit ccdtyp=object name+ >stars30.25
cc>imstat @stars30.25
cc>epar ccdproc
cc>epar flatcomb
cc>epar zerocomb
cc>zerocomb *.fit
```

```
cc>imstat Zero
cc>flatcomb *.fit
cc>ccdproc
cc>ccdlist *.fit ccdtype=object
cc>kpnoslit
kp>epar doslit
kp>doslit @stars30.25 arcs=@comps30.25
kp>onedspec
on>splot *.ms.fit

on>rv
rv>epar rvcorr
rv>epar dopcor
rv>rvcorr
rv>dopcor
rv>epar rvidlines
rv>rvidlines
rv>logout
```

3 The explanation of reduction commands

cd /home/slechta starting in the home directory to read personal `login.cl`

xgterm & The IRAF must run in the special graphical terminal.

cl Start of the IRAF `command language` environment.

noao loading the NOAO astronomical library.

imred loading the `image reduction` package.

ccdred loading the `ccd reduction` subpackage

cd /data/hd39853/ Change directory to that containing the raw data

setinst The setting of parameters for CCD header translation. The `coude.dat` file (see Appendix A) must be prepared by the administrator

ccdlist *.fit ccdtype=comp It will list of all comparison light (ThAr) files in the current directory. The typical output is, for example:

```
la290006.fit[2030,800][ushort][comp][30.25]:comparison_light
la290007.fit[2030,800][ushort][comp][30.25]:comparison_light
la290012.fit[2030,800][ushort][comp][30.25]:comparison_light
```

where `la290006.fit` is the name of the file
`2030,800` full size of the CCD-chip
`comp` type of the object (another possible types: `flat, object, offset`, where `object` is exposed star).
`30.25` is the grating angle (i.e. $30^o 15'$)
`comparison_light` - text included in the file header; it denotes type of the object. Another text may be `flat, offset` or name of the object (e.g. `4Her, HD39853` etc.)

ccdlist *.fit ccdtype=comp name+ > comps30.25 We list all comparison spectra in the current directory to a file (catalogue). Then we copy this file to several others (number of files should correspond to the number of grating positions) and edit them so that each catalogue contains data exposed in one grating position. E.g. catalogue `comps30.25` contains a list of ThAr taken at the grating angle $30^o 15'$.

ccdlist *.fit ccdtype=object name+ > stars30.25 The catalogues of stars are produced in the similar way.

imstat @stars30.25 gives a statistics of files listed in catalogue `stars30.25` (the reference to a catalogue is marked by @: see Barnes(1993))

epar ccdproc The full command `edit parameters` is abbreviated to `epar` which is a standard IRAF command; `ccdproc` is a task setting parameters for CCD data treatment. (see the Appendix for the recommended values)

epar flatcomb is the command "edit parameters of the `flatcombine` task".

epar zerocomb is the command setting parameters for the `zerocombine` task.

zerocomb In previous items we have set parameters and prepared tasks for the "pre-reduction" process. Now we combine all biases ("zero" exposures) saved in current directory. The task will average all biases. It reads all bias signals exposed in all pixels independently and computes the average bias signal for every pixel. The extremal signals (minimum and maximum) are not accounted.[1] The output of this process is written to the file `Zero.fit`

imstat Zero Statistics of the averaged file `Zero.fit`

flatcomb We combine all flats with the same angle of the grating. Output files are `Flat`<*angle*>.[2] The final `Flat*` is averaged pixel to pixel (in the same way as `zerocomb`). Cosmics are estimated using statistic assumptions and may be eliminated.

[1]**Example:** Let us have five "zeros". The signals in one selected (fixed) pixel are 1801, 1560, 1900, 1883, 2985. Extremal signals (1560 and 2985) are not accounted, averaged signal in this pixel is then 1861.3.

[2]**Example:** Let us assume that we have saved two configurations in the current directory: grating angle $30^o 15'$ and $38^o 45'$. Then the command `flatc` will give two output files: `Flat30.25` and `Flat38.75`

All files are trimmed i.e. regions not covered by signal are eliminated. The final file is thus relatively smaller than original ones.

ccdproc starts "prereduction" i.e. modifies raw data to be able to run task `doslit` (see following item). All files are trimmed i.e. regions which are not covered with signal are eliminated (the criterion is which part of the chip is covered by flat field). Next, the bias is estimated (using the overscan region), the averaged bias `Zero` is subtracted and image is flat fielded by particular `Flat`*dd.mm*

ccdlist *.fit ccdtype=object Now we check correct processing of stars — the flags `[OTZF]` show that the Overscan correction, Trimming, Zero frame subtraction and Flat-field division was finished

kpnoslit loading the package for KPNO slit spectrography

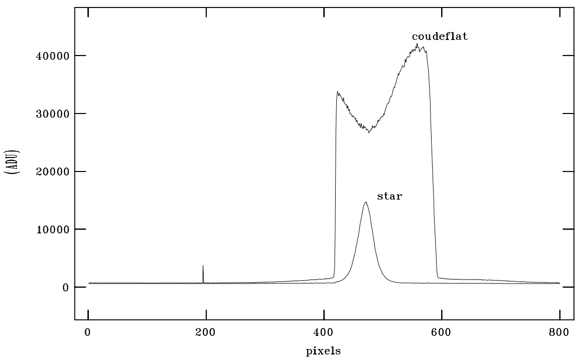

Fig. 1: The spatial profile of the flat field and a star.

epar doslit Preparing parameters of the `doslit` task. A sublevel `sparams` must be checked in `doslit`!

doslit @stars30.25 arcs=@comps30.25 It is the core of the reduction process. It extracts, sky subtracts, wavelength and flux calibrates 2D slit spectrograph data, determines airmass etc.; device characteristics must be eliminated (i.e. they must be bias, dark and flat field corrected) before `doslit` is run.

Extraction can be done by summing along rows (or columns – it depends how the spectrum is projected to the chip), if they run just across the dispersion (the wavelength difference along the profile must be negligible).

The task `doslit` is organised to semi-interactive setup.

- The spectral order is traced (width of the aperture may be adapted interactively or pre-fixed in configuration files).
- The first approximation of the dispersion is (interactively) determined.
- Comparison lines are automatically identified in the catalogue of ThAr lines. They may be interactively re-fitted (i.e. user can eliminate or add any lines).
- The dispersion relation is automatically determined. It may be interactively re-fitted: users may adapt the polynomial order of dispersion relation, tolerance ($\pm\sigma$). The resulting extracted spectra have the suffix `.ms.fit`

The task `doslit` allows flux calibration and also many others achievements, but we do not use them.

onedspec loading the package for 1D spectra treatment

splot *.ms.fit Very powerful task for analyzing extracted spectra

rvcorr + dopcorr Radial velocity correction to the center of mass of the solar system and to the motion of the Sun.

rvidlines the command enables detect the radial velocity of some spectral lines (for example, H_α). Then the task `rvidlines` computes `rms` of all detected radial velocities.

logout Finishing the IRAF session

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References

Barnes J.,1993, "A Beginner's Guide to Using IRAF"[3]

Massey P., Valdes F., Barnes J.,1992, "A User's Guide to Reduction Slit Spectra with IRAF"

Massey P., 1997, "A User's Guide to CCD Reduction with IRAF"

Willmarth D., 1990, "IRAF Reduction of coudé CCD Data"

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

A Configuration of IRAF parameters for the reduction of coudé slit data

Remark: One can save parameters and escape out of the environment by `:wq` (same command as edit `vi/vim` allows).

A.1 `Setinst` environment:

