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Starlink Cookbook 3.1

SC/3.1

Martin Clayton
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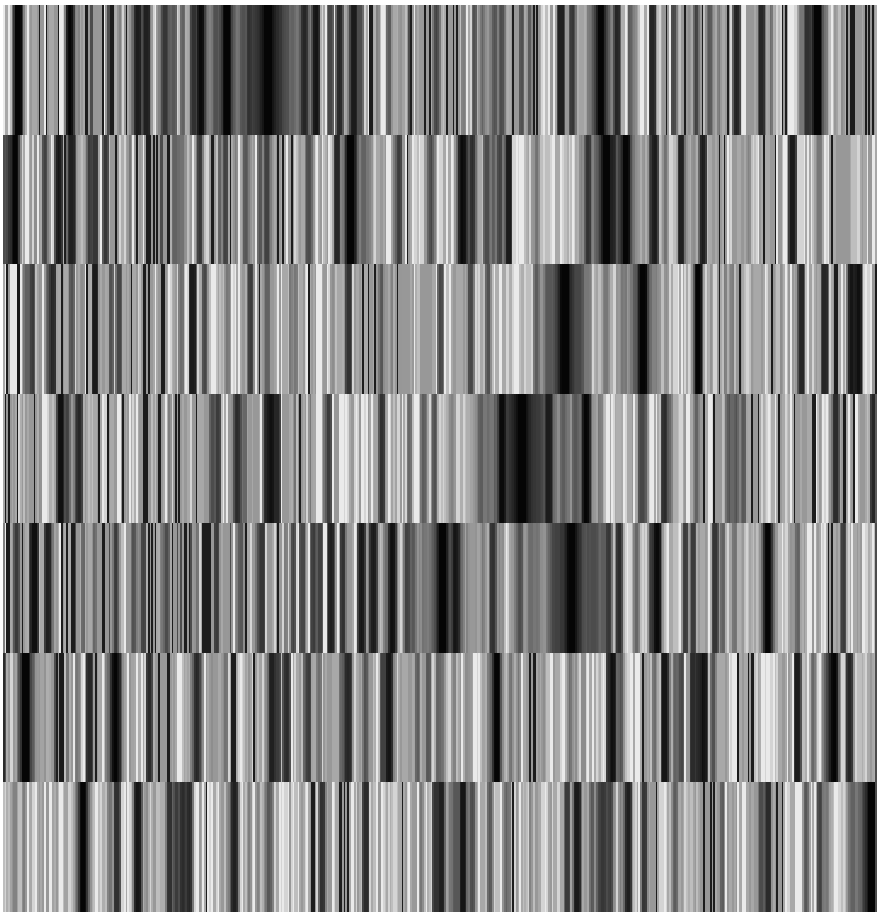
Echelle Data Reduction Cookbook



A collapsed Echelle spectrum

Contents

1 Introduction

This document is the first version of the Starlink Echelle Data Reduction Cookbook. It contains scripts and procedures developed by regular or heavy users of the existing software packages. These scripts are generally of two types; *templates* which readers may be able to modify to suit their particular needs and *utilities* which carry out a particular common task and can probably be used 'off-the-shelf'.

In the nature of this subject the recipes given are quite strongly tied to the software packages, rather than being science-data led. The major part of this document is divided into two sections dealing with scripts to be used with IRAF and with Starlink software.

1.1 Summary of the Available Scripts

The scripts included are the following:

MEANARC takes the weighted mean wavelength scale from two échelle arcs and applies it to an object spectrum. The weighting scheme is based on the times of the observations.

ECHTRACT takes a 'collapsed' échelle spectrum (*e.g.* from ECHOMOP) and produces a series of NDF files each containing a single order of the spectrum.

STACKGEN takes a collapsed échelle spectrum and reads the orders into a DIPSO stack.

TRACEPOLY & ARCPOLY TRACEPOLY extracts the trace fit curve parameters from an ECHOMOP reduction structure file and lists them. ARCPOLY similarly extracts the polynomials describing the wavelength scales and lists them.

