Chapter 6

Long-Slit and 1D Spectra

6.1 Introduction

This chapter describes the long-slit reduction package in a general way. One-dimensional spectra are considered to be a particular case of long-slit spectra and are also handled by the package. More instrument-specific operating instructions may be given in appendices to this MIDAS manual or in the relevant ESO Instrument Handbooks.

The package provides about 50 basic commands to perform the calibration and to display the results, defined in the context `LONG`. A tutorial procedure, `TUTORIAL/LONG`, illustrates how to operate the package. The context `SPEC` is a low-level context including general utility commands required by the different spectroscopy packages `ECHELLE`, `IRSPEC` and `LONG`. These commands are refered to and summarized in this chapter. The graphical user interface `XLong` is a MOTIF-based interface providing an easy access to the commands of the package. This interface is described in the Appendix G. Standard spectral analysis can be performed with the graphical user interface `XAlice` (command `CREATE/GUI ALICE`). The use of general MIDAS commands for spectral analysis is also discussed in this chapter.

The main characteristics of the `LONG` context are derived from its modularity, that allows to perform, in a first step, the image cosmetics and photometric corrections – which are detector dependent – and then, to correct for the geometric distortions. The method gives particular emphasis to an accurate wavelength calibration and correction of all distortions along the whole slit, so that the spatial structure of extended objects can be examined in detail.

Although the method is applicable to different instrumental configurations, we assume, in the following description, that the generic instrument consists of a spectrograph coupled to a CCD detector. In the current version it is assumed that the CCD frame is oriented with the rows in the dispersion direction and the columns along the slit.

Note

This chapter only provides a synopsis of the commands needed for the reduction of long-slit. It is important to realise that it can neither substitute the HELP *information available for each command nor be exhaustive, especially not with regard to the usage of general utilities such as the MIDAS Table System, the*

AGL Graphics package, etc. The Appendix G provides a practical approach to the reduction of long-slit spectra.

6.2 Photometric Corrections

6.2.1 Detector Non-Linearity

This section outlines the transformation from raw to radiometrically corrected data. For the purpose of this simple description we make a distinction between linear and non-linear detectors. Data acquired with detectors of the latter category require, at most, bias and dark signal subtraction plus division by a flat field exposure.

Most real detectors have nonlinear Intensity Transfer Functions (ITF), *e.g.* photographic plates, the effects of the dead time at high count rates in photon counting systems and the low light level nonlinearity of Image Dissector Scanners (see M. Rosa, *The Messenger*, **39**, 15, 1985). If the ITF is known analytically, the command `COMPUTE/IMAGE` will be sufficient for the correction of the raw data. For example, the paired pulse overlap (dead-time) correction of photoelectric equipment could be corrected for by `COMPUTE/IMA OUT = IN/(1+TAU*IN)`, where `TAU` is the known time constant of the counting electronics an `IN` must be in units of a count rate rather than total counts. If the ITF is defined in tabular form, the command `ITF/IMAGE` can be used to obtain the ITF correction for each image element (pixel value) by interpolation in an ITF table; this command assumes a uniform transfer function over the image field.

CCDs are generally more nearly linear than are most other detectors used in astronomy. However, especially in particular pixels or regions, CCDs are clearly non-linear and/or suffer deviating signal zero points. Procedures which may be useful for the treatment of such deficiencies are (partly) described in Appendix B.

Problems related to background estimation and more sophisticated flat-field corrections generally are very instrument dependent. Therefore, it is not possible to give one standard recipe here; check the various instrumental appendices for more specific advice.

6.2.2 Removing Cosmic Ray Hits

If two or more spectra have been taken under the same conditions, a very efficient way of removing particle hits from the raw data is to replace pixel values with large deviations from other observations with a local estimator, as done in the command `COMBINE/LONG`.

If multiple images are not available, cosmic ray hits have to be filtered out by a different method. The main requirement is that the image is **not** changed where there are no hits, especially on the area covered by the object under study. This can for instance be done with the command:

```
FILTER/MEDIAN inframe outframe 0,3,0.3 NR subframe
```

where `subframe` defines the region to filter. But you may wish to try other parameters and parameter values. This step is done twice to remove the hits on the sky on each side of the object.

Those cosmic ray hits in the area surrounding the object spectrum, which are particularly disturbing, were removed one by one using `MODIFY/AREA ? ? 1`, and working with the cursor on a zoomed display. Particular care must be exercised here, in order to modify only the few pixels affected by cosmic rays. For point sources and extended sources with very smoothly varying spatial profiles, `FILTER/MEDIAN` may also be tried. However, in order to preserve the instrumental profile the filter width along the dispersion axis *must* be set to 0.

Another possibility is to use the command `FILTER/COSMIC`. The algorithm detects hot pixels from a comparison of the pixel value with the ones of the neighbouring pixels. It rejects every 'feature' that is more strongly peaked than the point spread function.

Regardless of the method used, it is necessary to check the performance of the filter by careful inspection of the difference between raw and filtered image which can be computed as `COMPUTE/IMA TEST = RAW-FILTERED`.

6.2.3 Bias and Dark Subtraction

The dark signal is exposure time dependent. The one appropriate for a given observation has to be derived by interpolation between dark frames of different exposure times. Note that long dark exposures first have to be cleaned of particle hits (see above). Bias and dark signal will usually be determined and subtracted in the same step.

In a CCD with good cosmetic properties, bias and dark signal are the same for all pixels. Then, only a number (obtained from, *e.g.*, `STATISTICS/IMAGE`) should be subtracted in order to prevent the noise in the dark frames to propagate into the reduced spectra. If, because of local variations, this is not possible, some suitable smoothing should still be attempted.