```
                               I R A F
                   Image Reduction and Analysis Facility
PACKAGE = imred
   TASK = ccdred

(pixelty=           real real) Output and calculation pixel datatypes
(verbose=                 yes) Print log information to the standard output?
(logfile=             logfile) Text log file
(plotfil=                    ) Log metacode plot file
(backup =               orig/) Backup directory or prefix
(instrum=  ccddb$ond/coude.dat) CCD instrument file
(ssfile =             subsets) Subset translation file
(graphic=            stdgraph) Interactive graphics output device
(cursor =                    ) Graphics cursor input
(version=      2: October 1987)
(mode   =                  ql)
($nargs =                   0)
```

We remind you that one should escape by the command `q!` (as in `vi/vim` editor).
Then `setins` will open automatically next window:

```
images  =               *.fit  List of CCD images to correct
(output =                    ) List of output CCD images
(ccdtype=                    ) CCD image type to correct
(max_cac=                   0) Maximum image caching memory (in Mbytes)
(noproc =                  no) List processing steps only?

(fixpix =                 yes) Fix bad CCD lines and columns?
(oversca=                 yes) Apply overscan strip correction?
(trim   =                 yes) Trim the image?
(zerocor=                 yes) Apply zero level correction?
(darkcor=                  no) Apply dark count correction?
(flatcor=                 yes) Apply flat field correction?
(illumco=                  no) Apply illumination correction?
(fringec=                  no) Apply fringe correction?
(readcor=                  no) Convert zero level image to readout correction?
(scancor=                  no) Convert flat field image to scan correction?
(readaxi=                line) Read out axis (column|line)
(fixfile=                    ) File describing the bad lines and columns
(biassec=               image) Overscan strip image section
(trimsec=               image) Trim data section
(zero   =                Zero) Zero level calibration image
(dark   =                    ) Dark count calibration image
(flat   =               Flat*) Flat field images
(illum  =                    ) Illumination correction images
(fringe =                    ) Fringe correction images
(minrepl=                  1.) Minimum flat field value
(scantyp=           shortscan) Scan type (shortscan|longscan)
(nscan  =                   1) Number of short scan lines

(interac=                 yes) Fit overscan interactively?
(functio=           chebyshev) Fitting function
(order  =                   1) Number of polynomial terms or spline pieces
(sample =                   *) Sample points to fit
(naverag=                   1) Number of sample points to combine
```

