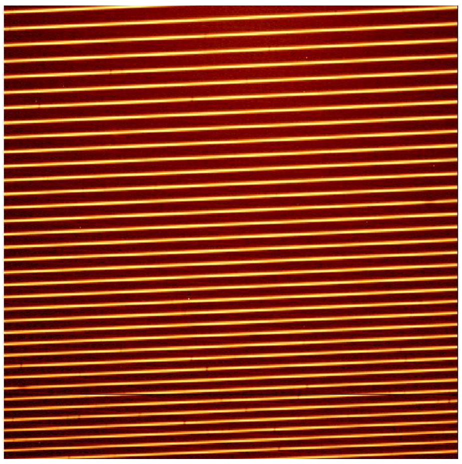
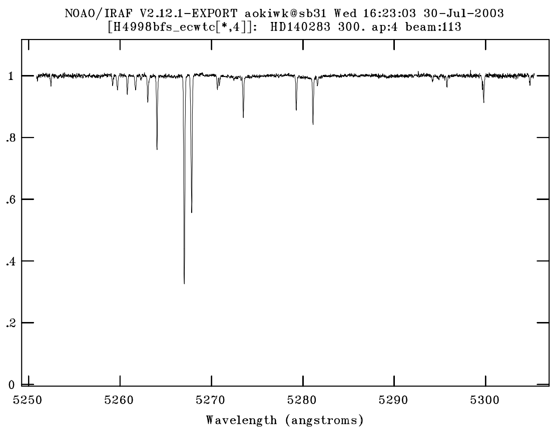
Data reduction of echelle spectra with IRAF

Version 1.1

October 2008




NOAO/IRAF V2.12.1-EXPORT aokiwk@sb31 Wed 16:23:03 30-Jul-2003
[H4998bfs_ecwtc[*,4]]: HD140283 300. ap:4 beam:113
1
.8
.6
.4
.2
0
5250
5260
5270
5280
5290
5300
Wavelength (angstroms)

Wako Aoki
National Astronomical Observatory of Japan

Preface

This is a brief instruction for reduction of echelle data with IRAF (Image Reduction and Analysis Facility), in particular for data obtained with the High Dispersion Spectrograph for the Subaru Telescope. For details of the reduction with IRAF. Readers are recommended to refer to the IRAF web page [1] where manuals for the "echelle" package as well as the CCD data reduction in general are available.

Examples of the parameter settings for IRAF tasks required for the echelle data reduction are given in this text. These will be useful for the first trial of the reduction for data from HDS and probably other spectrographs. However, the parameter setting is dependent on the data – please find better solution for yourselves.

Questions and comments for this text are welcome. The contact address is given below.

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Wako Aoki
National Astronomical Observatory of Japan
2-11-1 Osawa Mitaka, Tokyo 181-8588, Japan
TEL: +81-422-34-3531 FAX:+81-422-34-3545
E-mail: aoki.wako@nao.ac.jp

[1] http://iraf.noao.edu/

Contents

1 Reduction procedure

The goal of this text is to derive a wavelength-calibrated spectrum from the two dimensional CCD image (Figure 1). The procedure includes calibrations of CCD data, extraction of the spectra, wavelength calibration, continuum normalization and combining spectra of individual echelle orders. An example of the flow of the reduction procedure is summarized as follows;

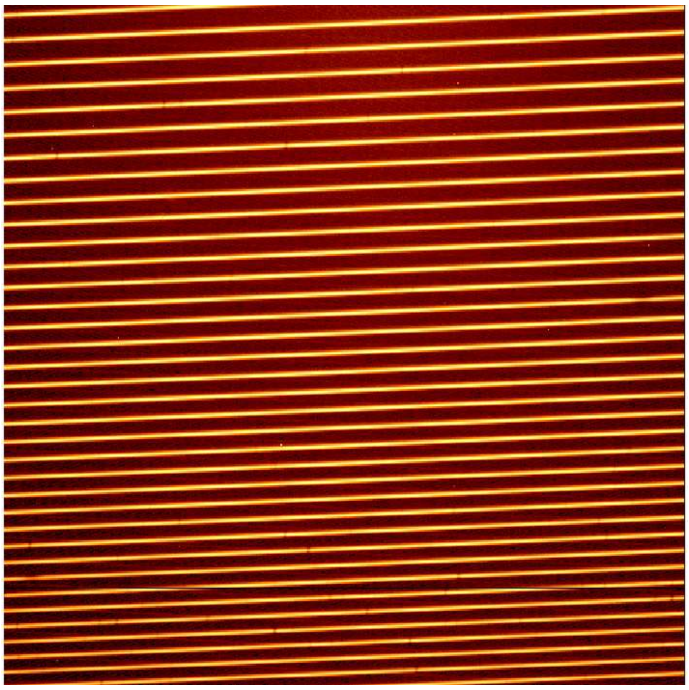
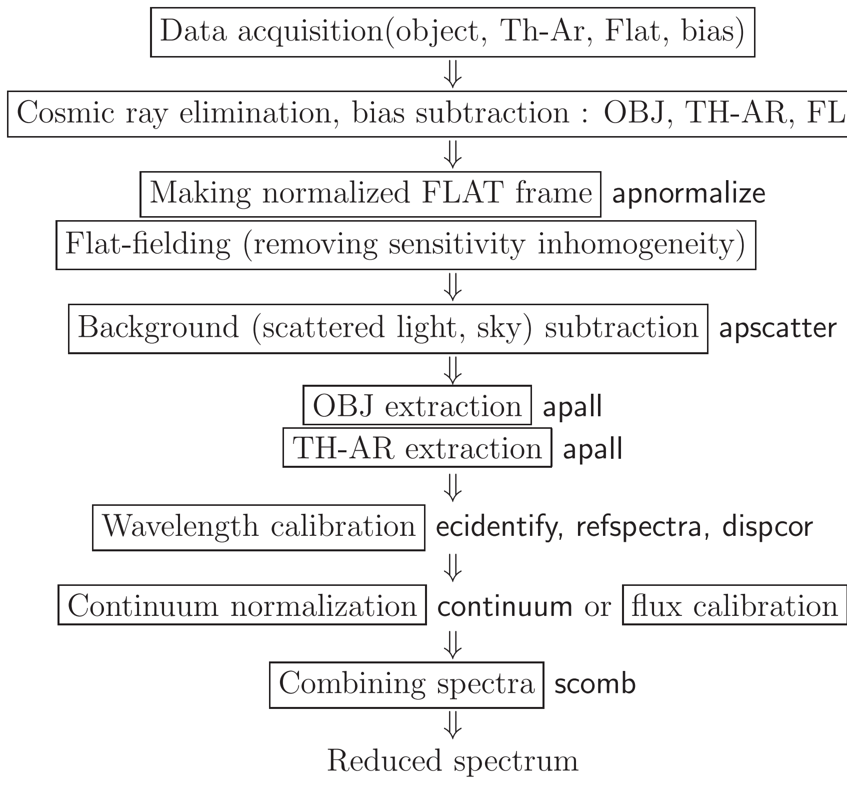


Figure 1: A two dimensional CCD image of object data. The horizontal and vertical axes are corresponding to the dispersion and slit directions, respectively.


Data acquisition(object, Th-Ar, Flat, bias)
Cosmic ray elimination, bias subtraction : OBJ, TH-AR, FLAT
Making normalized FLAT frame
apnormalize
Flat-fielding (removing sensitivity inhomogeneity)
Background (scattered light, sky) subtraction
apscatter
OBJ extraction
apall
TH-AR extraction
apall
Wavelength calibration
ecidentify, refspectra, dispcor
Continuum normalization
continuum or
flux calibration
Combining spectra
scomb
Reduced spectrum

2 Data preparation

In addition to the spectral data of objects, calibration data for bias subtraction, flat-fielding and wavelength calibration are usually obtained during observing runs. In the case of Subaru/HDS data, one may download data from the archive system (STARS and SMOKA). The data set should contain above frames. See Subaru's web page for details of the data archive system.

3 Setup of IRAF

First, a terminal (xgterm or xterm) is opened (xgterm is recommended if available). Execute 'mkiraf' command, and then answer a few questions on the initialization of parameter files and setup of the terminal:

```
> mkiraf
Initialize uparm? (y|n): y
-- initializing uparm
Terminal types: xgterm,xterm,gterm,vt640,vt100,etc.
Enter terminal type: xgterm
A new LOGIN.CL file has been created in the current directory.
You may wish to review and edit this file to change the defaults.
```

Then, the file login.cl will appear on the directory you are working. This is a setup file for IRAF that can be modified manually.

It is convenient to set the default image type to FITS (*.fits) rather than IRAF format (*.imh and *.pix). In that case, modify the line on the image type from

```
#set     imtype          = "imh"
```

to

```
set     imtype          = "fits"
```

IRAF is started by the cl command which must be executed on the directory where the login.cl file exists.

```
> cl
```

Then, IRAF starts with following messages.

```
# LOGIN.CL -- User login file for the IRAF command language.
    NOAO Sun/IRAF Revision 2.11.3 Sat Sep  9 23:18:55 MST 2000
    This is the EXPORT version of Sun/IRAF V2.11 for SunOS 4 and Solaris 2.7

    Welcome to IRAF.  To list the available commands, type ? or ??.  To get
    detailed information about a command, type ‘help command’.   To  run  a
    command  or  load  a  package,  type  its name.   Type  ‘bye’ to exit a
    package, or ‘logout’ to get out of the CL.   Type ‘news’  to  find  out
    what is new in the version of the system you are using.   The following
    commands or packages are currently defined:

      apropos     images.     noao.       proto.      stsdas.     utilities.
      dataio.     language.   obsolete.   softools.   system.
      dbms.       lists.      plot.       spiral.     tables.
cl>
```

Note that one can start IRAF on the directory where login.cl does no exist, but no information written in the file is read by the IRAF, and the performance of IRAF is significantly degraded.

The `cl>` is the prompt of the IRAF system, and one can directly apply some UNIX command (e.g. cd, ls). Move to the directory where you hope to work by the cd command.

The reduction procedures are carried out interactively using IRAF 'tasks' (commands). The tasks are classified into 'packages' depending on the roles. In order to execute a task, one first opens the package including the task by inputting the package name[2]. For example, the task apall is involved in the echelle package, which is involved in the imred package. So, one first inputs the package names imred and echelle:

```
cl> imred
      argus.      crutil.     echelle.    iids.       kpnocoude.  specred.
      bias.       ctioslit.   generic.    irred.      kpnoslit.   vtel.
      ccdred.     dtoi.       hydra.      irs.        quadred.
im> ec
      apall         aprecenter    demos         refspectra    sflip
      apdefault@    apresize      deredden      sapertures    slist
      apedit        apscatter     dispcor       sarith        specplot
      apfind        apsum         doecslit      scombine      specshift
      apfit         aptrace       dofoe         scopy         splot
      apflatten     bplot         dopcor        sensfunc      standard
      apmask        calibrate     ecidentify    setairmass
      apnormalize   continuum     ecreidentify  setjd
ec>
```

One can go back to the previous package by bye. The package name that includes the task one hopes to apply is found by help. Here is the case of apsum for example:

```
cl> help apsum
```

[2]A task can be executed by inputting only some part of the task name (or package name), if the name is distinguished from other tasks (or packages). For example, one can move to the echelle package by inputting only ec.