Automated ECHOMOP reduction takes the raw CCD data from an observing run and manages the CCD processing as well as running ECHOMOP. Scripts for doing each of the sub-tasks involved are provided.

ECHIMDIVIDE (IRAF) normalises and applies a flat field to an échelle image on an order-by-order basis.

ECHMKV (IRAF) extracts orders from a wavelength-calibrated échelle spectrum and converts to velocity at a specified wavelength, each order is output to a separate file.

ECHTRIM (IRAF) trims the orders of a collapsed échelle spectrum (in IRAF format) according to limits in a file provided.

Although the scripts are each for a specific purpose, you may well find that the task addressed closely matches your objective.

1.2 General Notes on the Scripts

In this document each of the scripts is described in outline.

At Starlink sites you should find copies of the complete scripts in the directory

```
/star/examples/sc3/
```

Some of the scripts are available in different flavours. For example the `stackgen` script is available in two versions – one for FIGARO ECHARC data, one for ECHOMOP data. These scripts are both in the examples directory and named `stackgen_echarc` and `stackgen_echomop` respectively.

The scripts are self documenting. I've commented them in places where they might be adapted to other purposes. The scripts may seem a little long as they contain many comments – this is to aid those wishing to make use of them as *templates* for their own work.

The C shell is used for most of the Starlink scripts and IRAF cl for the IRAF scripts.

1.3 Please Contribute

To be *really* useful this cookbook should contain as many of the tools and tricks used by échelle workers as possible. If you have a handy script, or are aware of one, please contribute it by contacting the author. Scripts need not be coded to any standard – its the algorithm which is important – Starlink will code and document the scripts as required. The cookbook will be re-released irregularly but often as new tools come to light.

2 Other Sources of Information

This cookbook complements the Starlink *Introduction to Echelle Spectroscopy* (Starlink document SG/9) which is a good first read for those new to échelle work.

A significant part of the process of successful spectrum extraction is the preliminary handling of the CCD data frames. Those planning to use IRAF[1] should consult *A User's Guide to CCD Reductions with IRAF* (UGCRI) by Philip Massey. UGCRI is quite a good document for *any* user of CCD data, even those planning to use *e.g.* CCDPACK or FIGARO, to do the preparation.

IRAF users should look at the two documents for échelle data reduction within IRAF: *A User's Guide to Reducing Echelle Spectra With IRAF* and *Guide to the Slit Spectra Reduction Task DOECSLIT*. These give a comprehensive description of the IRAF approach to échelle data. There is also a hypertext tutorial for DOECSLIT at

- `http://star-www.rl.ac.uk/iraf/web/tutorials/doecslit/doecslit.html`

You may be able to access a local copy of this tutorial; consult your system manager.

There is an excellent guide tailored to the reduction of échelle data taken using the Hamilton Spectrograph: *Introduction to Echelle Data Reduction Using the Image Reduction Analysis Facility,* which is a Lick Observatory Technical report. (A PostScript copy is available from the Starlink Echelle Support Pages.) This is a complete step-by-step run through of échelle data reduction using IRAF – from CCD data to calibrated spectra.

[1] IRAF documents can be found in your IRAF installation; you do not need to get them from Tucson or a mirror. Check with your manager for details.

The primary documentation for ECHOMOP is *ECHOMOP – Echelle data reduction package* (Starlink document SUN/152). This document explains each of the data reduction steps using ECHOMOP and includes some general advice and tips. There is some additional information and advice in the on-line HELP for ECHOMOP if you get stuck.

An up-to-date set of hypertext documents for Starlink échelle data reduction and related information; including hypertext help, bug reports, comments and news is maintained at

- `http://www.star.ucl.ac.uk/~mjc/echelle/`

The absolute latest version of this document is also kept in these pages. All the scripts included here are available in source form.

3 Acknowledgements

Thanks are due to Andrew Collier Cameron who has been the principal contributor of scripts using ECHOMOP and FIGARO on which §4.5 is based.

Horst Meyerdierks helped with some of the FIGARO based scripts.