```
(niterat=                  1) Number of rejection iterations
(low_rej=                 3.) Low sigma rejection factor
(high_re=                 3.) High sigma rejection factor
(grow   =                 0.) Rejection growing radius
(mode   =                 ql)
```

A.2 ccdproc

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = ccdred
   TASK = ccdproc

images  =               *.fit  List of CCD images to correct
(output =                    ) List of output CCD images
(ccdtype=                    ) CCD image type to correct
(max_cac=                   0) Maximum image caching memory (in Mbytes)
(noproc =                  no) List processing steps only?

(fixpix =                  no) Fix bad CCD lines and columns?
(oversca=                 yes) Apply overscan strip correction?
(trim   =                 yes) Trim the image?
(zerocor=                 yes) Apply zero level correction?
(darkcor=                  no) Apply dark count correction?
(flatcor=                 yes) Apply flat field correction?
(illumco=                  no) Apply illumination correction?
(fringec=                  no) Apply fringe correction?
(readcor=                  no) Convert zero level image to readout correction?
(scancor=                  no) Convert flat field image to scan correction?
(readaxi=                line) Read out axis (column|line)
(fixfile=                    ) File describing the bad lines and columns
(biassec=               image) Overscan strip image section
(trimsec=               image) Trim data section
(zero   =                Zero) Zero level calibration image
(dark   =                    ) Dark count calibration image
(flat   =               Flat*) Flat field images
(illum  =                    ) Illumination correction images
(fringe =                    ) Fringe correction images
(minrepl=                  1.) Minimum flat field value
(scantyp=           shortscan) Scan type (shortscan|longscan)
(nscan  =                   1) Number of short scan lines

(interac=                 yes) Fit overscan interactively?
(functio=           chebyshev) Fitting function
(order  =                   1) Number of polynomial terms or spline pieces
(sample =                   *) Sample points to fit
(naverag=                   1) Number of sample points to combine
(niterat=                   1) Number of rejection iterations
(low_rej=                  3.) Low sigma rejection factor
(high_re=                  3.) High sigma rejection factor
(grow   =                  0.) Rejection growing radius
(mode   =                  ql)
```

A.3 flatc

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = ccdred
   TASK = flatcombine

input   =               *.fit  List of flat field images to combine
(output =                Flat) Output flat field root name
```

```
(combine=              average) Type of combine operation
(reject =            avsigclip) Type of rejection
(ccdtype=                 flat) CCD image type to combine
(process=                  yes) Process images before combining?
(subsets=                  yes) Combine images by subset parameter?
(delete =                   no) Delete input images after combining?
(clobber=                   no) Clobber existing output image?
(scale  =             exposure) Image scaling
(statsec=                     ) Image section for computing statistics
(nlow   =                    1) minmax: Number of low pixels to reject
(nhigh  =                    1) minmax: Number of high pixels to reject
(nkeep  =                    1) Minimum to keep (pos) or maximum to reject (neg)
(mclip  =                  yes) Use median in sigma clipping algorithms?
(lsigma =                   3.) Lower sigma clipping factor
(hsigma =                   3.) Upper sigma clipping factor
(rdnoise=                    7) ccdclip: CCD readout noise (electrons)
(gain   =                 1.07) ccdclip: CCD gain (electrons/DN)
(snoise =                   0.) ccdclip: Sensitivity noise (fraction)
(pclip  =                 -0.5) pclip: Percentile clipping parameter
(blank  =                   1.) Value if there are no pixels
(mode   =                   ql)
```

A.4 zeroc

```
                               I R A F
                    Image Reduction and Analysis Facility
PACKAGE = ccdred
   TASK = zerocombine

input   =                *.fit  List of zero level images to combine
(output =                 Zero) Output zero level name
(combine=              average) Type of combine operation
(reject =               minmax) Type of rejection
(ccdtype=                 zero) CCD image type to combine
(process=                   no) Process images before combining?
(delete =                   no) Delete input images after combining?
(clobber=                   no) Clobber existing output image?
(scale  =                 none) Image scaling
(statsec=                     ) Image section for computing statistics
(nlow   =                    0) minmax: Number of low pixels to reject
(nhigh  =                    1) minmax: Number of high pixels to reject
(nkeep  =                    1) Minimum to keep (pos) or maximum to reject (neg)
(mclip  =                  yes) Use median in sigma clipping algorithms?
(lsigma =                   3.) Lower sigma clipping factor
(hsigma =                   3.) Upper sigma clipping factor
(rdnoise=                   10) ccdclip: CCD readout noise (electrons)
(gain   =                  1.5) ccdclip: CCD gain (electrons/DN)
(snoise =                   0.) ccdclip: Sensitivity noise (fraction)
(pclip  =                 -0.5) pclip: Percentile clipping parameter
(blank  =                   0.) Value if there are no pixels
(mode   =                   ql)
```

A.5 doslit

```
                               I R A F
                    Image Reduction and Analysis Facility
PACKAGE = kpnoslit
   TASK = doslit

objects =          @stars30.25  List of object spectra
(arcs   =          @comps30.25) List of arc spectra
(arctabl=                     ) Arc assignment table (optional)
```

```
(standar=                     ) List of standard star spectra

(readnoi=                    7) Read out noise sigma (photons)
(gain   =                 1.07) Photon gain (photons/data number)
(datamax=                INDEF) Max data value / cosmic ray threshold
(width  =                   7.) Width of profiles (pixels)
(crval  =                INDEF) Approximate wavelength
(cdelt  =                INDEF) Approximate dispersion

(dispcor=                  yes) Dispersion correct spectra?
(extcor =                   no) Extinction correct spectra?
(fluxcal=                   no) Flux calibrate spectra?
(resize =                  yes) Automatically resize apertures?
(clean  =                  yes) Detect and replace bad pixels?
(splot  =                  yes) Plot the final spectrum?
(redo   =                  yes) Redo operations if previously done?
(update =                  yes) Update spectra if cal data changes?
(quicklo=                   no) Minimally interactive quick-look?
(batch  =                   no) Extract objects in batch?
(listonl=                   no) List steps but don't process?