This results in the following message, where the package name `noao.twodspec.apextract` is given at the head. Other useful information is also included in the message.

```
APALL (Sep96)            noao.twodspec.apextract           APALL (Sep96)

NAME
    apall -- Extract one dimensional sums across the apertures


USAGE
    apall input


PARAMETERS

......
```

When one executes an IRAF task, some parameters along with the input and output files are required. The list of parameters is edited by the `eparam` task like `eparam task-name`. Examples are shown in the following sections.

4 Structure of HDS data and the overscan regions

4.1 Characteristics of the HDS data

- Frame ID

  A serial number is assigned to each frame of HDS data. HDS produces two FITS files corresponding to the two CCDs by one exposure, for which two frame IDs are assigned. The ID consists of the instrument ID HDSA and the serial number (e.g., HDSA00002480. In this case, the name of the FITS file is HDSA00002480.fits). Odd and even numbers correspond to the CCDs covering longer and shorter wavelengths, respectively. The number does not decrease: if the exposure is canceled and no FITS file is produced, the number is skipped.

- Characteristics of the FITS data produced with HDS

  The FITS file consists of the header unit, data unit, and ASCII extension tables and their header units. In the tables, the spectrum format of the obtained data (wavelength coverage of individual orders, position of the spectrum on the detector) is recorded. The format is calculated from grating angles etc.

4.2 Data format

The data unit contains the output of one CCD with 2048 (slit direction) by 4100 (dispersion direction) pixels, in the case that CCD on-chip binning is not applied, and the *over-scan* region. *Over-scan* indicates the additional readout to the CCD pixels exposed. The data in the over-scan region provides the bias level for the frame itself.

Figure 2 shows the data format of HDS. Since there are two readout ports for each CCD, the unit of data output originally consists of 1024×4100 pixels. The over-scan region (50×4100 pixels) is added to this data unit. One file consists of two units. Two files corresponding to the two CCDs (as shown in Figure 2) are obtained by one exposure. Note that the over-scan region of the same number of columns (50) is added to one data unit for the data with CCD on-chip binning. For instance, in the case of the 2×2 binning, the over-scan region of 50×2050 pixels is added.

The time variation of the bias level is corrected by using the data in the over-scan region. The method of the correction is explained in the next subsection.

4.3 Reduction method for HDS data (the first step)

1. Reading data neglecting ASCII extension tables

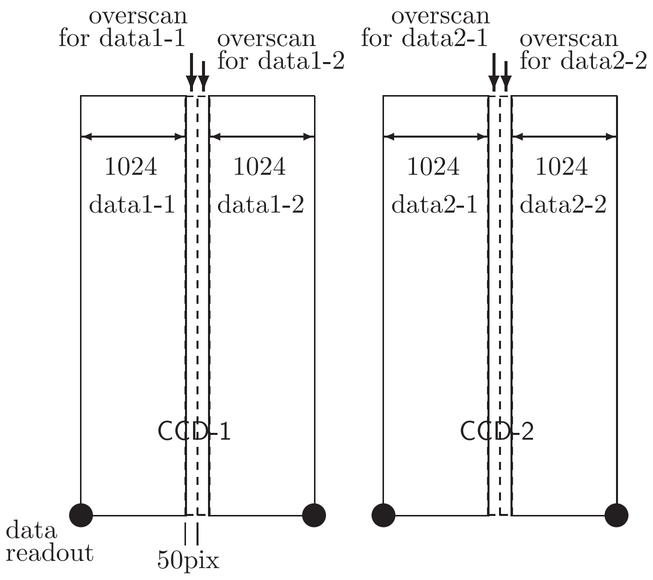


Figure 2: Schematic view of the HDS data format. The vertical and horizontal axes are corresponding to the dispersion and slit directions.

The data unit of the FITS file is read by attaching [0] to the file name (e.g., *HDSA00000001.fits[0]*). Then the data and header units can be directly dealt with by IRAF.

Alternatively, the task “rfits” reads the data unit from the original file and records it in a new FITS file:

ex.) rfits *input.fits* 0 *output.fits*

2. How to deal with the over-scan region

   As described in Section 4.2, the data of over-scan regions are attached to HDS data files. The over-scan data are useful to estimate the bias level for each CCD image. The bias level estimated from the over-scan region is subtracted from the real CCD image by the following procedure.

   - Calculate the average of the counts in the over-scan region (50 × 4100 pixels) for each unit of the CCD readout (1028 × 4100 pixels).
   - Subtract the above average from the data for each unit.
   - Multiply the *gain* to the data for each unit. The value of the gain for each output unit is given in Table 2.
   - Trim the effective data region off the whole data and combine to a single file (2048 × 4100 pixels).

   Note that the numbers of the pixels above are the case without CCD on-chip binning.

   The following table gives the values of gain (conversion factor) for individual readout units. These values are also given in the header unit of the FITS files (`H_GAIN1` for the data of longer wavelength, and `H_GAIN2` for the data of shorter wavelength).

   The IRAF script overscan.cl, which deals with the over-scan region as noted above, is available on the URL:

   `http://optik2.mtk.nao.ac.jp/HDS/index.html`

Table 1: Gain of CCD

unit of output	Gain (e^-/ADU)
CCD1, left(longer wavelength)	1.628
CCD1, right(shorter wavelength)	1.615
CCD2, left(longer wavelength)	1.782
CCD2, right(shorter wavelength)	1.665

The task is defined as follows;

```
cl>task overscan=overscan.cl
```

This script is executed with input and ouput file names as follows:

`cl>overscan` *input.fits[0] output.fits*

5 Displaying data

5.1 CCD image

A CCD image is shown by ds9 (SAOIMAGE). ds9 is started on an unix terminal with a FITS file name.

```
> ds9 filename.file &
```

Alternatively, the image is displayed from IRAF environment with ds9. The task name of this function is display. Following is an example to show the data of the file named H4998.fits:

```
cl> display H4998.fits 1
z1=1420. z2=1967.862
```

The display ranges are adjusted by parameters of the task display.

```
cl> epar display
```

Then, the following list of the parameters appears;

```
PACKAGE = tv
   TASK = display

image   =        ubc00478.fits  image to be displayed
frame   =                    1  frame to be written into
(bpmask =                  BPM) bad pixel mask
(bpdispl=                 none) bad pixel display (none|overlay|interpolate)
(bpcolor=                  red) bad pixel colors
(overlay=                     ) overlay mask
(ocolors=                green) overlay colors
(erase  =                  yes) erase frame
(border_=                   no) erase unfilled area of window
(select_=                  yes) display frame being loaded
(repeat =                   no) repeat previous display parameters
(fill   =                  yes) scale image to fit display window
(zscale =                  yes) display range of greylevels near median
(contras=                 0.25) contrast adjustment for zscale algorithm
(zrange =                  yes) display full image intensity range
(zmask  =                     ) sample mask
(nsample=                 1000) maximum number of sample pixels to use
(xcenter=                  0.5) display window horizontal center
(ycenter=                  0.5) display window vertical center
```

```
(xsize  =                   1.) display window horizontal size
(ysize  =                   1.) display window vertical size
(xmag   =                   1.) display window horizontal magnification
(ymag   =                   1.) display window vertical magnification
(order  =                    0) spatial interpolator order (0=replicate, 1=linea
(z1     =                     ) minimum greylevel to be displayed
(z2     =                     ) maximum greylevel to be displayed
(ztrans =               linear) greylevel transformation (linear|log|none|user)
(lutfile=                     ) file containing user defined look up table
(mode   =                   ql)
```

The display ranges are adjusted by the values of the parameters xmag, ymag etc. In order to finish the parameter setting, input colon symbol (:) and subsequently q. If one inputs colon (:) and go, then the task itself (display in this case) starts its job.

5.2 Cross-cut image

A cross-cut image of the CCD data is useful to evaluate spectral data. This is displayed by the task implot. Here the data for flat fielding are shown as an example:

```
cl> implot H4998.fits
```

A new window appears to show the cross-cut image of the data for the slit direction (Figure 3. Here only a small portion of the data is shown). The range of the X-axis is from 0 to 2048, indicating the pixel number of the slit direction. In this case, the count (photon) level of the flat lamp is approximately 30,000. The slit length is also measured from this image (about 30 pixels in this case). The display range is changed by inputting colon (:) and pixel numbers like 'x 500 1500', which results in a diagram showing the data between the pixel numbers. See help of the task implot for more details.

If one inputs 'c' on the window, a cross-cut image for the dispersion direction (i.e. direction that is perpendicular to the slit) is shown (c means column). A cross-cut image of the slit direction will be shown again by inputting 'l' (=line) on the window.

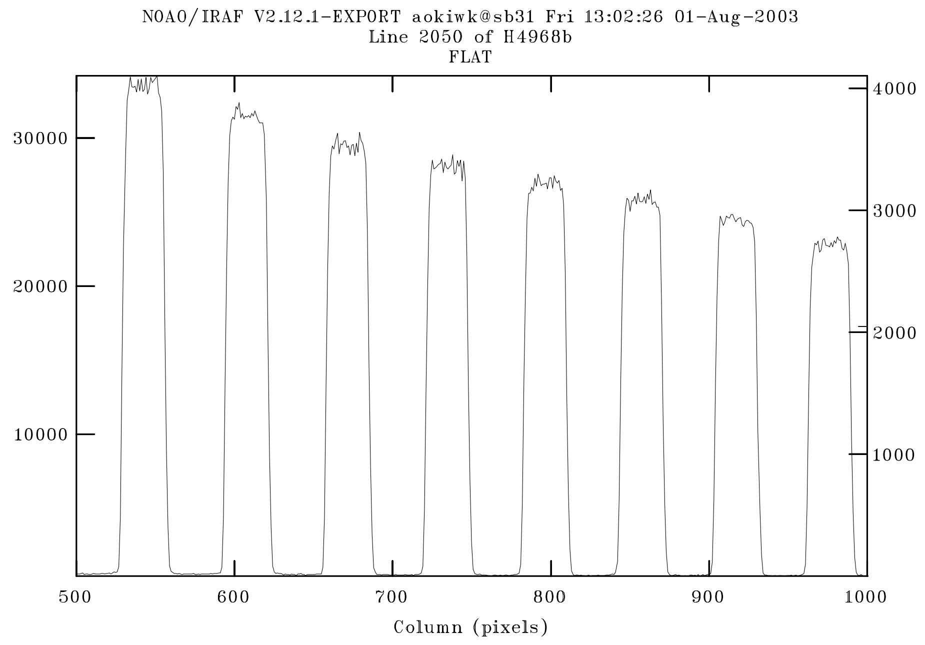


Figure 3: A portion of a cross-cut image of flat data for the slit direction. This is the case for the 2050th line (i.e. the center of the CCD image) for the dispersion direction.