The IRAF scripts are closely based upon scripts posted to the IRAF newsgroups by Francisco Valdes of the NOAO/IRAF group.

Pierre Maxted contributed a modified version of `tracepoly` called `arcpoly` for extracting the wavelength polynomials from ECHOMOP reduction structure files.

4 Starlink

4.1 MEANARC

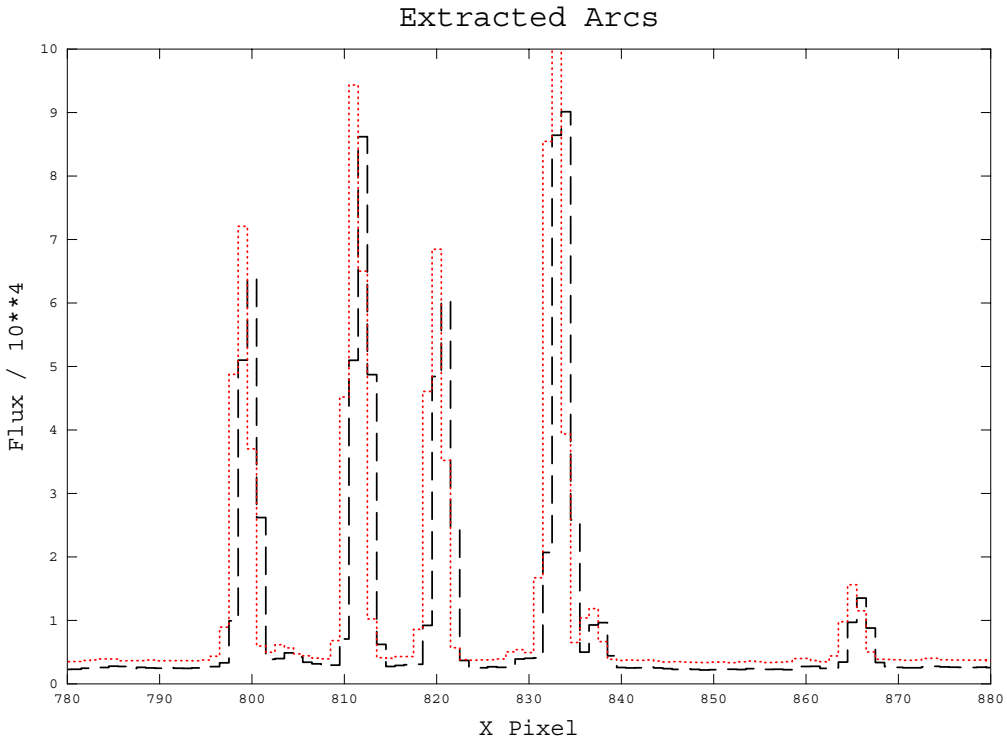


Figure 1: Two arc exposures. The exposures were taken before and after a series of object exposures. A shift of about one pixel between the two can be seen. Assuming this shift is linearly related to time, the MEANARC script could be used to interpolate between wavelength-scales based on the arc spectra and apply the scaling to the object spectra.

Purpose:

Pastes the average of two arc wavelength scales onto a spectrum.

Language:

Perl script.

Description:

A common data reduction task is to apply the wavelength calibration based an arc lamp spectrum to an object frame or several object frames. It is often the case that we have two arc lamp exposures which 'bracket' the astronomy frames in case there is some time dependence of the wavelength scale. FIGARO XCOPI allows a weighted mean of the wavelength scales of two arc frames to be applied to an object frame. This script takes this one step further by working out the weighting – based upon Modified Julian Dates extracted from FITS header information which should have propagated into the Starlink

data structures holding the object frames. If FITS headers are not present the script won't work as is, but could be modified to obtain date information from a different source.

This is a perl script – don't be alarmed! If it does what you need then it's very simple to use. Perl was chosen as a simple floating point calculation is needed. The script could be modified to drive a different FIGARO application.

This script will take two wavelength-calibrated arcs, typically bracketing object frames, use FIGARO XCOPI to find the mean wavelength scale for each of the object frames and apply this scale to the data. This script is suitable for processing spectra wavelength-calibrated with FIGARO ECHARC.