(sparams=                     ) Algorithm parameters
(mode   =                   ql)
```

Put the cursor to `sparams` and press `e` (as `edit`:

A.5.1 `sparams` – sublevel of `doslit`

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = kpnoslit
   TASK = sparams

(line   =                INDEF) Default dispersion line
(nsum   =                   10) Number of dispersion lines to sum or median
(extras =                   no) Extract sky, sigma, etc.?

                                -- DEFAULT APERTURE PARAMETERS --
(lower  =                  -4.) Lower aperture limit relative to center
(upper  =                   4.) Upper aperture limit relative to center

                                -- AUTOMATIC APERTURE RESIZING PARAMETERS --
(ylevel =                 0.05) Fraction of peak or intensity for resizing

                                -- TRACE PARAMETERS --
(t_step =                   10) Tracing step
(t_funct=            chebyshev) Trace fitting function
(t_order=                    5) Trace fitting function order
(t_niter=                  100) Trace rejection iterations
(t_low  =                   3.) Trace lower rejection sigma
(t_high =                   3.) Trace upper rejection sigma

                                -- APERTURE EXTRACTION PARAMETERS --
(weights=                varia) Extraction weights (none|variance)
(pfit   =                fit1d) Profile fitting algorithm (fit1d|fit2d)
(lsigma =                   3.) Lower rejection threshold
(usigma =                   3.) Upper rejection threshold

                                -- BACKGROUND SUBTRACTION PARAMETERS --
(backgro=                 none) Background to subtract
(b_funct=             legendre) Background function
(b_order=                    1) Background function order
```

```
(b_sampl=         -10:-6,6:10) Background sample regions
(b_naver=                -100) Background average or median
(b_niter=                   1) Background rejection iterations
(b_low  =                  3.) Background lower rejection sigma
(b_high =                  3.) Background upper rejection sigma

                               -- ARC DISPERSION FUNCTION PARAMETERS --
(thresho=                500.) Minimum line contrast threshold
(coordli=   linelists$thar.dat) Line list
(match  =                  3.) Line list matching limit in Angstroms
(fwidth =                  3.) Arc line widths in pixels
(cradius=                 10.) Centering radius in pixels
(i_funct=           chebyshev) Coordinate function
(i_order=                   3) Order of dispersion function
(i_niter=                 100) Rejection iterations
(i_low  =                  3.) Lower rejection sigma
(i_high =                  3.) Upper rejection sigma
(refit  =                 yes) Refit coordinate function when reidentifying?
(addfeat=                  no) Add features when reidentifying?

                               -- AUTOMATIC ARC ASSIGNMENT PARAMETERS --
(select =              interp) Selection method for reference spectra
(sort   =                  jd) Sort key
(group  =                 ljd) Group key
(time   =                  no) Is sort key a time?
(timewra=                 17.) Time wrap point for time sorting

                               -- DISPERSION CORRECTION PARAMETERS --
(lineari=                 yes) Linearize (interpolate) spectra?
(log    =                  no) Logarithmic wavelength scale?
(flux   =                 yes) Conserve flux?

                               -- SENSITIVITY CALIBRATION PARAMETERS --
(s_funct=             spline3) Fitting function
(s_order=                   1) Order of sensitivity function
(fnu    =                  no) Create spectra having units of FNU?
(mode   =                  ql)
```

A.6 rvcorr

```
                                  I R A F
                    Image Reduction and Analysis Facility
PACKAGE = rv
   TASK = rvcorrect

(files  =                    ) List of files containing observation data
(images =           *.ms.fit ) List of images containing observation data
(header =                 yes) Print header?
(input  =                 yes) Print input data?
(imupdat=                 yes) Update image header with corrections?

(epoch  =               INDEF) Epoch of observation coordinates (years)
(observa=            ondrejov) Observatory
(vsun   =                 20.) Solar velocity (km/s)
(ra_vsun=                 18.) Right ascension of solar velocity (hours)
(dec_vsu=                 30.) Declination of solar velocity (degrees)
(epoch_v=               1900.) Epoch of solar coordinates (years)

(year   =                    ) Year of observation
(month  =                    ) Month of observation (1-12)
(day    =                    ) Day of observation
(ut     =                    ) UT of observation (hours)
```

```
(ra     =                     ) Right ascension of observation (hours)
(dec    =                     ) Declination of observation (degrees)
(vobs   =                   0.) Observed radial velocity
(hjd    =                   0.) Heliocentric Julian Day (output)
(vhelio =                   0.) Heliocentric radial velocity (km/s) (output)
(vlsr   =                   0.) Local standard or rest radial velocity (km/s) (o
(mode   =                   ql)
```

A.7 dopcorr

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = kpnoslit
   TASK = dopcor

input   =             *.ms.fit  List of input spectra
output  = *%.ms.fit%hc.ms.fit%  List of output spectra
redshift=              -vhelio  Redshift or velocity (Km/s)
(isveloc=                  yes) Is the redshift parameter a velocity?
(add    =                   no) Add to previous dispersion correction?
(dispers=                  yes) Apply dispersion correction?
(flux   =                   no) Apply flux correction?
(factor =                   3.) Flux correction factor (power of 1+z)
(apertur=                     ) List of apertures to correct
(verbose=                  yes) Print corrections performed?
(mode   =                   ql)
```

A.8 rvidlines

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = rv
   TASK = rvidlines

images  =          *hc.ms.fit   Images containing features to be identified
(section=          middle line) Section to apply to two dimensional images
(databas=           merenistel) Database in which to record feature data
(coordli= /scratch/atm6367.stl) User coordinate list
(nsum   =                   10) Number of lines/columns/bands to sum in 2D image
(match  =                   1.) Coordinate list matching limit in user units
(maxfeat=                   50) Maximum number of features for automatic identif
(zwidth =                 100.) Zoom graph width in user units
(ftype  =           absorption) Feature type
(fwidth =                   4.) Feature width in pixels
(cradius=                   5.) Centering radius in pixels
(thresho=                   0.) Feature threshold for centering
(minsep =                   2.) Minimum pixel separation
(logfile=               mereni) Log file
(autowri=                   no) Automatically write to logfile and database
(keywpar=                     ) Header keyword translation pset
(graphic=             stdgraph) Graphics output device
(cursor =                     ) Graphics cursor input
(mode   =                   ql)
```