6 Corrections for bias and dark current

6.1 Corrections for bias

CCD data obtained with no exposure will have some counts. These values are called bias. The values are dependent on the CCD pixels in general, though the differences are usually quite small. The corrections for bias are made using the frames obtained with no exposure. In order to increase the data quality, several frames should be combined by adopting the median of the values of each pixel (median, rather than average, is recommended because some pixels possibly show very high values caused by cosmic-ray noise). For this purpose, the task imcombine is used. Following parameter table appears by executing 'eparam imcombine':

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = immatch
   TASK = imcombine

input   =             @bias_in  List of images to combine
output  =                 bias  List of output images
(headers=                     ) List of header files (optional)
(bpmasks=                     ) List of bad pixel masks (optional)
(rejmask=                     ) List of rejection masks (optional)
(nrejmas=                     ) List of number rejected masks (optional)
(expmask=                     ) List of exposure masks (optional)
(sigmas =                     ) List of sigma images (optional)
(logfile=               STDOUT) Log file

(combine=               median) Type of combine operation
(reject =                 none) Type of rejection
(project=                   no) Project highest dimension of input images?
(outtype=                 real) Output image pixel datatype
(outlimi=                     ) Output limits (x1 x2 y1 y2 ...)
(offsets=                 none) Input image offsets
(masktyp=                 none) Mask type
(maskval=                   0.) Mask value
(blank  =                   0.) Value if there are no pixels

(scale  =                 none) Image scaling
(zero   =                 none) Image zero point offset
(weight =                 none) Image weights
(statsec=                     ) Image section for computing statistics
(expname=                     ) Image header exposure time keyword

(lthresh=                INDEF) Lower threshold
(hthresh=                INDEF) Upper threshold
(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=                   0.) ccdclip: CCD readout noise (electrons)
(gain   =                   1.) ccdclip: CCD gain (electrons/DN)
(snoise =                   0.) ccdclip: Sensitivity noise (fraction)
(sigscal=                  0.1) Tolerance for sigma clipping scaling correction
(pclip  =                 -0.5) pclip: Percentile clipping parameter
(grow   =                   0.) Radius (pixels) for neighbor rejection
(mode   =                   ql)
```

The input file names of the bias data like 'H4946,H4948,H4950,H4952,H4954' are given for input ('.fits' can be omitted), while a name like bias is given for output. Alternatively, for the input the file names can be given by an *input file* which gives a file name in each line. For example, the input file bias_in containing the above five file names of bias data is given for the input parameter as @bias_in, then the all bias data are dealt with input data for imcombine. The parameter combine should be median. Input :go, then the bias frame bias.fits is produced. The combined data should be confirmed using implot or some other tasks.

The bias frame is subtracted from the object or other calibration frames. The task imarith is applied to this job:

```
cl> imarith H4998.fits - bias.fits H4998b.fits
```

Here the result is written in the new file H4998b.fits.

6.2 Corrections for dark current

The dark current is estimated by the 'exposure' without opening the shutter. We here neglect the dark current.

7 First extraction of spectra

For the further calibration of the data (e.g. flat-fielding, subtraction of scattered light) it is useful to once extract a spectrum from the data image using the task apall. This will produce reference data for the calibration procedures. First, the parameters of apall are given as follows;

```
ec> epar apall
```

Followings are examples of the parameters:

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = echelle
   TASK = apall

input   =               H4998b  List of input images
(output =            H4998b_ec) List of output spectra
(apertur=                     ) Apertures
(format =              echelle) Extracted spectra format
(referen=                     ) List of aperture reference images
(profile=                     ) List of aperture profile images

(interac=                  yes) Run task interactively?
(find   =                  yes) Find apertures?
(recente=                  yes) Recenter apertures?
(resize =                  yes) Resize apertures?
(edit   =                  yes) Edit apertures?
(trace  =                  yes) Trace apertures?
(fittrac=                  yes) Fit the traced points interactively?
(extract=                  yes) Extract spectra?
(extras =                   no) Extract sky, sigma, etc.?
(review =                  yes) Review extractions?

(line   =                INDEF) Dispersion line
(nsum   =                  100) Number of dispersion lines to sum or median

                                # DEFAULT APERTURE PARAMETERS

(lower  =                  -5.) Lower aperture limit relative to center
(upper  =                   5.) Upper aperture limit relative to center
(apidtab=                     ) Aperture ID table (optional)

                                # DEFAULT BACKGROUND PARAMETERS

(b_funct=            chebyshev) Background function
(b_order=                    1) Background function order
```

```
(b_sampl=          -10:-6,6:10) Background sample regions
(b_naver=                   -3) Background average or median
(b_niter=                    0) Background rejection iterations
(b_low_r=                   3.) Background lower rejection sigma
(b_high_=                   3.) Background upper rejection sigma
(b_grow =                   0.) Background rejection growing radius

                                # APERTURE CENTERING PARAMETERS

(width  =                   5.) Profile centering width
(radius =                  10.) Profile centering radius
(thresho=                   0.) Detection threshold for profile centering

                                # AUTOMATIC FINDING AND ORDERING PARAMETERS

nfind   =                   22  Number of apertures to be found automatically
(minsep =                   5.) Minimum separation between spectra
(maxsep =                1000.) Maximum separation between spectra
(order  =           increasing) Order of apertures

                                # RECENTERING PARAMETERS

(aprecen=                     ) Apertures for recentering calculation
(npeaks =                INDEF) Select brightest peaks
(shift  =                  yes) Use average shift instead of recentering?

                                # RESIZING PARAMETERS

(llimit =                 -10.) Lower aperture limit relative to center
(ulimit =                  10.) Upper aperture limit relative to center
(ylevel =                  0.1) Fraction of peak or intensity for automatic wid
(peak   =                  yes) Is ylevel a fraction of the peak?
(bkg    =                   no) Subtract background in automatic width?
(r_grow =                   0.) Grow limits by this factor
(avglimi=                  yes) Average limits over all apertures?

                                # TRACING PARAMETERS

(t_nsum =                   10) Number of dispersion lines to sum
(t_step =                   10) Tracing step
(t_nlost=                    3) Number of consecutive times profile is lost bef
(t_funct=             legendre) Trace fitting function
(t_order=                    3) Trace fitting function order
(t_sampl=                    *) Trace sample regions
(t_naver=                    1) Trace average or median
(t_niter=                    0) Trace rejection iterations
(t_low_r=                   3.) Trace lower rejection sigma
(t_high_=                   3.) Trace upper rejection sigma
(t_grow =                   0.) Trace rejection growing radius

                                # EXTRACTION PARAMETERS

(backgro=                 none) Background to subtract
(skybox =                    1) Box car smoothing length for sky
(weights=                 none) Extraction weights (none|variance)
(pfit   =                fit1d) Profile fitting type (fit1d|fit2d)
(clean  =                   no) Detect and replace bad pixels?
(saturat=                INDEF) Saturation level
(readnoi=                    8) Read out noise sigma (photons)
(gain   =                   1.) Photon gain (photons/data number)
(lsigma =                   4.) Lower rejection threshold
(usigma =                   4.) Upper rejection threshold
```

```
(nsubaps=                      1) Number of subapertures per aperture
(mode   =                     ql)
```

The input file name and an arbitrary name of the output file are given in the first two lines. This task first searches for spectra of individual echelle orders in the cross cut image of the data. Then the aperture position and size are determined and the result is displayed to provide an opportunity for manual corrections. In order to carry out these tasks, one specify the parameters find, recente, resize and edit to 'yes'.

For the determined aperture size and position, individual spectra are traced and the counts are summed along the direction of the slit. The parameters trace, fittrac and extract are set to 'yes'.

Other important parameters are as follows;

- # AUTOMATIC FINDING ... (nfind): this gives the number of spectra extracted
- # RESIZING PARAMETERS (peak and ylevel): If the parameter peak is yes, the aperture size is determined as the width of the cross cut image of each spectrum at the ylevel height of the peak. For example, if the ylevel is 0.2, the width at the 20% of the peak of the cross cut image is adopted to be the aperture size.

At the first step, the parameters extras and bkg should be no while the avglimi should be yes.

Execute the task and answer the questions, then a diagram like Figure 4 appears. This is a result of the automatic searches for the aperture position and size. The position and size of apertures are confirmed or corrected if necessary. If the aperture searches are not satisfactory, one may stop the task (inputting q and answering no for subsequent questions) and execute again with changed parameters of the task apall.

A special care should be paid for the order numbers. The number should be from left to right without any gap or duplication.

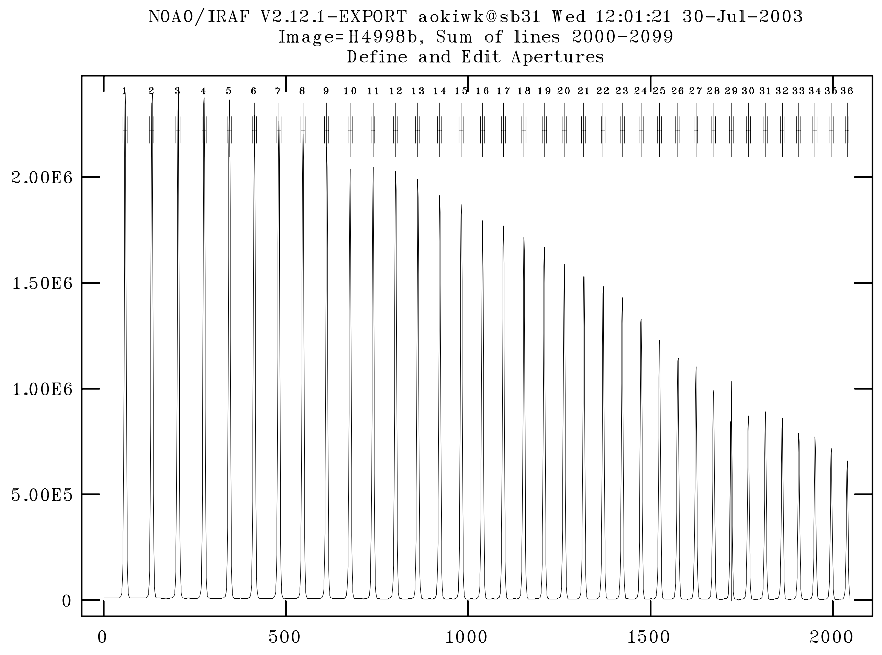


Figure 4: A cross cut image of the data along the slit direction. A result of the first step of the task apall that determines the aperture positions with the order numbers.

If the position, the size of the apertures, and the order numbering are satisfactory, input 'q' at the window of the diagram, then tracing process for each spectrum starts. A diagram like Figure 5 appears. This diagram shows a tentative result of the order trace where the horizontal and vertical axes indicate pixel numbers of the dispersion and slit directions, respectively. The detected peak of the spectrum is shown by the '+' symbol, while the fitting to these detected peaks are shown by a dashed line.

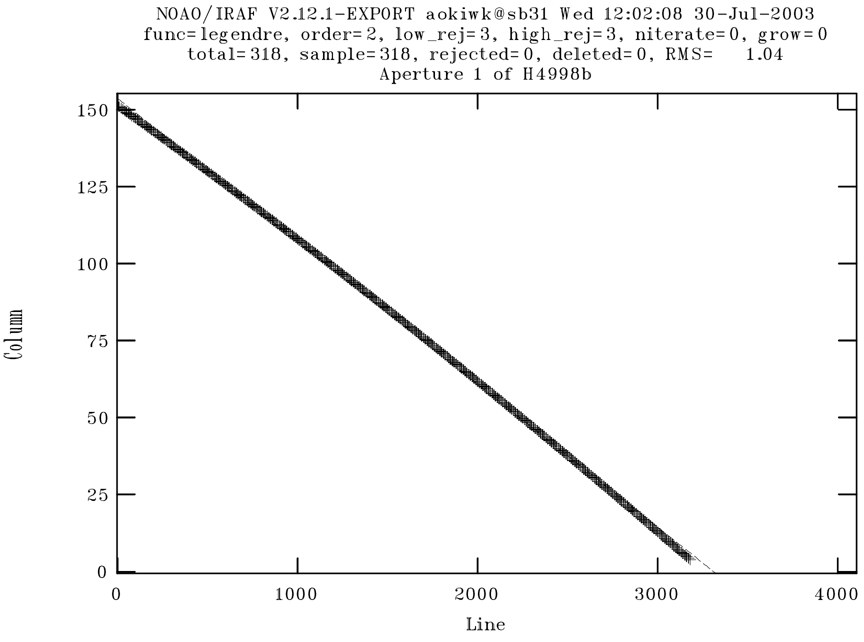


Figure 5: Order tracing for a spectrum. The horizontal axis means the dispersion direction and the vertical axis means the slit direction of the data (unit is the pixel number of the CCD).