6.2.4 Flat-Fielding

The lamps used for flat fields have an uneven spectral emissivity. Combined with the uneven spectral sensitivity of the spectrograph and detector, this results in flat fields which usually have very different intensities in different spectral regions. Therefore a direct flat-fielding, *i.e.*, division by the original dark subtracted flat-field, produces spectra which are artificially enhanced in some parts and depressed in others. In principle, this should not be a problem because the instrumental response curve should include these variations and permit them to be corrected. However, the response curve is established by integration over spectral intervals of small but finite width. At this stage, strong gradients obviously introduce severe problems. Also the wish, at a later stage to evaluate the statistical significance of features argues strongly against distorting the signal scale in a basically uncontrolled way.

Therefore, it is better first to remove the low spatial frequencies along the dispersion axis (but not perpendicular to it!) from the flat-field, using the command `NORMALIZE/FLAT`. This command first averages the original image along the slit (assumed to be along the Y-axis) and fits the resulting one-dimensional image by a polynomial of specified degree. Then the fitted polynomial grows to a two-dimensional image and divides the original flat-field by this image to obtain a "normalized" flat-field.

In some cases, *e.g.*, EFOSC in its B300 mode which gives a very low intensity flat-field at the blue end, the polynomial fit is not satisfactory and it is advisable to do the sequence manually. Instead of fitting a polynomial one could fit a spline using the command `INTERPOLATE/II` or `NORMALIZE/SPECTRUM`. The latter belongs to the low-level context `SPEC` and is interactively operated on a graphical display of the spectrum.

6.3 Geometric Correction

An accurate two dimensional geometric correction over the entire frame is an important part of the whole reduction process. It strongly affects velocity measurements along the slit and is very critical even for point sources if narrow night sky lines shall be properly subtracted. If the spectrum contains only a point source the user may prefer to extract it from the 2D image (`EXTRACT/LONG`) and then proceed with the normal one-dimensional spectral reduction.

On the other hand, if the spatial information along the slit is of no interest and night sky lines do not have to be corrected for, much time can be saved by properly averaging the signal along the slit (`EXTRACT/AVERAGE`).

The full geometrical correction of long-slit spectra is a transformation from the raw pixel coordinates (X, Y) to the sampling space (λ, s), where λ is the wavelength and s is an angular coordinate in the sky along the slit. Logically, it often makes sense to separate the geometrical transformation into two orthogonal components: the dispersion relation $\lambda = \lambda(X, Y)$, which can be obtained from an arc spectrum with a fully illuminated slit and the distortion along the slit $s = s(X, Y)$, which can be derived from the continuum spectra of point sources. Practically, these two transformations should, whenever possible, be combined into one before rectifying the data, because this saves one non-linear rebinning step, each of which necessarily leading to some loss of information.

As far as the reduction is concerned, the easiest way to achieve this is to observe the comparison lamp used for wavelength calibration through a a pin-hole mask. (Of course, this method can account only for instrumental distortions, not for differential atmospheric refraction, *etc.*)

In the presence of strong distortions along the slit, a 2-D modeling must be attempted and the command `RECTIFY/LONG` could be considered. If distortions along the slit can be neglected or suitably corrected for in a separate step, a 2-D modeling of the dispersion relation is still a valid approach. However, a separate reduction of detector row after detector row along the slit, then, often is a superior alternative. A broad overview of the major options is given in the next subsections; **a detailed comparison and a Cookbook for the usage of the two methods are provided in Appendix G.**

6.3.1 Detecting and Identifying Arc Lines

For optimum results, it is important to use a comparison spectrum with as high a signal-to-noise ratio of the lines as possible. It is therefore advisible to flat-field also the arc spectrum in order to correct for small-scale fluctuations. Another good idea is to filter the frame along the slit using the command FILTER/MEDIAN with a rectangular filter window of one pixel in the dispersion direction and several pixels in the perpendicular direction. For the row-by-row method one could also consider smoothing the spectra along the slit axis which would provide for a stronger coupling between neighbouring rows and thereby yield a solution which is intermediate between the extremes presented by the two pure methods.

- SEARCH/LONG: Finds the positions of reference lines in world coordinates. Positions are by default estimated by the center of fitted Gaussians. Other centering methods are available (Gravity, Maximum) but could result in systematic position errors (See Hensberge & Verschueren, Messenger, **58**, 51). The results are stored in a table called line.tbl. The parameter YWIND corresponds the half-size of the row averaging window applied to adjacent rows of the spectrum for an improvement of the signal to noise ratio. The parameter YSTEP controls the step in rows between successive arc line detections. The value YSTEP=1 corresponds to the default row-by-row method and larger values can be used to get a quicker calibration. The algorithm detects lines whose strength exceeds a certain threshold (parameter THRES) above the local background. The local background results from a median estimate performed on a sliding window which size is controlled by the parameter WIDTH. The command PLOT/SEARCH allows to check the results at this stage. Note that for a two-dimensional spectrum, both options 1D and 2D can be used (See HELP PLOT/SEARCH).
- The command IDENTIFY/LONG allows an initial interactive identification, by wavelength, of some of the detected lines. Spectral line atlas are provided in the instrument operating manuals. The command PLOT/IDENT visualizes the interactive identifications.