B The FITS header of final spectrum

```
SIMPLE  =                    T / Fits standard
BITPIX  =                  -32 / Bits per pixel
NAXIS   =                    1 / Number of axes
NAXIS1  =                 1997 / Axis length
ORIGIN  = 'NOAO-IRAF FITS Image Kernel July 1999' / FITS file originator
IRAF-TLM= '00:52:40 (04/03/2002)' / Time of last modification
EXTEND  =                    F / File may contain extensions
OBJECT  = 'Alp Dra '           / Title of observation
DATE    = '2002-03-03T23:52:40'/ Date FITS file was generated
SYSVER  = 'BIAS-headers'       / P no  8 12:19:09 CET 2002
OBSERVAT= 'ONDREJOV'           / Name of observatory (IRAF style)
LATITUDE=            49.910555 / Telescope latitude  (degrees), +49:54:38.0
LONGITUD=            14.783611 / Telescope longitud  (degrees), +14:47:01.0
HEIGHT  =                 0528 / Height above sea level [m].
OBSERVER= 'Sarounova, Rezba'   / Observers
IMAGETYP= 'object'             / Type of observation, eg. FLAT
FILENAME= 'lc020017.fit'       / BIAS filename
TELESCOP= 'ZEISS-2m'           / 2m Ondrejov observatory telescope
TELSYST = 'COUDE'              / Telescope setup - COUDE or CASSegrain
EXPTIME =             2000.000 / Length of observation excluding pauses
DARKTIME=             2000.000 / Length of observation including pauses
EXPVAL  =                1.433 / Exposure value in photon counts [Mcounts]
DATE-OBS= '2002-03-03'         / UTC date start of observation
TM_START=                 5797 / 01:36:37
TM_END  =                 7826 / 02:10:26
COMMENT =                      /
COMMENT1=                      /
UT      = '01:36:37'           / UTC of  start of observation
!UTMIDDL=                      / UTC of middle of observation - effective
INSTRUME= 'COUDE700'           / Coude spectrograph setup - 1400/700mm focus
CAMERA  = 'BROR'               / Camera head name
DETECTOR= 'SITe 2000x800'      / Name of the detector
CHIPID  = 'SITe005 800x2000'   / Name of CCD chip
BUNIT   = 'ADU'                / Unit of the array of image data
GAINM   = 'HIGH'               / Gain mode
AMPLM   = 'A '                 / Amplifier A,B or AB
MPP     =                    T / Multiphase pinned mode (T/F)
PREFLASH=                    0 / Length of preflash in seconds
GAIN    =                 1.36 / Electrons per ADU
READNOIS=                 9.81 / Readout noise in electrons per pix
CCDTEMP =               -100.0 / Detector temperature
LN2TEMP =               -175.5 /
CCDXSIZE=                 2030 / X Size in pixels of digitised frame
CCDYSIZE=                  800 / Y Size in pixels of digitised frame
CCDXIMSI=                 2030 / X Size of useful imaging area
CCDYIMSI=                  800 / Y Size of useful imaging area
CCDXIMST=                    1 / X Start pixel of useful imaging area
CCDYIMST=                    1 / Y Start pixel of useful imaging area
CCDXPIXE=                   15 / Size in microns of the pixels, in X
CCDYPIXE=                   15 / Size in microns of the pixels, in Y
CCDXBIN =                    1 / Binning factor, in X
CCDYBIN =                    1 / Binning factor, in Y
XOVERSC =                    0 /
YOVERSC =                    0 /
!AOVERSC=                    0 /
!CCDSEC = '[00:0000,00:0000]'  / Orientation to full frame
!DATASEC= '[00:0000,00:0000]'  / Image portion of frame
!ORIGSEC= '[00:0000,00:0000]'  / Original size full frame
CCDSUM  = '1 1'                / CCD binning in both axes
GRATNAME= '3'                  / Grating name - ID
```

```
GRATANG =                30.25 / 30:15
GRATPOS =                10889 / Grating angle in increments
GRATCWAV=                      / Central Wavelength in A
DICHMIR =                    1 / Dichroic mirror number
SPECFILT=                    1 / Spectral filter
SLITTYPE= 'BLADE'              / Type of slit - blade or image slicers
SLITWID =                 0.20 / Slit width in mm
SLITHEIG=                 16.9 / Slit hight in mm
COLIMAT = 'OPEN'               / Collimator mask status
CAMFOCUS=                      / Camera focus position
FLATTYPE= 'PROJECT'            / Flat type (Projector/Dome)
COMPLAMP= 'ThArHK4/15mA'       / Comparison arc setup
COMPMIDA=                      / CCD line at the middle of comp aperture
SEEING  =                      / Estimate of FWHM of seeing disk in arcsec
AUTOGUID= 'NO'                 / Status of autoguider system
COMMENT3=                      /
HISTORY1
RA      = '14:04:28.5'         / 14.074583
DEC     = '64:21:16.7'         / 64.354639
EQUINOX =          2002.166992 / Equinox of RA and DEC
EPOCH   =          2002.166992 / Same as EQUINOX - for back compat.
!MJD-OBS=                      / Modified Julian Date of midtime of observation
!JD     =                      / Julian Date of midtime of observation
ST      = '13:26:17.4'         / Local sidereal time at start of observation
AZIMUTH =                170.4 / Mean azimuth of observation (degrees)
ZD      =                 15.3 / Mean horizon-distance of observation (degrees)
TELFOCUS=               -12.96 / Telescope focus (milimeters)
DOMEAZ  =                231.6 / Mean dome azimuth during observation
AIRPRESS=                  958 / Atmospheric preasure in (hPa)
AIRHUMEX=                102.2 / Air humidity outside the dome
AIRHUMIN=                 71.8 / Air humidity inside the dome
OUTTEMP =                  1.4 / Temperature outside of the dome
DOMETEMP=                  0.6 / Temperature inside the dome
SPECTEMP=                 25.0 / Temperature in spectrograph room
CAT-NAME=                      / Target input-catalogue name
CAT-RA  =                      / Target Right Ascension
CAT-DEC =                      / Target Declination
CAT-EQUI=                      / Equinox of target coordinates
CAT-EPOC=              2000.00 / Target epoch of proper motions
HISTORY2
WCSDIM  =                    1
LTM1_1  =                    1.
WAT0_001= 'system=equispec'
WAT1_001= 'wtype=linear label=Wavelength units=angstroms'
TRIM    = 'Mar  4  0:40 Trim data section is [16:2012,430:570]'
OVERSCAN= 'Mar  4  0:40 Overscan section is [6:12,1:800] with mean=619.8679'
ZEROCOR = 'Mar  4  0:40 Zero level correction image is Zero'
FLATCOR = 'Mar  4  0:40 Flat field image is Flat10889.fit with scale=34148.39'
CCDSEC  = '[16:2012,430:570]'
CCDPROC = 'Mar  4  0:40 CCD processing done'
JD      =     2452336.57866898
LJD     =             2452336.
AIRMASS =             1.034162
UTMIDDLE= '1:53:17.0'
BANDID1 = 'spectrum - background none, weights variance, clean yes'
APNUM1  = '1 1 7.83 84.20'
CTYPE1  = 'LINEAR  '
CRVAL1  =     6255.97880284089
CRPIX1  =                   1.
CDELT1  =    0.256657149478512
CD1_1   =    0.256657149478512
```

```
DC-FLAG =                    0
DCLOG1  = 'REFSPEC1 = lc0200171c020014.ms 0.4326539'
DCLOG2  = 'REFSPEC2 = lc0200171c020019.ms 0.5673461'
DISPCOR =                    0
HJD     =      2452336.5693805
VHELIO  =   -0.805196947010124
VLSR    =     11.9746962030632
VSUN    = '   20.    18.    30.  1900.'


END
```