If the fitting is insufficient, one may increase the order of the fitting function, and/or change the fitting range for the horizontal axis. The order of the fitting function is changed, for example, to 3 by inputting ':order 3' on the display. The fitting range is changed by the key 's' at the two positions on the display (the fitting range is initialized by inputting 't'). The fitting using new parameters is made by the key 'f'.

If the fitting is satisfactory, input 'q' at the display, and apply a similar procedure to the next spectrum. After fitting for all spectra contained in the image, the extracted spectrum of the first echelle order appears as shown in Figure 6.

The task splot is useful to display spectra;

```
ec> splot H4998b_ec
```

See last section for the details of splot.

8 Flat fielding

In order to correct the pixel-to-pixel inhomogeneity of the sensitivity of the detector, images of white light (practically the light of a halogen lamp) are obtained with the same setup of the spectrograph (Figure 3). These data provide an estimate of the sensitivity of the detector including their wavelength dependence.[3]

One usually makes a 'flat frame' from the median of several flat images as in the case of bias frames with the task imcombine. Here the name of the flat frame is given as 'flat.fits'.

Flat fielding of the object data are made by dividing the object frame by the flat frame. Before that, however, the flat frame is usually 'normalized' for the count, in order to keep the count of the object data. The normalization of the flat frame is made with the task apnormalize (or apflatten). The parameters for apnormalize are as follows;

```
                                  I R A F
                    Image Reduction and Analysis Facility
```

[3]When the wavelength coverage of the spectrograph is so wide that the intensity of the flat lamp may not be sufficiently high in some wavelength ranges, flat data are obtained by changing the exposure time or filter setting. In the case of HDS, flat data are usually obtained for each CCD.

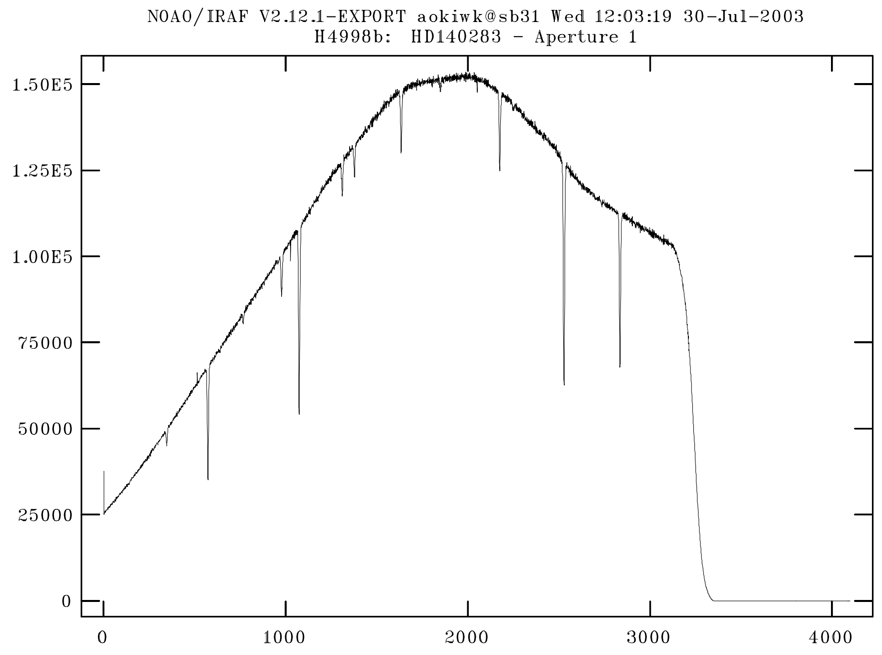


Figure 6: A spectrum obtained by the task apall. The unit of the horizontal axis is the pixel number of the CCD at this stage.

```
PACKAGE = echelle
   TASK = apnormalize

input   =                flat  List of images to normalize
output  =               flatn  List of output normalized images
(apertur=                   ) Apertures
(referen=              H4998b) List of reference images

(interac=                 yes) Run task interactively?
(find   =                  no) Find apertures?
(recente=                 yes) Recenter apertures?
(resize =                 yes) Resize apertures?
(edit   =                 yes) Edit apertures?
(trace  =                  no) Trace apertures?
(fittrac=                  no) Fit traced points interactively?
(normali=                 yes) Normalize spectra?
(fitspec=                 yes) Fit normalization spectra interactively?

(line   =               INDEF) Dispersion line
(nsum   =                  10) Number of dispersion lines to sum or median
(cennorm=                  no) Normalize to the aperture center?
(thresho=                 10.) Threshold for normalization spectra

(backgro=                none) Background to subtract
(weights=                none) Extraction weights (none|variance)
(pfit   =               fit1d) Profile fitting type (fit1d|fit2d)
(clean  =                  no) Detect and replace bad pixels?
(skybox =                   1) Box car smoothing length for sky
(saturat=               INDEF) Saturation level
(readnoi=                  0.) Read out noise sigma (photons)
(gain   =                  1.) Photon gain (photons/data number)
(lsigma =                  4.) Lower rejection threshold
(usigma =                  4.) Upper rejection threshold
```

```
(functio=              spline3) Fitting function for normalization spectra
(order  =                    3) Fitting function order
(sample =                    *) Sample regions
(naverag=                    1) Average or median
(niterat=                    5) Number of rejection iterations
(low_rej=                   3.) Lower rejection sigma
(high_re=                   3.) High upper rejection sigma
(grow   =                   0.) Rejection growing radius
(mode   =                   ql)
```

These are similar to the parameters of the task apall, because the extraction of the flat spectra is once made for the normalization. This time, however, the object data (e.g., H4998) to which extraction was already applied can be used as a reference image. Since the object and flat images are obtained with the same setup of the spectrograph, the positions of the recorded spectra on the CCD are the same in principle. [4]

In order to refer to the object file, the name of the object file (e.g., H4998b) is given as the parameter referen. *The reference image is the two dimensional data before extraction, rather than the extracted one dimensional spectrum data (e.g., H4998b,ec).* The reference image is used to search for the apertures and to trace the spectra. In that case the parameters find, trace and fittrac are set to no. The detailed position and the size of apertures are determined for the flat frame, because they are different in general between the object and flat images. Therefore, the parameters aprec and apres are set to yes. Unfortunately, the parameters peak and ylevel do not exist in the parameter list of apnormalize. They are given separately in the parameter list of apresize, which is called from apnormalize, as follows;

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = echelle
   TASK = apresize

input   =                          List of input images
(apertur=                        ) Apertures
(referen=                        ) Reference images

(interac=                      no) Run task interactively?
(find   =                     yes) Find apertures?
(recente=                      no) Recenter apertures?
(resize =                     yes) Resize apertures?
(edit   =                     yes) Edit apertures?

(line   =                   INDEF) Dispersion line
(nsum   =                       1) Number of dispersion lines to sum or median
(llimit =                    -20.) Lower aperture limit relative to center
(ulimit =                     20.) Upper aperture limit relative to center
(ylevel =                     0.4) Fraction of peak or intensity for automatic wi
(peak   =                     yes) Is ylevel a fraction of the peak?
(bkg    =                      no) Subtract background in automatic width?
(r_grow =                      0.) Grow limits by this factor
(avglimi=                     yes) Average limits over all apertures?
(mode   =                      ql)
```

Extraction of flat spectra is made by apnormalize as that by apall for object spectra. However, since the reference data are used for tracing the spectra, there is no manual work in this case. Then the first extracted spectrum appears as Figure 7.

A profile fit to the data points is also shown in the diagram. In order to improve the fitting, one may chance the function and the order of the function by, for example, ':function spline3' and ':order 9', respectively. One

[4]The positions of the spectra on the CCD image are recorded in the file like apH4998 below the directory database. So one should not delete or move this directory and be careful for the correspondence between the data file itself and the file in the database directory.

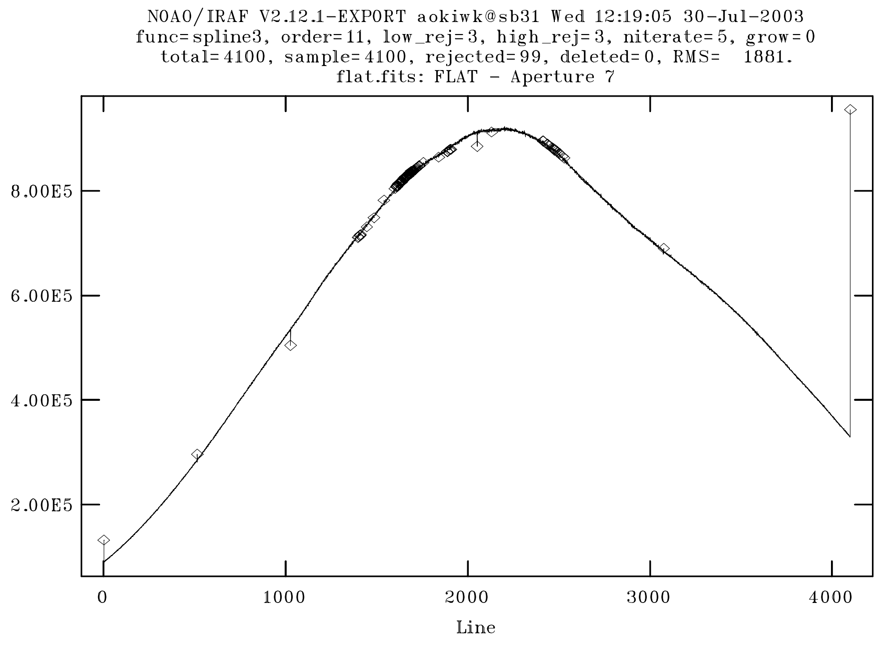


Figure 7: Fitting of a curve to an extracted flat spectrum

may also change the fitting range by double 's' keys to avoid the inappropriate parts of the spectra for the fitting, e.g. pixels affected by bad columns. Then the key 'f' makes a re-fitting for the new parameter setup.

Inputting 'q' finishes the procedure for this spectrum, then the next one appears. This procedure is applied to all orders of the spectra.

The result is seen by implot. The normalized flat frame looks like Figure 8. The part where the count is exactly unity is the outside of the aperture, i.e. the region between the two adjacent spectra where (essentially) no light is detected. The scatter found within the apertures indicates the inhomogeneity of the detector sensitivity.

Flat fielding of an object frame is made by dividing the object frame by the normalized flat frame with the task imarith:

```
imarith H4998b / flatn H4998bf
```

where the normalized flat frame is flatn.fits and the flat-fielded object frame is H4998bf.fits.

9 Background subtraction

As found in the cross cut image of the object frame (Figure 9), the counts of the region between the two adjacent orders are not zero due to the background including scattered light inside the spectrograph. Estimates of background is made by masking the apertures of the spectra and applying surface fitting to the other regions. The background subtraction is made only for object frames here [5].

The task apscatter is used for this purpose. An example of parameter setting for this task is given below. The parameters referen, apfind, aprecenter, apresize, apedit, aptrace and fittrac are set as in the case of apnormalize. The reference file is again the object frame for which the order trace and extraction is once made. The aperture size is given in the parameter list of apresize.

The first part of the task is carried out like that of apnormalize. After the (automatic) order tracing, a result of the surface fitting for the slit direction is displayed like Figure 10. One may correct the fitting function and its order. The key 'q' finishes the fitting process for this cross cut image. Then one may see the fitting result for other lines by inputting, for example, 'line 200'. If the fitting for the slit direction looks satisfactory, input 'q' or 'quit', then the fitting for the dispersion direction like Figure 11 is shown (this may take a few minutes).

[5]The background subtraction should be made also for the flat data before flat fielding. This process is skipped here because the effect is minor.

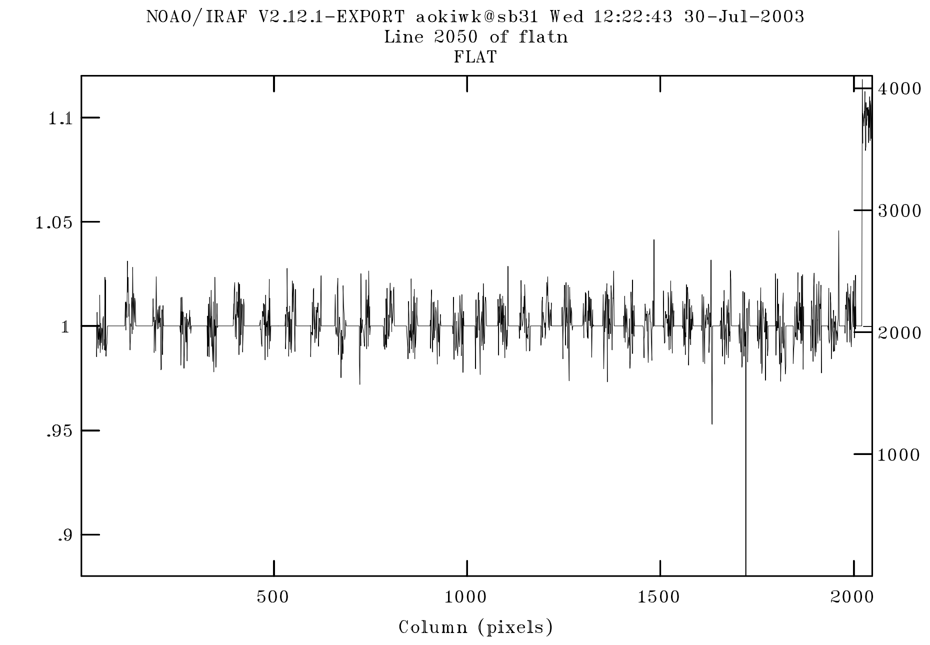


Figure 8: A cross cut image of the flat frame along the slit direction

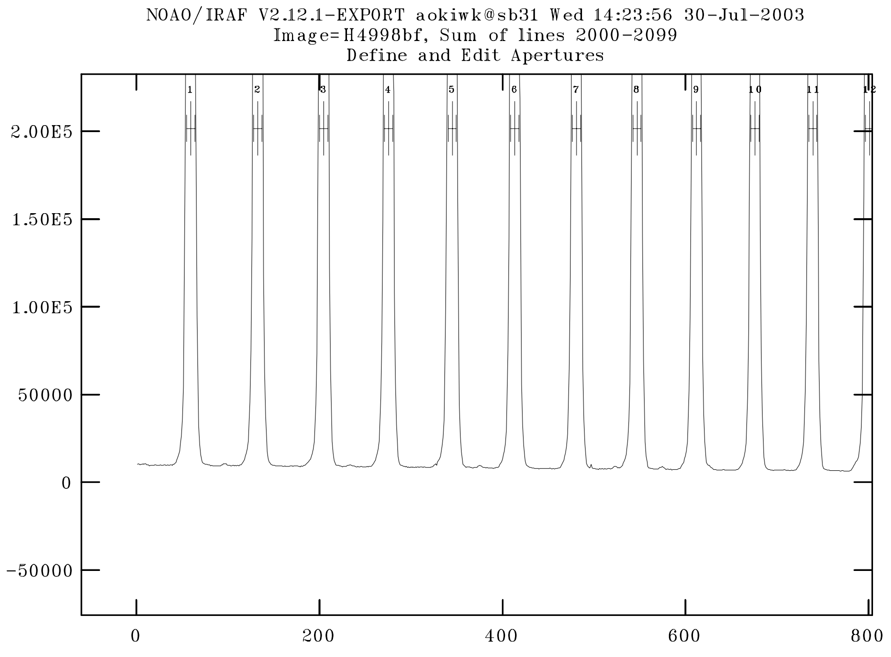


Figure 9: A cross cut image of the object frame obtained during the procedure of apscatter.

One may see the cross cut images of other orders by inputting 'column 2500' etc. If the fitting is satisfactory, input 'q' or 'quit', then a background subtracted image is obtained.

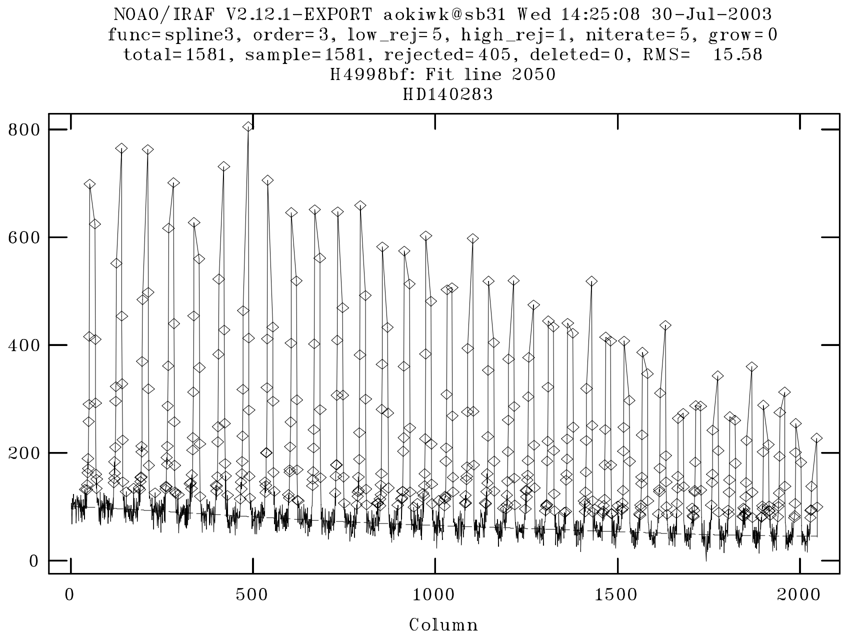


Figure 10: A cross cut image of the aperture-masked data for the slit direction. The result of surface fitting to the estimated background image is shown by the dashed line.

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = echelle
   TASK = apscatter

input   =             H4998bf  List of input images to subtract scattered lig
output  =            H4998bfs  List of output corrected images
(apertur=                    ) Apertures
(scatter=                    ) List of scattered light images (optional)
(referen=              H4998b) List of aperture reference images

(interac=                 yes) Run task interactively?
(find   =                  no) Find apertures?
(recente=                 yes) Recenter apertures?
(resize =                 yes) Resize apertures?
(edit   =                 yes) Edit apertures?
(trace  =                  no) Trace apertures?
(fittrac=                  no) Fit the traced points interactively?
(subtrac=                 yes) Subtract scattered light?
(smooth =                 yes) Smooth scattered light along the dispersion?
(fitscat=                 yes) Fit scattered light interactively?
(fitsmoo=                 yes) Smooth the scattered light interactively?

(line   =               INDEF) Dispersion line
(nsum   =                 100) Number of dispersion lines to sum or median
(buffer =                  1.) Buffer distance from apertures
(apscat1=                    ) Fitting parameters across the dispersion
(apscat2=                    ) Fitting parameters along the dispersion
(mode   =                  ql)
```

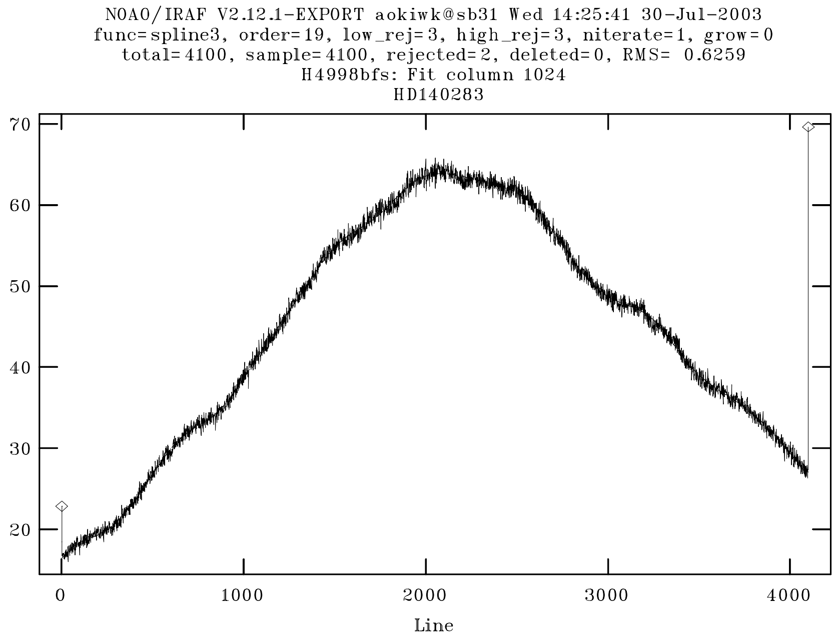


Figure 11: The same as Fig.10, but for the dispersion direction.

10 Extraction of one dimensional spectra

The extraction of spectra from the flat-fielded and background-subtracted object frame is made again using the task apall. In this case, however, one can use the first object frame to which extraction was applied as a reference data. Followings are an example of the parameter setting for the first 16 lines:

```
                                    I R A F
                     Image Reduction and Analysis Facility
PACKAGE = echelle
   TASK = apall

input   =             H4998bfs  List of input images
(output =          H4998bfs_ec) List of output spectra
(apertur=                     ) Apertures
(format =              echelle) Extracted spectra format
(referen=              H4998b) List of aperture reference images
(profile=                     ) List of aperture profile images

(interac=                  yes) Run task interactively?
(find   =                   no) Find apertures?
(recente=                  yes) Recenter apertures?
(resize =                  yes) Resize apertures?
(edit   =                  yes) Edit apertures?
(trace  =                   no) Trace apertures?
(fittrac=                   no) Fit the traced points interactively?
(extract=                  yes) Extract spectra?
(extras =                   no) Extract sky, sigma, etc.?
(review =                  yes) Review extractions?
```

11 Wavelength calibration

The above procedure provides the one dimensional spectra for individual echelle orders as a function of the pixel number. The wavelength calibration is made using comparison spectra (spectra of Th-Ar arc lamp) obtained by the same setup of the spectrograph as applied to the object. The laboratory wavelengths of individual Th spectral lines are known. Here the relation between the wavelength and the CCD pixel number is made using the Th-Ar spectra.

11.1 Identification of Th spectral lines

First, the Th-Ar spectra are extracted using apall as for the object data. In this case, the aperture position and size should be just the same as those for the object data. That is, the object file (before extraction) is given as the reference file (the parameter referen), and the parameters find, aprecent, ..., fittrac are specified to be no. Then, a spectrum as shown in Figure 12 is obtained.