6.3.2 Getting the Dispersion Solution

The command CALIBRATE/LONG approximates the dispersion relation for each searched row of the arc spectrum. The algorithm can be activated in different modes, controlled by the parameter WLCMTD:

- The mode IDENT must be used if the lines have been identified interactively using IDENTIFY/LONG.
- The mode GUESS allows a previously saved session to be used (command SAVE/LONG) for the determination of the dispersion relation. The two observation sets must in principle correspond to the same instrumental set-up. Limited shifts (up to 5 pixels) are taken into account by a cross-correlation algorithm. The name of the reference session must be indicated by the parameter GUESS.
- It is also noteworthy to indicate the presence of a mode LINEAR introduced in the package for the purpose of on-line calibration. This mode is still **in evaluation phase** and allows the results of the command ESTIMATE/DISPERSION to be taken into account in the calibration process.

The command `CALIBRATE/LONG` provides the following results:

- The coefficients of the dispersion relation for each searched row of the two-dimensional spectrum are computed as a series of polynomials $\lambda = p_y(x)$. The results are written in the table `coerbr.tbl`.
- The starting, final and average step wavelength of the spectrum are estimated and written in the keywords `REBSTRT, REBEND, REBSTP` used by the commands `REBIN/LONG` and `RECTIFY/LONG`.
- A two-dimensional dispersion relation of the form $\lambda = \lambda(X, Y)$ is estimated if the parameter `TWODOPT` is set to `YES`. This bivariate dispersion relation is necessary to use the command `RECTIFY/LONG`. The resulting dispersion coefficients are stored in the keyword `KEYLONGD`.

The command `CALIBRATE/TWICE` performs a two-pass determination of the dispersion relation. In a first pass, the lines are identified by a standard `CALIBRATE/LONG`. Only the lines which have consistently identified at all rows are selected for the second pass, which then performs a new calibration on a stable set of arc lines. If after selection a good spectral coverage of the arc spectrum is secured, this method provides very stable estimates of the dispersion relation.

The command `PLOT/CALIBRATE` visualizes the lines found by the calibration process. The dispersion curve and the lines that were used to determine it are presented by `PLOT/DELTA`. Residuals to the dispersion curve are plotted by `PLOT/RESIDUAL`. For two-dimensional spectra, the command `PLOT/DISTORTION` can be used to check the stability of the dispersion relation along the slit.

The iterative identification loop consists of estimating the wavelength of all lines in the arc spectrum and associate them to laboratory wavelengths to refine the estimates of the dispersion relation. The line identification criterion will associate a computed wavelength λ_c to the nearest catalog wavelength λ_{cat} if the residual:

$$\delta\lambda = |\lambda_c - \lambda_{cat}|$$

is small compared to the distance of the next neighbours in both the arc spectrum and the catalog:

$$\delta\lambda < min(\delta\lambda_{cat}, \delta\lambda_c) * \alpha$$

where $\delta\lambda_{cat}$ is the distance to the next neighbour in the line catalog, $\delta\lambda_c$ the distance to the next neighbour in the arc spectrum and *alpha* the tolerance parameter. Optimal values of α are in the range $0 < \alpha < 0.5$. The tolerance value is controlled by the parameter `ALPHA`.

Lines are identified in a first pass without consideration of the rms of the residual values by an iterative loop controlled by the parameter `WLCNITER`. The residuals for each line are then checked in order to reject outliers which residual is above the value specified by the final tolerance parameter `TOL`. The degree of the polynomials is controlled by the parameter `DCX` and the iterative loop is stopped if residuals are found to be larger than `MAXDEV`.

6.3.3 Distortion Along the Slit

The distortion along the slit $s = s(X, Y)$ can be modelled using an image containing one or several spectra of (ideally: point-) sources with well defined continuum. The command `SEARCH/LONG` can be used to generate a table with the positions of the spectra at several wavelengths. (Contrary to the general conventions used throughout this chapter, for this particular application the dispersion direction must be parallel to the 'Y'-axis!) The distortion is then modelled by a two-dimensional polynomial fitted to these positions (using, *e.g.*, `REGRESSION/TABLE`). If the resulting coefficients are stored in the keyword `COEFY*, (*=I,R,D)` and combined with suitable (if necessary: dummy) coefficients for the dispersion resolution in the keyword `KEYLONG*, (*=I,R,D)`, the command `RECTIFY/LONG` can be applied.

Note that these steps are not implemented as a convenient-to-use high-level command procedure.

6.3.4 Resampling the Data

In the standard row-by-row option, the dispersion coefficients are kept in the table (`coerbr.tbl`). The rebinning to constant step in wavelength is accomplished, row by row, with the command `REBIN/LONG`.

If the 2-D option described above for the solution of the dispersion relation is followed (`TWODOPT=YES`), the polynomial coefficients in both directions are stored in the keywords `KEYLONGD` and `COEFYD`, respectively. This information is then used by the command `RECTIFY/LONG` to resample the image in the (λ, s) space.

Data resampling can be avoided by the command `APPLY/DISPERSION` which generates a table with the columns `:WAVE` and `:FLUX`, each row corresponding to the central wavelength and flux of a CCD detector pixel.

6.4 Sky Subtraction

As stated before, sky subtraction can be a very critical step in the reduction of long slit spectra with the main problem being the curvature of the lines along the slit (due to both misalignment of CCD and spectrum and residual optical distortions).

Although one may intuitively tend to subtract the sky spectrum still in pixel space in order to avoid the problems inherent to non-linear rebinning, experience shows that a proper wavelength calibration can remove the curvature of the sky lines to a high degree of accuracy (one should aim for ± 0.1 pixels rms).