C Example plots of various stages of the CCD data processing

The typical appearance of the data acquired by the CCD detector in coudé 700mm camera is shown on figures Fig. 2 (raw data), Fig. 3 (display of intermediate processing steps) and Fig. 4 (the final reduced spectra of several typical stars). We show flat field in section along rows and along columns and, for comparison, spectrum of a star along the same row (in particular, 474-th row where we usually expect maximum of signal). The cross-section of flat shows typical deformation due to shadows of the detector holder and that of the small flat mirror in front of the Dewar bottle. The ThAr comparison arc example has already marked several selected lines used for calculation of the dispersion function.
Next figure gives an example of the graphical output expected during the pipe-line processing. First the spatial profile (across dispersion) of the stellar spectrum and the extraction aperture is depicted. Then the trace of the spectra is shown as it is approximated by the 5-th order polynomial. The extraction aperture runs along this trace and the point values in the aperture range are summed together with the iteratively estimated weights.
The last two images show the dispersion function obtained from the marked lines as well as the residua of this fit.
The final stellar spectra reduced with routines described above are presented on Fig. 4. As one can see, the quality of spectra is very good; the continuum is quite flat and smooth without any unexpected patterns. For the comparison, we show typical hot stars (HD206773 with strong emission and α Dra in red spectral region; η UMa and 66 Oph in blue one) compared with cold star τ Boo. Both regions, blue and red, and also all stars, give similar quality of data. On the other hand, it is necessary to prolong the exposure time in blue region due to many reasons (sensitivity of the chip, transmissivity or reflectivity of lens and mirrors etc.). We estimate that the bluest part of the spectra (near to Balmer's edge) needs typically 10-times longer exposure time then the spectrum in the neighbourhood of H_α to get comparable S/N. One should notice that the spectra are not normalized to unity (rectified) yet. The fitting of the continuum is the task already influenced by the personal subjective opinion (especially in the wings of wide lines) and thus it should not be done by the automatic pipeline. So we finish the reduction with the extracted one-dimensional spectrum where the values on the ordinate represent the number of effective ADU's summed along the spatial profile with appropriate weights in each dispersion point. It is influenced by the shape of flat field, however.