HDSTRACE is used to search for the MJD record of a FITS header from which the Modified Julian Date for the file can be extracted. The weighting of the 'mean' wavelength scale for an object frame is based on the MJD for each of the two arcs and that of the object itself. Schematically the weighting is:

$$\mathbf{OUTPUT} = \mathbf{ARC1} + \frac{T_{OBJ} - T_{ARC1}}{T_{ARC2} - T_{ARC1}} \times (\mathbf{ARC2} - \mathbf{ARC1})$$

where:

OUTPUT is the wavelength scale produced.

ARC1 is the wavelength scale of ARC1.

ARC2 is the wavelength scale of ARC2.

T_{ARC1} is the MJD for ARC1.

T_{ARC2} is the MJD for ARC2.

T_{OBJ} is the MJD for the object.

Usage:

You can simply invoke this script with no arguments and you will be prompted for the required information. Alternatively, you can supply the arguments on the command line. For example, if you have two object frames `obj1` and `obj2` bracketed by the arc exposures `arc1` and `arc2` this would be a suitable way to invoke the script:

```
% meanarc arc1 arc2 obj1 obj2
```

If supplied, command-line arguments must be in this order:

1. **First Arc.** Name of the first arc frame file.
2. **Second Arc.** Name of the second arc frame file.
3. **List of object frames.** Names of the files to which the calibration should be applied. You can supply as many names as you like, separated by spaces. If you are prompted for a list of objects, then you should supply a comma-separated list of object frames.

Missing command-line arguments are prompted for.

Source code:

In a standard Starlink installation the source code for MEANARC can be found in the file:

```
/star/examples/sc3/meanarc
```

Notes:

1. FIGARO V5.0-0 or higher is required.
2. By default, this script modifies the wavelength scales of the object files on which it acts. To create new files with a postfix (e.g. `file_wcal.sdf` from `file.sdf`) modify the value of the variable `$Postfix` as commented in the script.
3. If FITS header information has not been propagated to the Starlink data structure, or there is no Modified Julian Date present, this script will not work. The routine 'getmjd' in the script could be modified to use date information from a different source. See the script for details.