The command `SKYFIT/LONG` makes a polynomial fit to the sky in two windows above and below the object spectrum, either with one single function for the full length of the spectrum (`mode = 0`) or with one function for every column (`mode = 1`). `Mode 0` is recommended for the spectral regions where the sky is faint, because usually there is not enough signal to achieve a meaningful fit for every column. The same is not true for the bright sky lines, where `mode 1` helps dealing with the variable line width and with residual line curvature.

For this reason, it often is best to prepare two sky spectra first: `sky0` fitted obtained in `mode 0` and with a polynomial of degree 0-2 fitted to windows with "clear" sky, and `sky1` derived with `mode 1` and multiple polynomials of degree 2-4 on windows going as close as possible to the object. The final sky spectrum, (`sky`), to be subtracted from the object is obtained from a combination of the two sky spectra and essentially consists of `sky0` which only for the bright sky lines has been replaced with `sky1`. Such a combination can be prepared by mean of the command `REPLACE/IMAGE` (e.g., `REPLACE/IMA sky0 sky 120.,>=sky1`).

6.5 Flux Calibration

The commands `EXTINCT/LONG` followed by `RESPONSE/FILTER` or by `INTEGRATE/LONG` and `RESPONSE/LONG` permit a one-dimensional response curve `response.bdf` to be obtained from the extracted (*e.g.*, via `EXTRACT/LONG` or `EXTRACT/AVERAGE`) and wavelength calibrated spectrum of a standard star.

The command `RESPONSE/FILTER` divides the standard star spectrum by the flux table values and uses median and smooth filterings (parameters `FILTMED` and `FILTSMO`) to smooth the instrumental response function.

The command `INTEGRATE/LONG` also performs a division of the standard star spectrum by the flux table but generates an table of response values at a wavelength step equal to the one of the flux table. The command `RESPONSE/LONG` interpolates these values using a polynomial or spline interpolation scheme.

This response curve can be applied to a one- or two-dimensional extracted, wavelength calibrated and extinction corrected (`EXTINCTION/LONG`) spectrum by the command `CALIBRATE/FLUX`.

Verification commands include `PLOT/FLUX` to visualize the standard star reference flux table and `PLOT/RESPONSE` to vizualize the final instrumental response function.

6.5.1 Flux Calibration and Extinction Correction

To calibrate the chromatic response, observations of a standard star (preferably more than one) are needed, for which the absolute fluxes are known. The spectral response curve of the instrument can then be determined with the command `RESPONSE/LONG`, and absolute fluxes for the objects of interest are obtained with `CALIBRATE/FLUX`. The extinction correction must previously be done in a separate step with the command `EXTINCTION/LONG`.

An alternative procedure, if no standard star spectrum is available, is the normalisation of the continuum as described below.

6.5.2 Airmass Calculation

The commands in the previous Section require the airmass as input parameter. Some instrument/telescope combinations provide raw data files with the proper values of right ascension, declination, siderial time, geographical latitude, duration of measurement and eventually even "mean" airmass. In most cases it will however be necessary to compute an appropriate airmass using the `COMPUTE/AIRMASS`. Refer to `HELP COMPUTE/AIRMASS` for the details of the image descriptors which are needed. Otherwise, the required information must be provided by the user on the command line. It is important to keep in mind that "mean airmass" and "mean atmospheric extinction correction" are different from the values at mid-exposure, especially for larger zenith distances. This is so because the airmass depends non-linearly on zenith distance ($\sec z$) and extinction corrections depend non-linearly on airmass ($10^{-(0.4 \times \mathrm{airm} \times \mathrm{ELAW(mag)})}$). For reasonable combinations of exposure time and zenith distance, the weighted mean airmass supplied by `COMPUTE/AIRMASS` should be appropriate.

6.6 Spectral Analysis

6.6.1 Rebinning and Interpolation

Raw spectra are usually not sampled at constant wavelength or frequency steps, and sometimes even with gaps in between the bins. At some stage the independent variable will have to be converted into linear or non-linear functions of wavelength or frequency units and gaps will have to be filled with interpolated values. Frequent cases are: wavelength calibration, redshift correction, $\log(F_\lambda)$ versus $\log(\lambda)$ presentation, and the comparison of narrow-band filter spectrophotometry with scanner data. Related commands are `REBIN/LONG`, already described, `REBIN/LINEAR` for linear rebinning, i.e. scale and offset change, `REBIN/II (IT,TI,TT)` to do nonlinear rebin conserving flux (see below) and `CONVERT/TABLE` to interpolate table data into image data.

Note that in our implementation we make a conceptual difference between straightforward interpolation and rebinning. `REBIN/II (IT, TI, TT)` redistributes intensity from one sampling domain into another. There is no interpolation across undefined gaps and no extrapolation at the extremities of the input data. If you need these, you will have to manipulate the input data first (generating non-existent information !). `REBIN/II (IT, TI, TT)` conserves flux locally and globally.

6.6.2 Normalization and Fitting

A frequently used procedure, alternative to the correction for the chromatic response, is to normalise the continuum to unity by dividing the observed spectrum by a smooth approximation of its continuum. This approximation can be obtained either interactively with the graphic cursor, or from a table (command `NORMALIZE/SPECTRUM`) or by dividing the raw data by itself after filtering or smoothing. Median filtering and running average algorithms are well suited for this purpose (command `FILTER`). A spline fit can be made to the points defined interactively as well as to the filtered data (command `CONVERT/TABLE`). The MIDAS Fitting Package permits to go further and perform a more advanced modelling of the continuum.