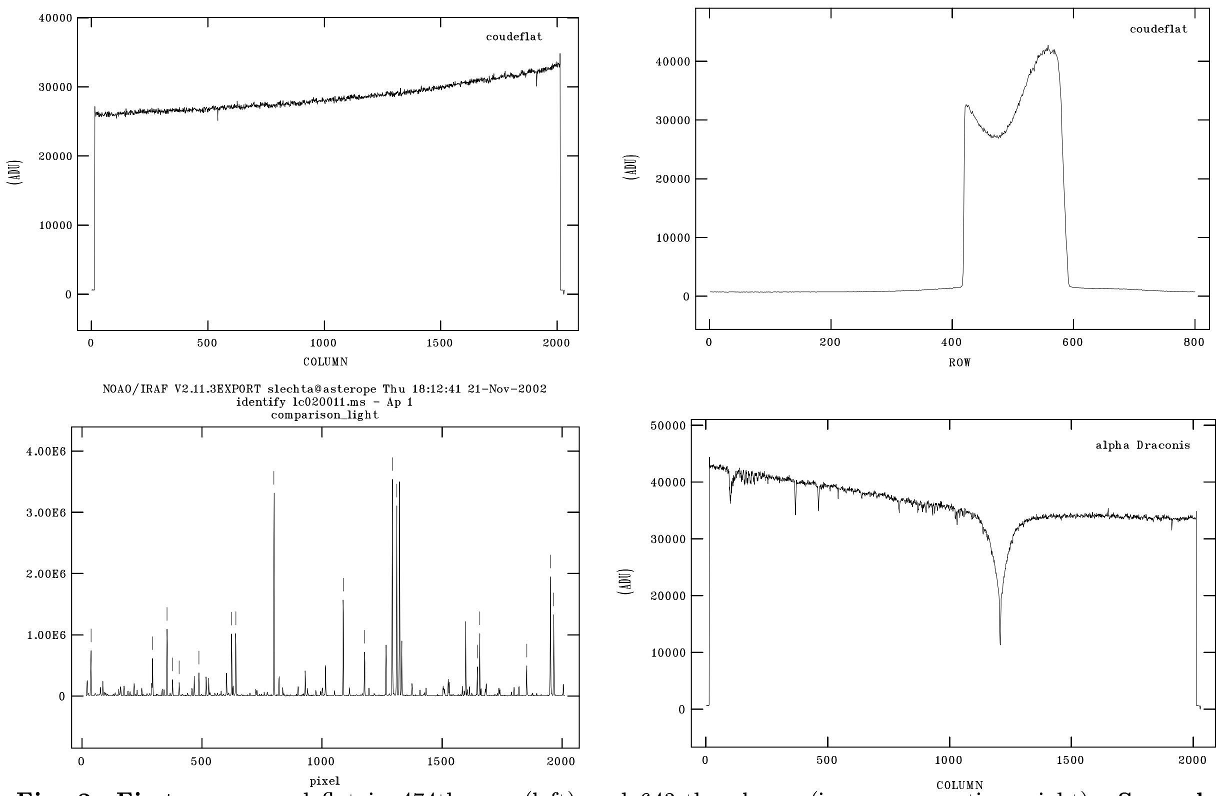

Fig. 2: **First row:** coudeflat in 474th row (left) and 643-th column (i.e. cross-section, right). **Second row:** comparison light with marked identified lines (left); raw stellar spectrum – 474-th row (right).