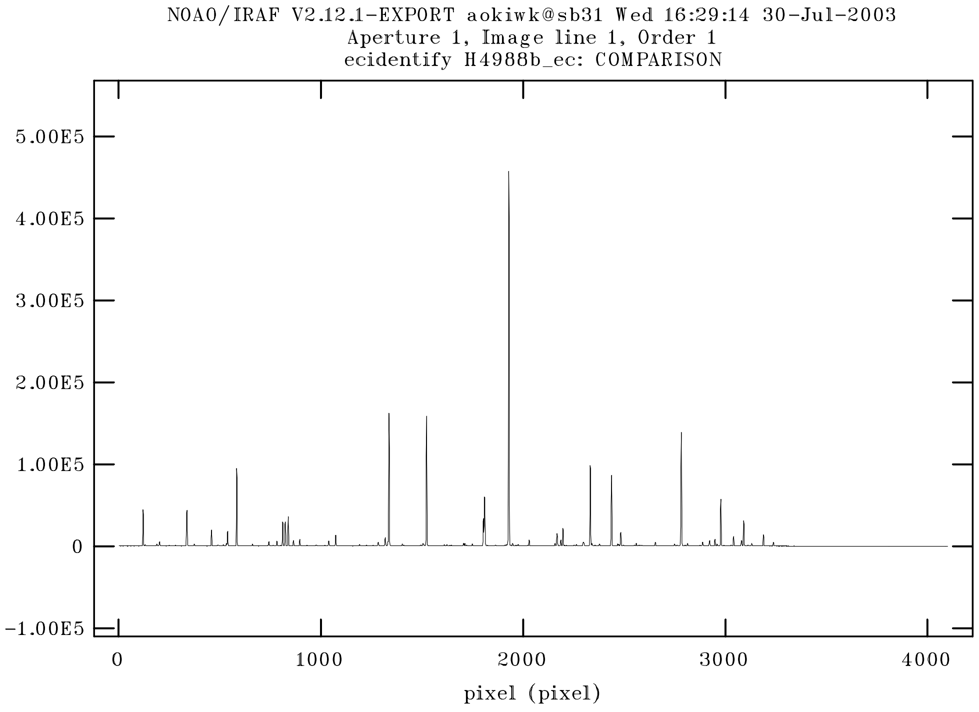


Figure 12: An example of comparison spectrum. This plot appears in the ecidentify procedure.

A number of Th (and Ar) lines appear in the comparison spectra. The next step is to identify the spectral lines and assign the wavelengths. For this purpose, it is useful to know the wavelength coverage of the data. The wavelength coverage calculated for the spectrograph setup is given in the FITS header as follows:

```
WAVELEN =                480.60 / Center wavelength of the center order (nm)
WAV-MAX =                540.17 / Maximum wavelength recorded (nm)
WAV-MIN =                414.20 / Minimum wavelength recorded (nm)
```

In this case, this frame approximately covers 414.2–540.17 nm.

On the other hand, an atlas of wavelengths for individual Th lines is provided for the HDS data reduction [6]. The wavelength of each Th line is identified by comparisons of the above plot and the atlas.

11.2 Wavelength identification for Th lines and wavelength scaling

The wavelength identification for each Th line is made by the task ecidentify.

[6]Honda & Aoki 2001, http://www.naoj.org/Observing/Instruments/HDS/

```
ec> epar ecident
```

The name of the comparison spectrum is given for the parameter images, while the 'linelists$thar.dat' is set to coodli. which means the list of Th lines involved in the IRAF.

A spectrum like Figure 12 is displayed in the course of executing this task. One may magnify the plot using the 'window' mode as in the case of splot (Section 15). Point the cursor at one emission line, and input 'm' there. Then a stick appears above the emission line. Give its wavelength identified from the atlas of Th-Ar data. Several lines should be identified for each echelle order. One may delete mis-identified line by pointing the cursor on the line and inputting the key 'd'. (The stick may remain on the window. In that case, re-display the plot by the key 'r'.)

One may move to the next order of the spectra by the key 'k' (and go back to the previous order by 'j'). This procedure is made for each order of the spectra. Practically, one may skip some orders to save the manual job.

If the identification of lines for the whole data is completed, input 'f' to fit a function to the identified lines, providing relation between the line position on the detector and the wavelength. A plot of the fitting residual as a function of the pixel number of the dispersion direction is displayed as Fig. 13. The data point that significantly deviates from others may be deleted by the key 'd' (pointing it by the cursor). The function for the order of the fitting function are changed by inputting, for example, ':xorder 4' ':yorder 3', which are corresponding to the fitting functions for dispersion and slit directions. Figure 13 shows a result of the appropriate fitting (the number of data points are very large because this is a result of the automatic searching for the lines. See below for details).

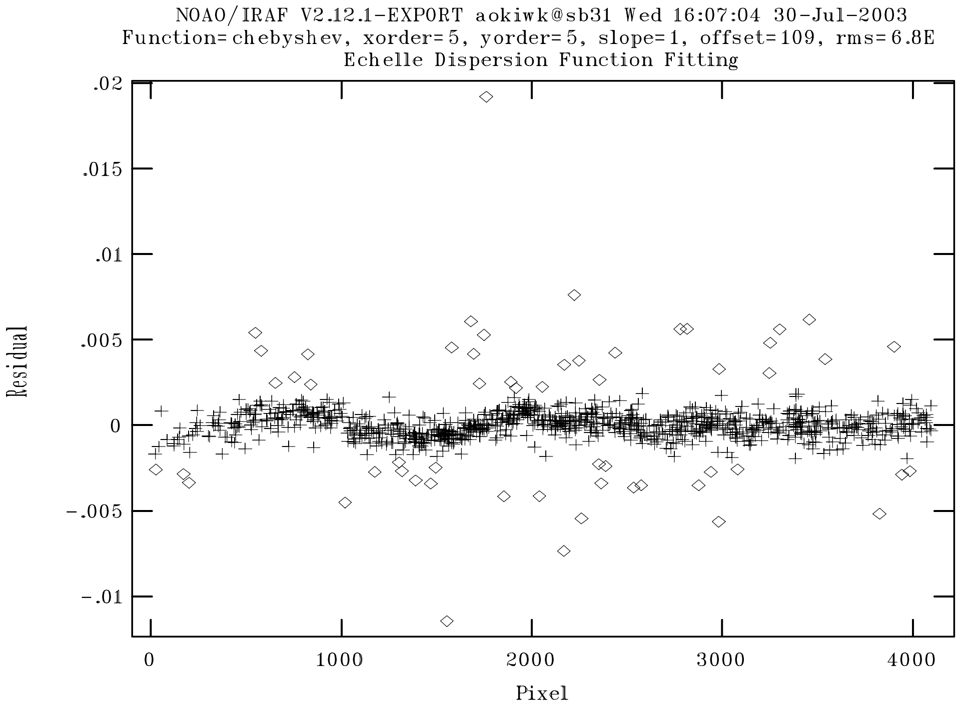


Figure 13: A result of the identification of Th lines and fitting. The residual of the fitting (the unit is Å) is shown as a funtion of the pixel number of the dispersion direction

A plot for the slit direction is shown by the keys 'x' and 'o' (the keys 'x' and 'p' shows again the fitting for the dispersion direction.)

If the fitting result is satisfactory (the rms of residual is usually smaller than 0.01 for the xorder=yorder=3), exit this plot by the key 'q' (the plot like Figure 12 appears again). The key 'l', executes automatic searches for Th lines using the Th line list included in the IRAF package. The maximum number of automatic identification is given in the parameter file of ecidentify as maxfeat. The fitting result is shown again by the key 'f': this time, many lines are identified as found in Fig. 13. Changing the parameters xorder and yorder to obtain satisfactory fit. For typical HDS data xorder=yorder=4 provides satisfactory results. The task is finished by the key 'q'.

If there are problems in the first manual identifications for Th lines, the automatic fit possibly produces incorrect results. The resulting plots of the line identifications and fitting should be carefully examined.

11.3 Wavelength calibration

Now the wavelength scale produced by the ecidentify is applied to the stellar spectra. First, the stellar spectra are linked to the above comparison data by the task refspectra as follows.

```
on> refs H4998bfs_ec refe=H5008b_ec
```

Here the H4998bfs_ec.fits is the stellar spectrum data, while H5008b_ec.fits is the comparison data.[7]

Finally, the wavelength calibration for the spectra is made by the task dispcor (the meaning is 'dispersion correction'):

```
on> dispcor H4998bfs_ec H4998bfs_ecw
```

Then, the wavelength-calibrated spectrum H4998bfs_ecw.fits is obtained (Figure 14).

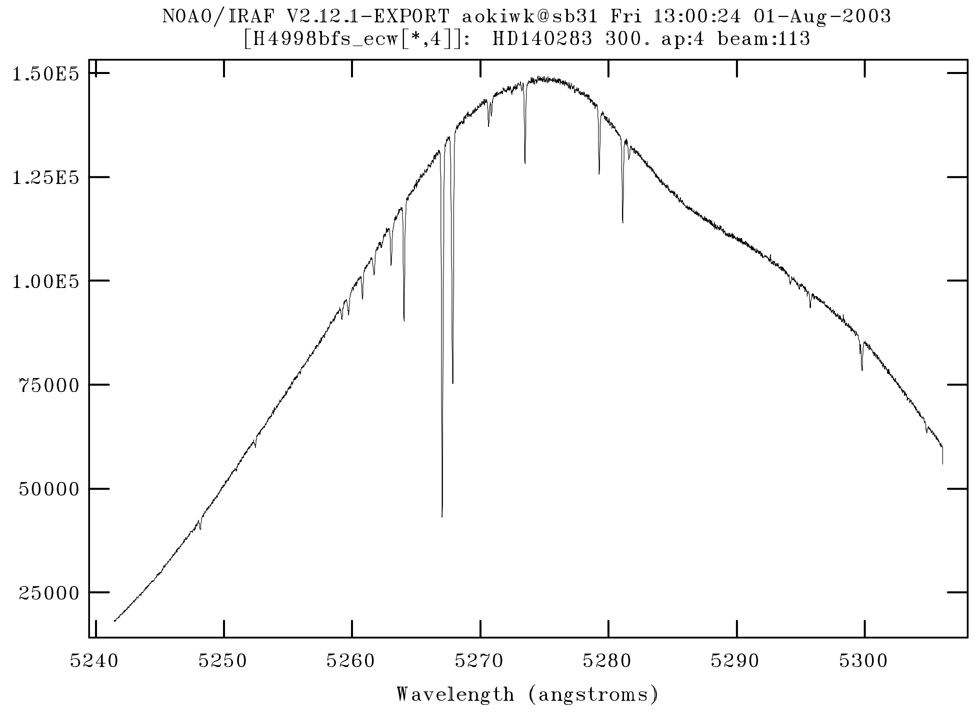


Figure 14: Wavelength-calibrated spectrum obtained by dispcor.

12 Continuum normalization

The next step is to make normalized spectra by fitting curves. Echelle spectra usually have the efficiency peak near the center of CCD, and the count level is sometimes very low at the edges of spectra. An example is shown in Figure 14, where the count of the shorter wavelength is quite low. In such cases, some portion that has very low count may be trimmed from the spectrum. The trimming is done by the task imcopy as follows;

```
imcopy H4998bfs_ecw[601:4100,*] H4998bfs_ecwt
```

[7]The default setting for the parameters sort and group of this task are jd. However, jd does not appear in the HDS fits header, while MJD is given. Delete jd from these two lines, or give MJD (or UT) for sort.

Then 600 pixels are trimmed from of the spectrum.

The normalization is carried out by the task continuum.

```
ec> continuum H4998bfs_ecw H4998bfs_ecwc.fits
```

Figure 15 shows an example of the fitting of a function to a spectrum, where the absorption lines are excluded from the fitting. The fitting function and its order are changed by inputting, for example, 'func spline3' and ':order 5', respectively. Fitting ranges are also given by the key 's' as in the case for apnorm. The fitting is updated by the key 'f'.