4.2 ECHTRACT

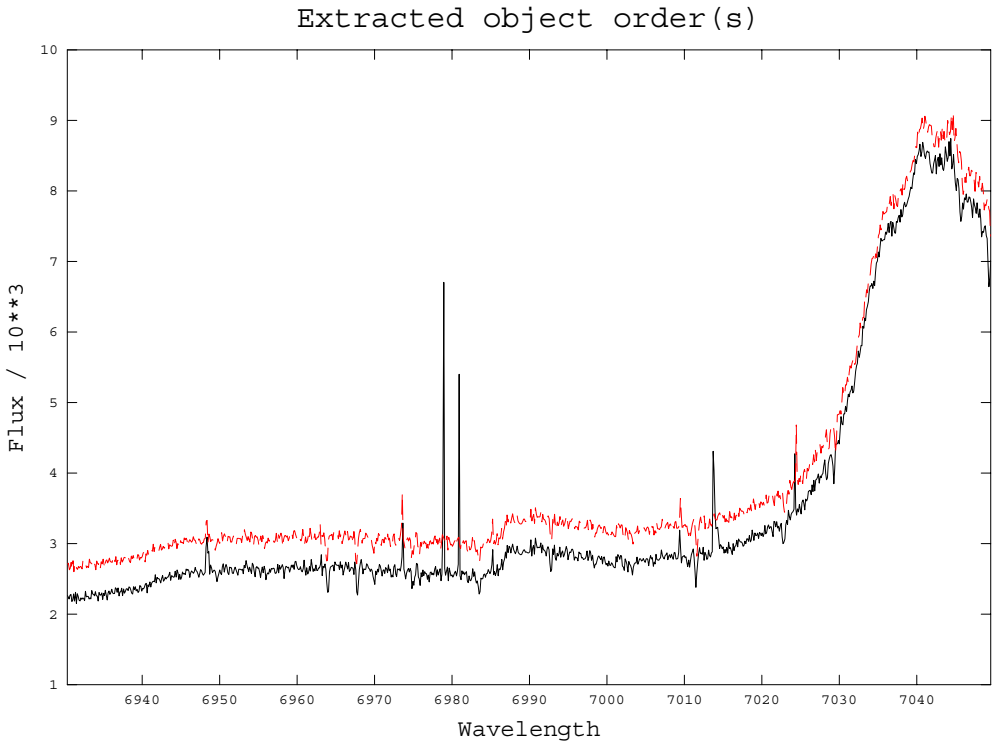


Figure 2: These are two ECHOMOP-extracted orders from different exposures. The orders were extracted from collapsed échelle spectra into single-order NDFs using ECHTRACT. The orders were then read into DIPSO with SP0RD and plotted. Note that the level of the upper-plotted line has been shifted for clarity. The lower-plotted spectrum shows some cosmic-ray contamination.

Purpose:

Script to extract orders from a reduced échelle image to individual NDF files suitable for reading into DIPSO.

Language:

C shell script.

Description:

This script performs a common task; slicing out individual orders from a collapsed, extracted échelle image. In a collapsed échelle image each row of the 2-D image is a single order from the echellogram. Each order has its own wavelength scale, which is stored in an NDF extension. This script will pair up each order with its wavelength scale and output them as individual NDFs with flux data in the main NDF data array and wavelength data in the `AXIS(1)` data array, in other words, an NDF which can be read by DIPSO, FIGARO and so on.

The input image should be one output from ECHOMOP (produced using `ech_result`

or `echmenu` Option 14) or FIGARO ECHARC, or one which consists of a 2-dimensional image where each order occupies a single line of the image.

There are two versions of this script available:

- `echtract_echomop` is specifically for processing ECHOMOP output.
- `echtract_echarc` is specifically for processing FIGARO ECHARC output.

The scripts expect the wavelength data in the input images to be stored in NDF extensions as follows:

- `.MORE.ECHELLE.ECH_2DWAVES` for ECHOMOP data.
- `.AXIS(1).MORE.FIGARO.DATA_ARRAY.DATA` for ECHARC data.

if this is not the case you can still use the script by modifying the value of the `AXISDATA` variable in the scripts.

The full all-order wavelength scales would normally be propagated to the output NDFs; to reduce the size of the individual-order NDFs this extension is deleted in each output file. You can modify this behaviour by commenting out the part of the script which 'shrinks' the per-order NDFs.

The main 2-D order array is expected to be in the NDF main `DATA_ARRAY` (it will be for ECHOMOP or ECHARC data). If you want to take the data from a different location, then set the variable `FLUXDATA` in the scripts to reflect the location. For example, if the data are in the extension `.MORE.ECHELLE.DATA_ARRAY`, then edit the appropriate line in the script to:

```
set FLUXDATA = '.MORE.ECHELLE.DATA_ARRAY';
```

Be sure to include the leading '.' or the extension will not be found.

Usage:

You can simply invoke this script with no arguments and you will be prompted for the required information. Alternatively, you can supply the arguments on the command line. For example, if you have a collapsed échelle spectrum `extobj.sdf` which contains 42 orders and you want each order to be stored in an NDF called `extord_nn.sdf`, where `nn` is the number of the order, invoke the script thus:

```
% echtract extobj 1 42 extord
```

If supplied, command-line arguments must be in this order:

1. **Input image.** Name of the image containing the échelle orders.
2. **Number of first order.** Number of the first échelle order to be extracted.
3. **Number of last order.** Number of the last échelle order to be extracted.
4. **Output root.** Root name for output images, e.g. a value `ech` will lead to output files `ech_01.sdf`, `ech_02.sdf` and so on.

Missing command-line arguments are prompted for.

Source code:

In a standard Starlink installation the source code for ECHTRACT can be found in the:

- `/star/examples/sc3/echtract_echomop` for ECHOMOP data.
- `/star/examples/sc3/echtract_echarc` for FIGARO ECHARC data.