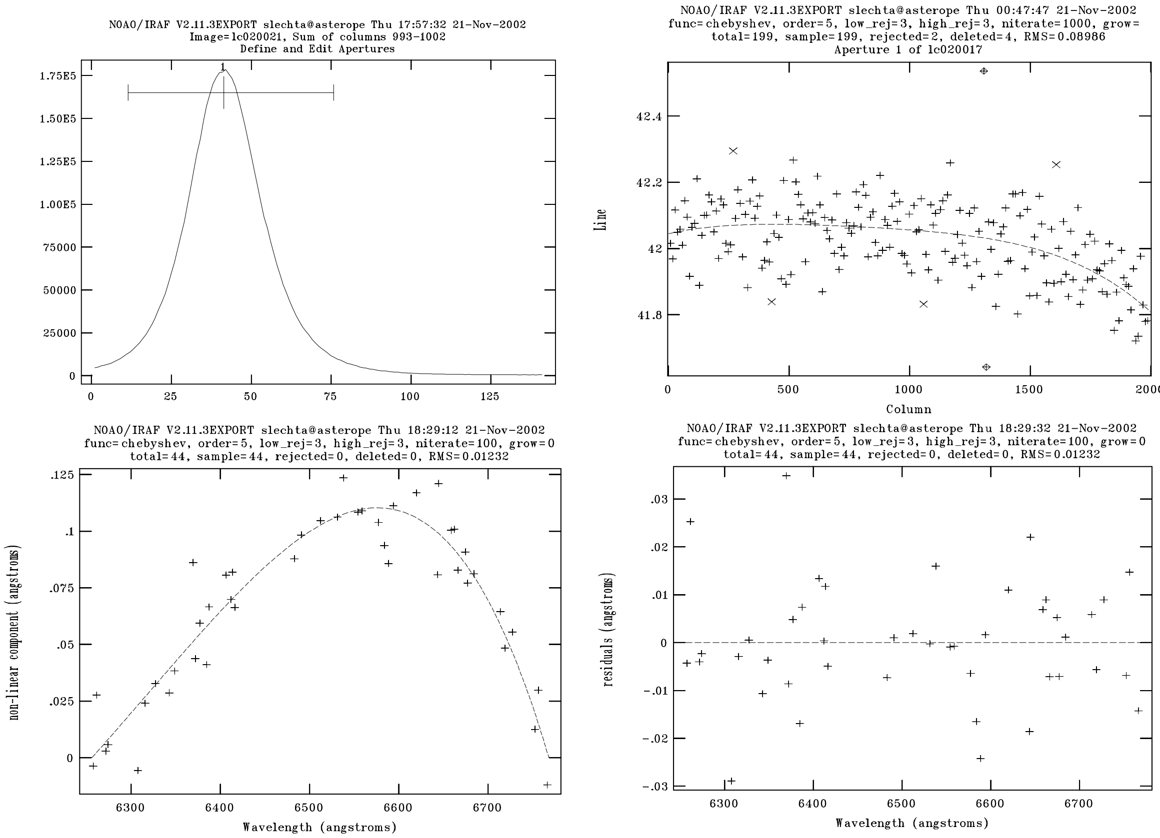

Fig. 3: **First row:** aperture detected on the spatial profile of a stellar spectrum (left); tracing the spectral order based on the aperture (right – compare with the left); **Second row:** dispersion relation (left); residuals of the dispersion relation (right).

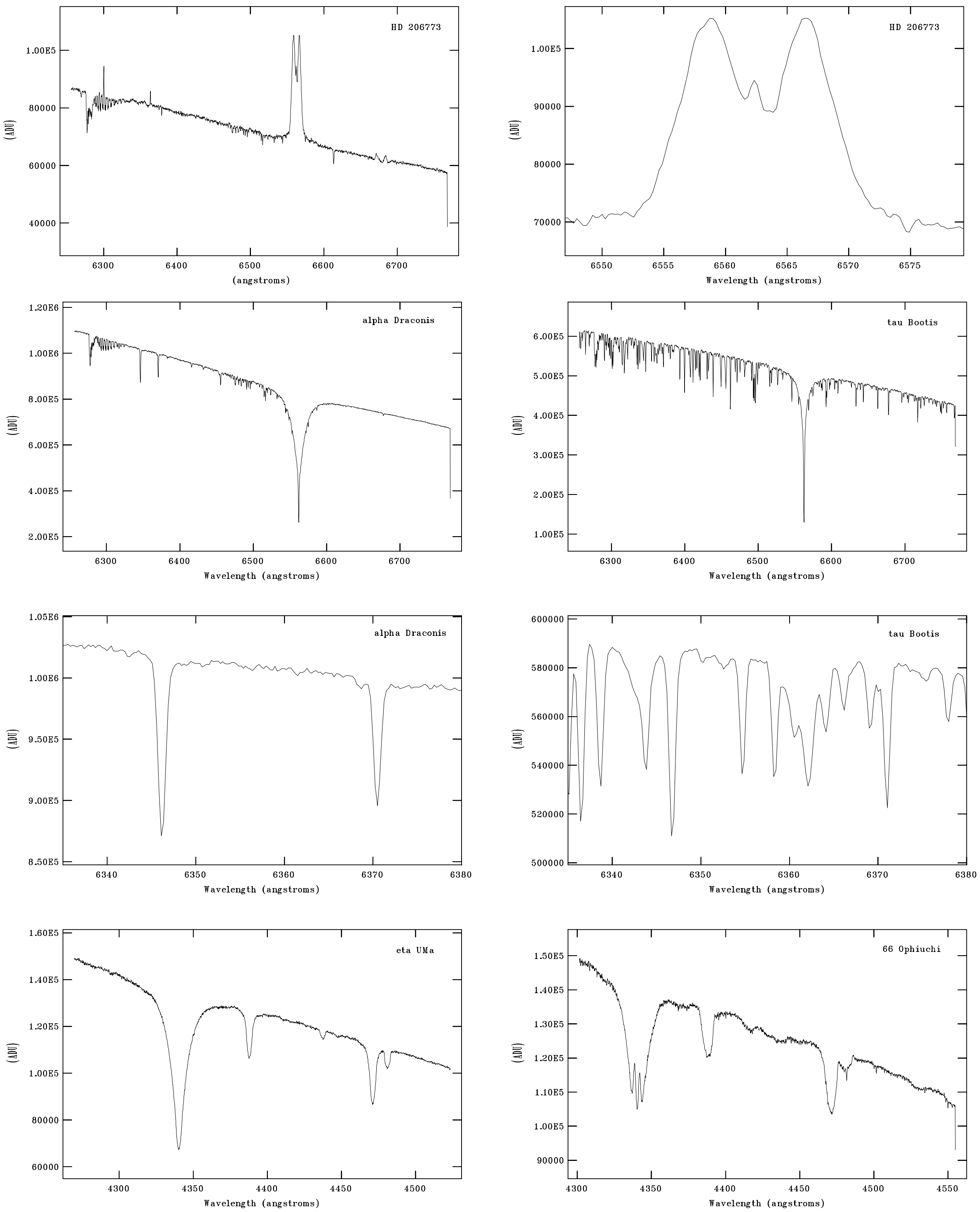

Fig. 4: **First row:** HD 206773 (left), detail of H_α (right). **Second row** α Draconis (left), τ Bootis (right). **Third row:** α Dra, neighbourhood of the silicon lines (left) and τ Boo in the same region (right). **Fourth row:** η UMa in the blue region (left) and 66Ophiuchi in the same region (right).