6.6.3 Convolution and Deconvolution

Estimating the instrumental point spread function and correcting the observed spectra for the instrumental profile by deconvolution is a delicate subject. Here, the available tools are only briefly mentioned. The point spread function (PSF) can be estimated from the observations (*e.g.*, from the profile of suitable lines in the comparison, night sky, or interstellar medium spectrum), possibly using the fitting package if a noise-free, analytical approximation is desired. Once this is done, the command `DECONVOLVE/IMAGE` can be applied to deconvolve the observed data. Conversely, the convolution of, *e.g.*, a synthetic spectrum with the PSF can be done with the command `CONVOLVE`.

6.6.4 Other Useful Commands

Interactive continuum determination can be done with the command `NORMALIZE/SPECTRUM` as mentioned above. There are commands to measure the position of spectral features. `CENTER/MOMENT` determines positions from moments whereas `CENTER/GAUSS` fits a Gaussian profile; for very sparsely sampled point spread functions, `CENTER/UGAUSS` is preferred. Optionally, all positions can be stored in a working table file. Measurements of line strengths and equivalent widths can be obtained with the command `INTEGRATE/LINE`. Unwanted spectral features (*e.g.*, spikes due to particle events) can be interactively removed with `MODIFY/GCURSOR`. The commands `GET/GCURSOR` and `CONVERT/TABLE` provide means to generate artificial images from cursor positions.

The fitting package permits the determination of line parameters and additional modelling of the data.

6.7 Auxiliary Data

Wavelength calibration and absolute flux determination procedures require some auxiliary data. Some tables are provided by the system, but the user can modify or include new information using the available table commands (Vol. A, Chapter 5). In addition to columns of interest to the user, user-supplied tables *must* have the columns and column labels required by the various MIDAS commands they are to be used with.

For the purpose of the reduction of spectral data, there are three basic table structures:

a) Line identification tables, used in the wavelength calibration step. One column must contain the laboratory (if the reference frame is to be used) wavelengths in the units desired for the calibrated spectrum. A sample table with comparison lines of the spectrum He-Ar is available in `MID_ARC:hear.tbl` it contains lines in the range from 3600 Å to 9300 Å and is suitable for data with dispersions between about 5 and 10 Å/mm.

b) Flux tables, used for flux calibration and rectification of spectra. These tables contain at least three columns defining for each entry central wavelength, bin width and flux, with labels `:WAVE`, `:BIN_W`, `:FLUX_W`. When composing your own tables, take care that the wavelength unit is the same for all three quantities and agrees with the one used for the wavelength calibration. Some sample flux tables are available in the directory `MID_STANDARD`. If you are still preparing your observations, note that the data available for the various stars is very inhomogeneous whereas the quality of the calibrations depends very sensitively on the number and spacing of entries within the spectral range to be observed.

c) Sample atmospheric and interstellar extinction laws are contained in directory `MID_EXTINCTION`. All interstellar laws are normalised to $A_v/E(B-V) = 3.1$ at 5500 Å, and interpolated and rebinned to a constant step in wavelength (10 Å or nm). Note that the wavelength coverage is very different for various data sets.

Filename	Ref.	Filename	Ref.	Filename	Ref.
BD2015	(2)	GD190	(3)	HR4963	(4)
HR5573	(4)	HR6710	(4)	HR8414	(4)
HR8518	(4)	HR8747	(4)	HZ14	(3)
HZ4	(3)	HZ7	(3)	L745X4	(3)
L870X2	(3)	L930X8	(3)	L970X3	(3)
LB227	(3)	LDS235	(3)	LDS749	(3)
LT3218	(1)	LT7987	(1)	W485A	(3)

(1) Stone, Baldwin, 1983, *M.N.R.A.S.*, **204**, 347
(2) Stone, 1977, *Ap. J.*, **218**, 767
(3) Oke, 1974, *Ap. J. Suppl.*, **27**, 21
(4) Breger, 1976, *Ap. J. Suppl.*, **32**, 7
Flux units are 10^{-16}ergs/s/cm^2/ Å for refs 1, 2 and 3
and 10^{-13}ergs/s/cm^2/ Å for ref 4

Table 6.1: Standard Stars for Absolute Flux Calibration in system area MID_STANDARD.

Filename	Description	column number	Ref.
INSTEXAN	Interstellar: Galaxy(Å)	2	(1)
INSTEXAN	Interstellar: LMC (Å)	3	(2)
INSTEXAN	Interstellar: SMC (Å)	4	(3)
INSTEXAN	Interstellar: LMC (Å)	5	(4)
INSTEXAN	Interstellar: Galaxy fit (Å)	6	(5)
INSTEXAN	Interstellar: Galaxy fit (Å)	7	(6)
INSTEXAN	Interstellar: LMC fit (Å)	8	(6)
ATMOEXAN	Atmospheric (Å)	2	(7)
INSTEXNM	Interstellar (nm) †	-	(1-6)
ATMOEXNM	Atmospheric (nm) ‡	2	(7)

(1) Savage, Mathis, 1979, *An.Rev.Astr.Ap.*, **17**, 73
(2) Nandy *et al*, 1981, *MNRAS*, **196**, 955
(3) Prevot *et al*, 1984, *Astron.Astrophys.*, **132**, 389
(4) Koornneef, Code, 1981, *Ap. J.*, **247**, 860
(5) Seaton, 1979, *M.N.R.A.S.*, **187**, 73P
(6) Howarth, 1983, *M.N.R.A.S.*, **203**, 301
(7) Tüg, 1977, *Messenger*, **11**
†The same as INSTEXAN but wavelengths in nanometers
‡The same as ATMOEXNM but wavelengths in nanometers

Table 6.2: Extinction Tables in directory MID_EXTINCTION

6.8 Command Summary

This section summarizes the commands of the contexts LONG and SPEC as well as general MIDAS commands that can be used for spectral analysis. These latter commands are described in Vol. A, Chapter 5 (MIDAS Tables) and Chapter 8 (Fitting of Data).