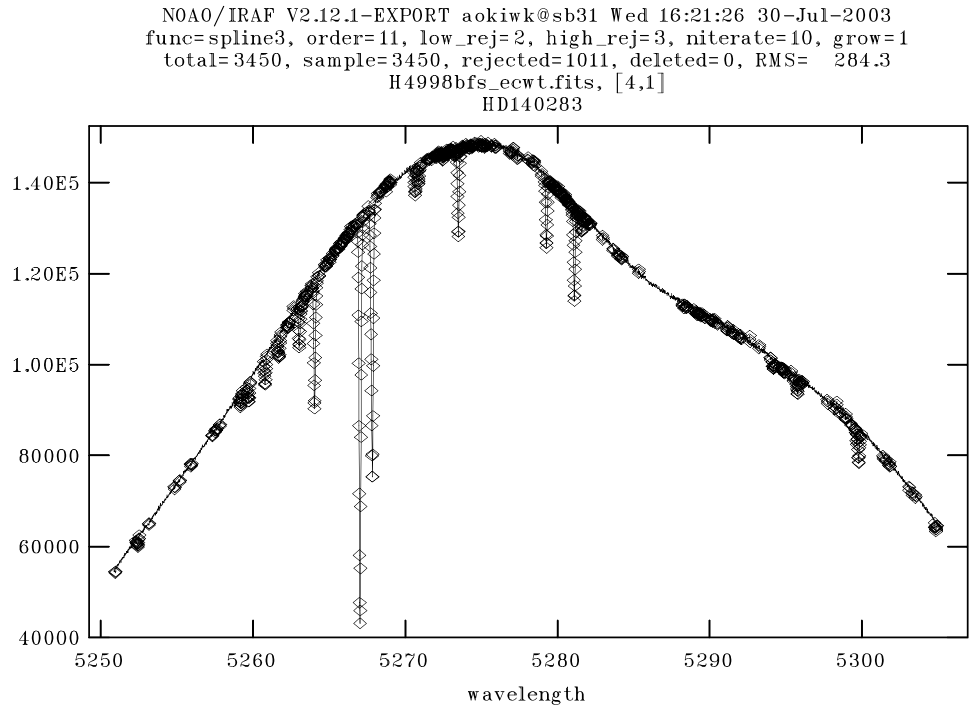


Figure 15: An example of continuum fitting

If the fitting is satisfactory, input 'q', then the spectrum of the next order appears. The procedure is repeated for all orders. Figure 16 shows an example of the normalized spectrum.

13 Making a combined spectrum

The multi-order spectra are merged by the task scombine. [8] A simple method is to average the normalized spectra for the overlapped range (the portion which is covered by adjacent orders). In this case, the parameters of this task group and combine are set to images and average, respectively.

However, this simple method results in a significantly degraded spectrum in the merged region, if the photon counts at the edge of one spectrum compared with the other are quite low as seen in Fig. 17, because the noise of such portion is magnified by the normalization process. Figure 18 shows an example of the result by the above simple method. The spectrum includes ranges where the quality is significantly low (i.e. around 3468 Å and 3488 Å).

This problem is avoided by the following procedure. First, normalized spectra are made by the continuum task as done in the previous section. Then, the spectra are divided by the normalized spectra using the task imarith (or sarith), then the spectra of the continuum are obtained, as shown in Figure 19. They are just the curves fit to the spectra in the normalization process.

[8] scombine is used for adding spectra obtained by different exposures with the same setup. In this case, the input files are given like "input=A.ec,B.ec,C.ec", while the parameters group and combine are set to aperture and sum, respectively.

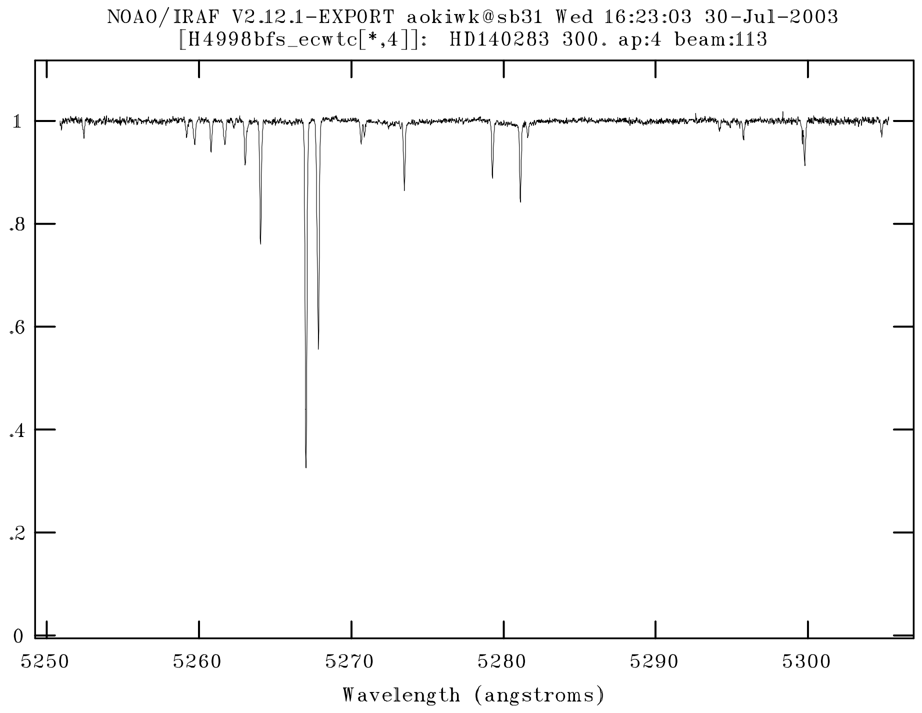


Figure 16: An example of the normalized spectrum

Next, the spectra are merged by the task scombine with the parameter combine of sum as follows;

```
(group  =               images) Grouping option
(combine=                  sum) Type of combine operation
```

Then, the summed spectrum is obtained, as shown in Figure 20.

The same procedure is applied to the continuum spectra. The result is shown in Figure 21. Finally, the summed spectrum is divided by the summed continuum spectrum using imarith (or sarith), then the normalized and merged spectrum is obtained (Figure 22).

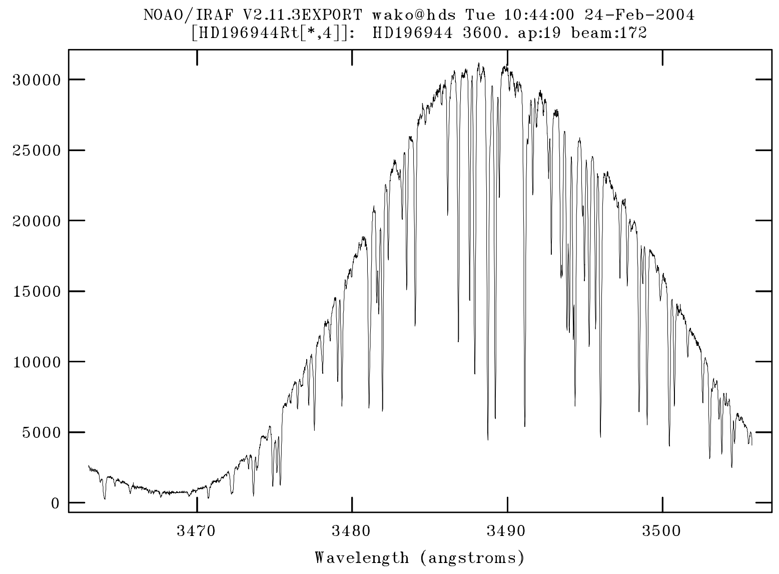


Figure 17: An example of wavelength-calibrated spectra. The count at the edge of the spectrum is quite low.

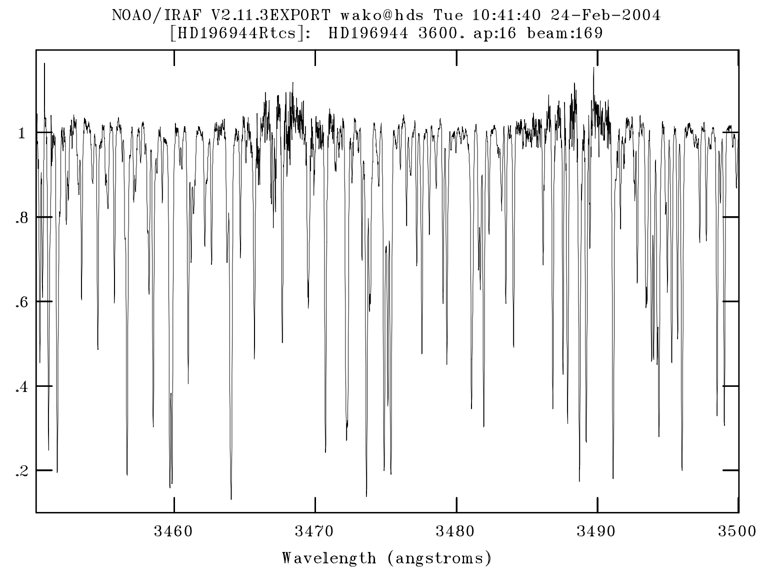


Figure 18: A combined spectra by applying a simple average of normalized spectra. The quality of the data is significantly low at the wavelengths corresponding to the edges of each spectra.

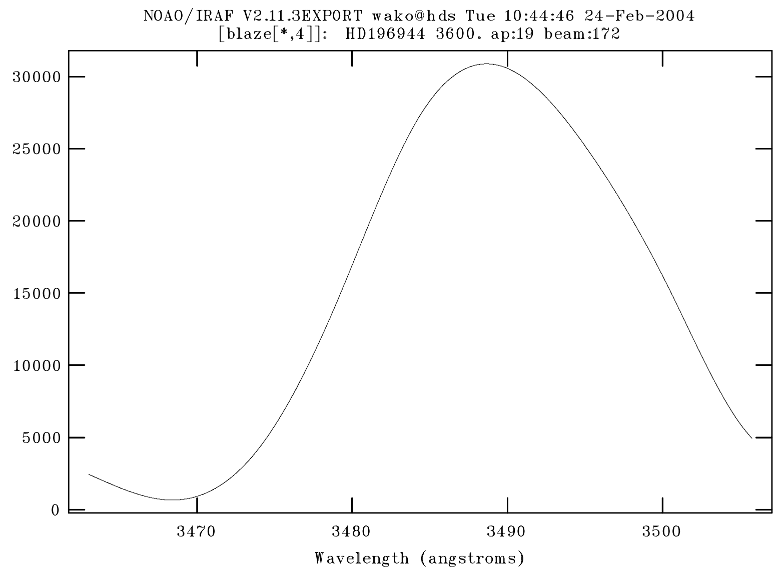


Figure 19: Spectra of continuum.