- Context LONG	
APPLY/DISPERSION	in out [y] [coef]
BATCH/LONG	
CALIBRATE/FLUX	in out [resp]
CALIBRATE/LONG	[tol] [deg] [mtd] [guess]
CALIBRATE/TWICE	
CLEAN/LONG	
COMBINE/LONG	cat out [mtd]
EDIT/FLUX	[resp]
ERASE/LONG	
ESTIMATE/DISPERS	wdisp wcent [ystart] [line] [cat]
EXTINCTION/LONG	in out [scale] [table] [col]
EXTRACT/AVERAGE	in out [obj] [sky] [mtd]
EXTRACT/LONG	in out [sky] [obj] [order,niter] [ron,g,sigma]
GCOORD/LONG	[number] [outtab]
GRAPH/LONG	[size] [position] [id]
HELP/LONG	[keyword]
IDENT/LONG	[wlc] [ystart] [lintab] [tol]
INITIALIZE/LONG	[session]
INTEGRATE/LONG	std [flux] [resp]
LINADD/LONG	in w,bin [y] [mtd] [line] [out]
LOAD/LONG	image [scale_x,[scale_y]]
MAKE/DISPLAY	
NORMALIZE/FLAT	in out [bias] [deg] [fit] [visu]
PLOT/CALIBRATE	[mode]
PLOT/DELTA	[mode]
PLOT/DISTORTION	wave [delta] [mode]
PLOT/FLUX	[fluxtab]
PLOT/IDENT	[wlc] [line] [x] [id] [wave]
PLOT/RESIDUAL	[y] [table]
PLOT/RESPONSE	[resp]

Table 6.3: Commands of the context LONG

- Context LONG	
PLOT/SEARCH	[mode] [table]
PLOT/SPECTRUM	table
PREPARE/LONG	in [out] [limits]
REBIN/LONG	in out [start,end,step] [mtd] [table]
RECTIFY/LONG	in out [reference] [nrep] [deconvol_flag] [line]
REDUCE/INIT	partab
REDUCE/LONG	input
REDUCE/SAVE	partab
RESPONSE/FILTER	std [flux] [resp]
RESPONSE/LONG	[plot] [fit] [deg] [smo] [table] [image] [visu]
SAVE/LONG	[session]
SEARCH/LONG	[in] [thres] [width] [yaver] [step] [mtd] [mode]
SELECT/LINE	
SET/LONG	key=value [...]
SHOW/LONG	[section]
SKYFIT/LONG	input output [sky] [degree] [mode] [g,r,t] [radius]
TUTORIAL/LONG	
VERIFY/LONG	file mode
XIDENT/LONG	[wlc] [ystart] [lintab] [tol]

Table 6.4: Commands of the context LONG (continued)

- Context SPEC	
CORRELATE/LINE	table_1 table_2 [pixel] [cntr,tol,rg,st] [pos,ref,wgt] [ref_value] [outima]
EXTINCTION/SPECTRUM	inframe outframe scale [table] [col]
FILTER/RIPPLE	frame outframe period [start,end]
MERGE/SPECTRUM	spec1 spec2 out [interval] [mode] [var1] [var2]
NORMALIZE/SPECTRUM	inframe outframe [mode] [table] [batch_flag]
OVERPLOT/IDENT	[table] [xpos] [ident] [ypos]
PLOT/RESIDUAL	[table]
SEARCH/LINE	frame w,t[,nscan] [table] [meth] [type]

Table 6.5: Commands of the context SPEC

- Spectral Analysis	
CENTER/method	GCURSOR table EMISSION/ABSORPTION
COMPUTE/FIT	output = function[(refima)]
COMPUTE/FUNCTION	output = function[(refima)]
CONVERT/TABLE	image = table indep dep refimage method
CONVOLVE	input output psf
CREATE/GUI ALICE	
DECONVOLVE	input output psf
FIT/IMAGE	niter,chisq,relax image [function]
GET/GCURSOR	table
INTEGRATE/LINE	image [y0] [x0,x1] [nc,degree] [type]
MODIFY/GCURSOR	image [y0] [x0,x1] [nc,degree] [type]
REBIN/II	input output
REBIN/LINEAR	input output
STATISTICS/IMAGE	image

Table 6.6: Spectral Analysis Commands

6.9 Parameters

For the storage of control parameters and results, the context `LONG` uses a number of special keywords. They are intialised by the command `SET/CONTEXT LONG`, their values can at any time be listed by typing `SHOW/LONG`. The following table provides a brief description of the purpose of the `LONG` keywords:

Parameter	Description
ALPHA	Rejection parameter for lines matching [0,0.5]
AVDISP	Average dispersion per pixel
BETA	Non-linearity in mode LINEAR
BIAS	Bias image or constant
BIASOPT	Bias Correction (YES/NO)
COERBR	Table of coefficients for RBR
COMET	Combination method (AVERAGE/MEDIAN)
COORFIL	Name of coords table of GCOORD/LONG
COROPT	Computes correlation
CORVISU	Plots correlation peak
DARK	Dark image or constant
DARKOPT	Dark Correction (YES/NO)
DCX	fit degree of the dispersion coeff.
DISPCOE	Dispersion coefficients
EXTAB	Extinction Table
EXTMTD	Extraction method (AVERAGE, LINEAR)
EXTOPT	Extinction Correction Option (YES/NO)
FDEG	Flat fitting degree
FFIT	Flat fitted function
FILTMED	Radius of median filter
FILTSMO	Radius of smoothing filter
FITD	Degree of fit
FITD	fit degree of the dispersion coeff.
FITYP	Type of fit (POLY, SPLINE)
FLAT	Flat-Field Image
FLATOPT	Flat Correction (YES/NO)
FLUXTAB	Flux Table of the standard star
FVISU	Visualisation flag (YES/NO)
GAIN	Gain (e-/ADU)
GUESS	Guess session name
IMIN	lower limit from LINCAT
INPNUMB	Input generic name
INPUTF	Input generic name
INSTRUME	instrument
LINCAT	line catalogue
LINTAB	Table of line identifications
LOWSKY	Lower, upper row number of lower sky
MAXDEV	Maximum deviation (pixels)
NITER	Number of iterations
NPIX	size of the raw images in pixels
OBJECT	Lower, upper row number of object spectrum
ORDER	Order for optimal extraction

Table 6.7: Keywords Used in Context LONG

Parameter	Description
OUTNUMB	Output starting number
OUTPUTF	Output generic name
PLOTYP	Type of plot (RATIO, MAGNITUDE)
RADIUS	Radius for cosmics rejection
REBEND	Final wavelength for rebinning
REBMTD	Rebinning method (LINEAR, QUADRATIC, SPLINE)
REBOPT	Rebin Option (YES/NO)
REBSTP	Wavelength step for rebinning
REBSTRT	Starting wavelength for rebinning
RESPLOT	Plot flag for response computation
RESPONSE	Response Image
RESPOPT	Response Correction Option (YES/NO)
RESPTAB	Intermediate Response Table
RON	Read-Out-Noise (ADU)
ROTOPT	Rotation Option (YES/NO)
ROTSTART	Y-start after rotation
ROTSTEP	Y-step after rotation
SEAMTD	Search centering method (GAUSS, GRAV, MAXI)
SESSION	Session name
SHIFT	Shift in pixels
SIGMA	Threshold for rejection of cosmics (std dev.)
SKYMOD	Mode of fitting
SKYORD	Orderfor sky fit
SMOOTH	Smoothing factor for spline fitting
START	start points of the raw image.
STD	Standard Star Spectrum
STEP	start points of the raw image.
THRES	Threshold for line detection (above local median)
TOL	tolerance in Angstroms for wavelength ident.
TRIM	Trim window (x1,y1,x2,y2) in pixels
TRIMOPT	Trim Option (YES/NO)
TWODOPT	Computes bivariate polynomial option.
UPPSKY	Lower, upper row number of upper sky
WCENTER	Central wavelength
WIDTH	Window size in X for line detection (pixels)
WLC	wavelength calibration image
WLCMTD	Wavelength calibration method (IDENT,GUESS)
WLCNITER	Minimum, Maximum number of iterations
WRANG	wavelength range to take from LINCAT
YSTART	Starting row for the calibration (pixel value)
YSTEP	Step in Y for line searching (pixels)
YWIDTH	Window size in Y for line detection (pixels)

Table 6.8: Keywords Used in Context `LONG` (continued)

6.10 Example

As an example of the use of the commands described above, we here include the tutorial procedure, executed as `TUTORIAL/LONG`.