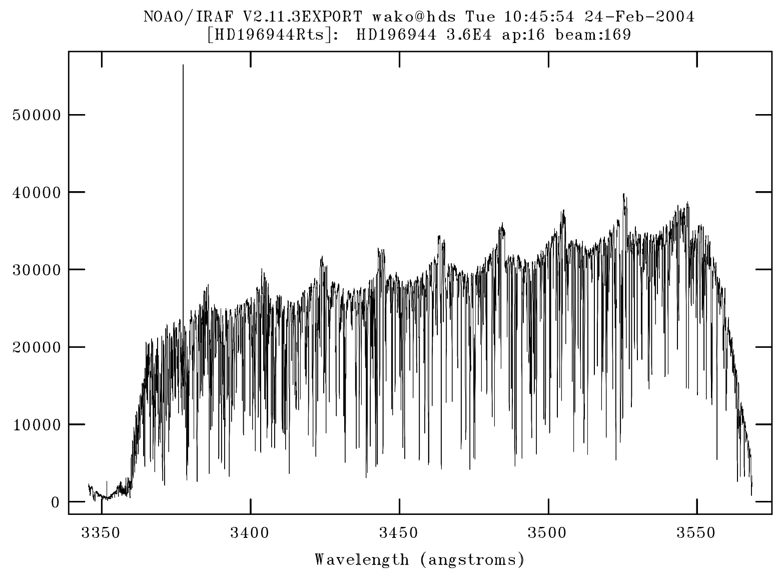


Figure 20: A spectrum combined by simple sum

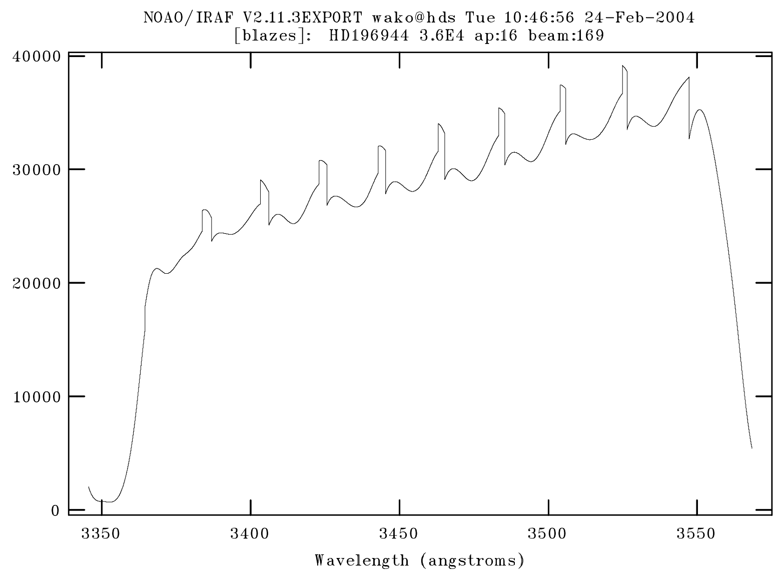


Figure 21: The same as Figure 20, but for the continuum spectrum.

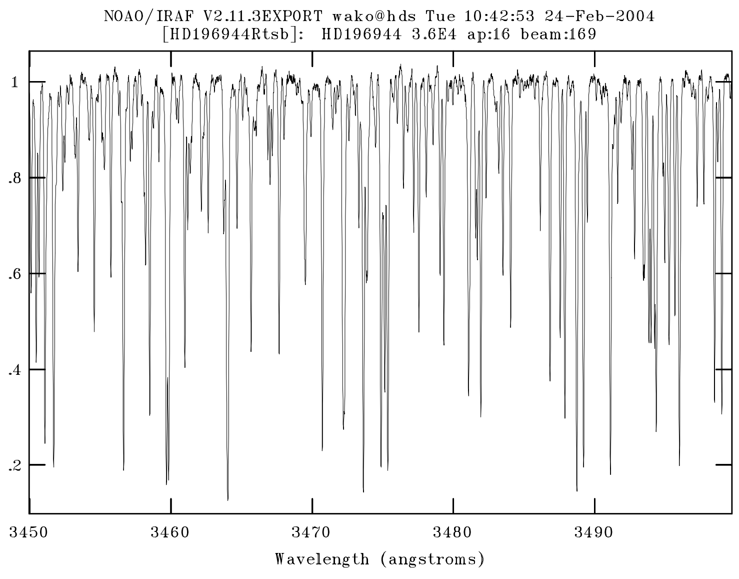


Figure 22: The spectrum obtained by dividing the object spectrum (Figure 20) by the continuum spectrum (Figure 21)

14 Useful tasks for analyses of obtained spectra

Here some useful tasks to analyze the obtained spectra are briefly introduced. Please see help or IRAF manual for details.

14.1 Statistics

Statistics of data (e.g. average, standard deviation) are obtained with the task imstatistics:

```
cl> imstat object
#              IMAGE      NPIX      MEAN    STDDEV       MIN       MAX
             OBJECT   92822    0.8684     10.98    -2594.     219.1
```

The range to which the task applied is given for the input data name like *object[1000:3000,*]*.

14.2 Measurements of spectral lines

The task splot may be used to measure equivalent widths, FWHM of lines, line positions etc. Gaussian fitting is available for these purposes. See the help of this task for details.

14.3 Doppler correction for observers motion

The correction from the apparent radial velocity to the helio-centric radial velocity (or others) is calculated using the task rvcorrect in the package noao.astutil. Before that, information of the observatory is given by changing parameters for observatory in the package noao as follows:

```
                                   I R A F
                    Image Reduction and Analysis Facility
PACKAGE = noao
   TASK = observatory

command =                  set  Command (set|list|images)
obsid   =              obspars  Observatory to set, list, or image default
images  =                       List of images
(verbose=                   no) Verbose output?

(observa=              subaru) Observatory identification
(name   =              Subaru) Observatory name
(longitu=      155.47611111111) Observatory longitude (degrees)
(latitud=      19.825555555556) Observatory latitude (degrees)
(altitud=                4139.) Observatory altitude (meters)
(timezon=                  10.) Observatory time zone
override=                       Observatory identification
(mode   =                   ql)
```

Below is an example of the parameters for rvcorrevt, where the apparent radial velocity is given to vobs. The parameter observa is set to obspars, then the information given by observatory is applied.

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

(files  =                     ) List of files containing observation data
(images =                     ) List of images containing observation data
(header =                  yes) Print header?
(input  =                   no) Print input data?
(imupdat=                   no) Update image header with corrections?
```

```
(epoch  =               2000.) Epoch of observation coordinates (years)
(observa=             obspars) Observatory
(vsun   =                 20.) Solar velocity (km/s)
(ra_vsun=                 18.) Right ascension of solar velocity (hours)
(dec_vsu=                 16.) Declination of solar velocity (degrees)
(epoch_v=               2000.) Epoch of solar coordinates (years)

(year   =                1996) Year of observation
(month  =                   1) Month of observation (1-12)
(day    =                  18) Day of observation
(ut     =              18.969) UT of observation (hours)
(ra     =              8.7278) Right ascension of observation (hours)
(dec    =             -7.2336) Declination of observation (degrees)
(vobs   =               12.34) Observed radial velocity
(hjd    =     2450101.2953037) Helocentric Julian Day (output)
(vhelio =     20.483996801402) Helocentric radial velocity (km/s) (output)
(vlsr   =     5.3777605335745) Local standard or rest radial velocity (km/s) (o
(mode   =                  ql)
```

Followings is an example of results, where the value “VHELIO” and others are listed.

```
# RVCORRECT: Observatory parameters for OAO
#       latitude = 34.5738889
#       longitude = -133.5963889
#       altitude = 372.
##   HJD          VOBS   VHELIO     VLSR   VDIURNAL   VLUNAR  VANNUAL   VSOLAR
2450101.29530    12.34    20.48     5.38     -0.268    0.007    8.404  -15.106
```

14.4 Writing spectral data to ASCII data

The task wspectxt in the package onedspec is used to write the FITS spectral data to an ASCII file.

```
ec> oned
      aidpars@       dopcor         reidentify     sensfunc       specplot
      autoidentify   fitprofs       rspectext      setairmass     specshift
      bplot          identify       sapertures     setjd          splot
      calibrate      lcalib         sarith         sfit           standard
      continuum      mkspec         sbands         sflip          telluric
      deredden       names          scombine       sinterp        wspectext
      dispcor        ndprep         scoords        skytweak
      disptrans      refspectra     scopy          slist
on> e
wspectext H4998bfs_ecwtcs HD140283.txt
```

The spectral data (wavelength and count) are listed with the header unit of the FITS data.

```
BITPIX  =                    8  /  8-bit ASCII characters
NAXIS   =                    1  /  Number of Image Dimensions
NAXIS1  =               110420  /  Length of axis
ORIGIN  = 'NOAO-IRAF: WTEXTIMAGE'  /
IRAF-MAX=                   0.  /  Max image pixel (out of date)
IRAF-MIN=                   0.  /  Min image pixel (out of date)
IRAF-B/P=                   32  /  Image bits per pixel
IRAFTYPE= 'REAL FLOATING     '  /  Image datatype
```

```
OBJECT  = ' HD140283          '  /
FILENAME= 'H4998BFS_ECWTCS    '  /  IRAF filename
....

4110.51308358849  0.9839716
4110.52538877657  0.990428
4110.53769396465  0.9826592
4110.54999915273  0.978662
4110.56230434081  0.9812679
4110.57460952889  0.9803735
4110.58691471697  0.974153
4110.59921990505  0.9779771
4110.61152509312  0.9771149
4110.6238302812  0.9719001
4110.63613546928  0.9783365
4110.64844065736  0.9836422

....
```

15 Appendix

15.1 Some special attentions

Some special attentions for data reduction with IRAF are given in order to avoid frequently found troubles.

- IRAF is started by cl commant *in the directory in which login.cl file exists.*
- *Do not delete the window ("irafterm") in which spectra and other images are shown* using the "close" button of the window. If deleted, the IRAF must be re-started after killing the previous processes.
- HDS has two CCDs to cover longer and shorter wavelengths. As a result, two separate FITS files are produced by one exposure. The odd and even numbers in the file names correspond to the CCDs covering longer and shorter wavelengths, respectively. The data reduction procedures are applied separately to each file.
- implot and splot: Cross-cut images of the two dimensional data are usually seen by implot, while splot is useful for plotting spectra. The data ranges displayed are determined by different methods in these tasks (see below).
- The directory database: The detailed information for the aperture determination by apall and the wavelength calibration by ecident is recorded in "apXXXX" and "ecXXXX" files, respectively, in the directory database. When the reference data for apall and ecident are copied to other directory, the corresponding files in the database directory should also be copied to the corresponding directory.

15.2 Useful tasks and functions

- Task history

  The tasks executed previously are selected and modified by e.

- @ Files

  When a large number of files are dealt with by the same task with the same parameter setting, the names of input and output files can be given in text files, in which one file name is given in each line. The files are referred to with @ at the head. For instance, when the object files are divided by a flat frame (e.g., flat.fits), the names of object files may be given in the file "input_list" like

  ```
  object1
  object2
  object3
  ...
  ```

The names of output files are also given in the file “output_list” like

```
object1f
object2f
object3f
...
```

The process to divide the object frames by the flat is carried out as follows;

```
imarith @input_list / flat @output_list
```

- splot

  Spectral data are plotted by splot. The spectrum of the next or previous echelle order is displayed by inputting “shift + 0” or “shift + 9”, that is, “(” or “)”, respectively.

  The display ranges are changed as follows: one may shift to the so-called ’window mode’ by inputting ’w’ on the display. In this mode the key ’j’ trims the left hand side of the data from the position of the cursor. Similarly, the keys ’k’, ’t’, and ’b’ trim the right hand side, upper part, and the lower part of the data, respectively, from the position of the cursor. The key ’a’ shows the whole range of the data again. (The window mode is applied to only one key. So one use the above keys with ’w’, e.g. ’w’+’j’, ’w+t’.)

  The plot is printed by inputting “:.snap” on the display. That is saved in an eps file by “:.snap epsf”.

- implot

  This is useful to see a cross-cut image of a two-dimensional CCD data. The display ranges are changed by inputting, for example, “:x 1000 2000” or “:y 0 5000”.