The input images are `wlc`, the wavelength calibration frame, and `obj`, the object. The catalogue of laboratory wavelengths used is stored in the table `lincat`.

```
INIT/LONG
GRAPH/LONG
MAKE/DISPLAY
!
WRITE/OUT Copy test images
-DELETE lndemo_*.*
-COPY MID_TEST:emhear.bdf   lndemo_wlch.bdf
-COPY MID_TEST:emth.bdf     lndemo_wlcth.bdf
-COPY MID_TEST:emstd.bdf    lndemo_wstd.bdf
-COPY MID_TEST:emmi0042.bdf lndemo_bias1.bdf
-COPY MID_TEST:emmi0043.bdf lndemo_bias2.bdf
-COPY MID_TEST:emmi0044.bdf lndemo_bias3.bdf
-COPY MID_TEST:emmi0045.bdf lndemo_bias4.bdf
-COPY MID_TEST:emmi0046.bdf lndemo_flat1.bdf
-COPY MID_TEST:emmi0047.bdf lndemo_flat2.bdf
-COPY MID_TEST:emmi0048.bdf lndemo_flat3.bdf
-COPY MID_TEST:emmi0049.bdf lndemo_flat4.bdf
-COPY MID_TEST:thorium.tbl  lndemo_thorium.tbl
-COPY MID_TEST:hear.tbl     lndemo_hear.tbl
-COPY MID_TEST:l745.tbl     lndemo_l745.tbl
-COPY MID_TEST:atmoexan.tbl lndemo_atmo.tbl
!
WRITE/OUT "This tutorial shows how to calibrate long slit spectra"
WRITE/OUT "The package assumes wavelengths increasing from"
WRITE/OUT "left to rigth."
WRITE/OUT "It is assumed that the images have been already"
WRITE/OUT "rotated, corrected for pixel to pixel variation"
WRITE/OUT "and the dark current has been subtracted."
WRITE/OUT "Input data are:"
WRITE/OUT "wlc.bdf       - wavelength calibration image"
WRITE/OUT "obj.bdf       - object image"
WRITE/OUT "lincat.tbl    - line catalogue"
!
WRITE/OUT  "Combining flat and dark images"
!
LOAD   lndemo_flat1
CREATE/ICAT bias lndemo_bias*.bdf
COMBINE/LONG   bias  lnbias  MEDIAN
STAT/IMA       lnbias
!
CREATE/ICAT flat lndemo_flat*.bdf
SET/LONG TRIM=20,60,520,457
PREPARE/LONG   flat.cat lndemo_ft
```

```
CREATE/ICAT flat lndemo_ft*.bdf
COMBINE/LONG   flat  lnff    AVERAGE
NORMALIZE/FLAT lnff  lnflat  190.
!
CREATE/ICAT  lndemocat  lndemo_w*.bdf
READ/ICAT    lndemocat
LOAD         lndemo_wlch
WRITE/OUT "Extracting useful part of spectra with command PREPARE/LONG"
SET/LONG  TRIM = 0,60,0,457
PREPARE/LONG  lndemocat.cat lndemo
!
WLC:

SET/GRAPH PMODE=1 XAXIS=AUTO YAXIS=AUTO
SET/LONG WLC=lndemo1 LINCAT=lndemo_hear YWIDTH=10 THRES=30.
SET/LONG YSTEP=10 WIDTH=8 TWODOPT=YES DCX=2,1
!
SESSDISP = "NO "
SHOW/LONG wlc
!
WRITE/OUT Search lines:
WRITE/DESCR {WLC}  STEP/D/2/1  -2.
SEARCH/LONG                ! search calibration lines
PLOT/SEARCH
!
WRITE/OUT "Identify some of the brightest lines:"
WRITE/OUT
WRITE/OUT " X   = 379.30     922.50 "
WRITE/OUT " WAV = 5015.680   5606.733"
WAIT 2
IDENTIFY/LONG              ! interactive line identification
SET/LONG  WLCMTD=IDENT  TOL=0.3
CALIBRATE/TWICE            ! wavelength calibration
PLOT/IDENT                 ! display initial identifications
!
WRITE/OUT Compute the dispersion coefficients by fitting a 2-D polynomial
WRITE/OUT to the whole array
PLOT/CALIBRATE             ! display all identifications
PLOT/RESIDUAL
PLOT/DISTORTION 5015.680
!
SAVE/LONG ses1
WRITE/OUT "Now calibrating another arc spectrum in GUESS mode"
SET/LONG  WLCMTD=GUESS GUESS=ses1 WLC=lndemo2 LINCAT=lndemo_thorium
SET/LONG  WIDTH=4  THRES=3.  TOL=0.1   ALPHA=0.2
LOAD {wlc}
SEARCH/LONG
CALIBRATE/LONG
!
```

```
WRITE/OUT "Now demonstrating the three possible ways to apply the"
WRITE/OUT "dispersion relation : "
WRITE/OUT " - APPLY/DISPERSION involves no rebinning and outputs a table."
WRITE/OUT "     Input must be a 1D spectrum or a row of a long-slit spectrum"
WRITE/OUT " - REBIN/LONG       rebins row by row, taking coefficients from coerbr.tbl"
WRITE/OUT " - RECTIFY/LONG     applies the 2D polynomial dispersion relation"
WRITE/OUT "Note: Rebin can be applied before or after extraction"
!
!INIT/LONG ses1
!
APPLY/DISPERSION {wlc}  wlct  @100
PLOT/SPECTRUM    wlct
!
REBIN/LONG {wlc} wlcrb
LOAD      wlcrb
PLOT      wlcrb  @100
!
RECTIFY/LONG {wlc}  wlc2
LOAD        wlc2
PLOT        wlc2  @100
!
WRITE/OUT "Session is now saved, initialized, and loaded from session tables"
SAVE/LONG mysess
INIT/LONG
SESSDISP = "NO "
SHOW/LONG
INIT/LONG mysess
SESSDISP = "NO "
SHOW/LONG
!
WRITE/OUT "Now extracting a spectrum with two possible methods:"
WRITE/OUT "  - Simple rows average with EXTRACT/AVERAGE"
WRITE/OUT "  - Optimal extraction  with EXTRACT/LONG"
LOAD/IMA         lndemo3
SET/LONG         REBSTR=4600. REBEND=5800. REBSTP=2.00
REBIN/LONG       lndemo3   ext8
SET/LONG         LOWSKY = 189,198  UPPSKY = 204,215
SET/LONG         GAIN=2. RON=5. THRES=3. RADIUS=2
SKYFIT/LONG      ext8    stdsky
LOAD             stdsky
COMPUTE/IMAGE    ext7 = ext8 - stdsky
SET/LONG         OBJECT = 199,203
EXTRACT/AVERAGE  ext7   stda
PLOT             stda
EXTRACT/LONG     ext8   stde  stdsky
PLOT             stde
!
WRITE/OUT  "Now computing instrumental response"
!
```

```
SET/LONG FLUXTAB=lndemo_l745  EXTAB=lndemo_atmo
PLOT/FLUX
EXTINCTION/LONG  stde stdext
RESPONSE/FILTER  stdext
INTEGRATE/LONG   stdext
RESPONSE/LONG fit=SPLINE
PLOT/RESPONSE
CALIBRATE/FLUX   stdext stdcor
CUTS             stdcor   100.,500.
PLOT             stdcor
```