Notes:

1. FIGARO V5.0-0 or higher is required.
2. KAPPA V0.9-0 or higher is required.
3. By default, wavelength data in the input file should be in the extension:
   - `.MORE.ECHELLE.ECH_2DWAVES` for ECHOMOP data.
   - `.AXIS(1).MORE.FIGARO.DATA_ARRAY.DATA` for ECHARC data.

   Use HDSTRACE to check this.
4. By default, the flux array is assumed to be in the main

   ```
   .DATA_ARRAY
   ```

   of the input file. Use HDSTRACE to check this.
5. This script performs a Starlink login, setup for FIGARO and KAPPA commands. This is so that the script need not be 'source'd to use. You can reduce the script set up time (and get rid of the login/setup messages) if you have already done a Starlink login, setup for FIGARO and for KAPPA. Edit out the lines as indicated in the script then, to use this script, you **must** source it. For example:

   ```
   % source echtract extobj 1 42 extord
   ```

4.3 STACKGEN

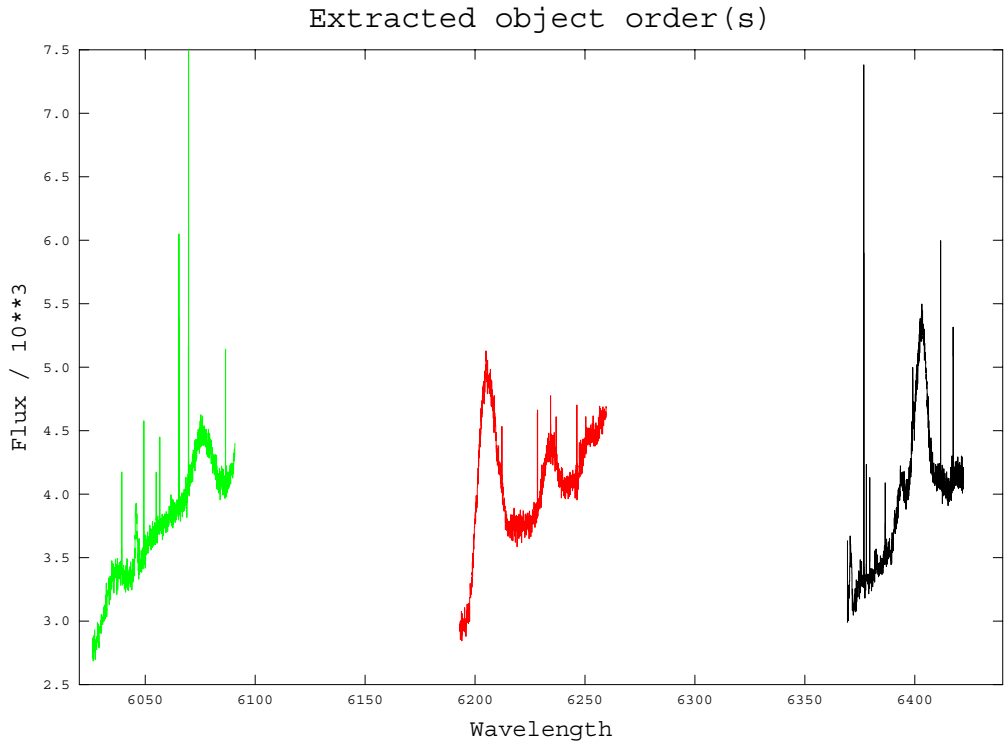


Figure 3: Partial échelle orders plotted from a DIPSO stack. The stack was generated from ECHOMOP data using the STACKGEN script. Note that these are UES data – only about half of each order has been recorded on the CCD, hence the large inter-order gaps in the wavelength coverage. Note also that the data are not blaze-corrected, hence the general rise in signal level with increasing wavelength.

Purpose:

Script to generate a DIPSO stack containing orders from a collapsed échelle image.

Language:

C shell script.

Description:

This script converts an NDF containing a collapsed échelle spectrum into a DIPSO stack where each stack entry holds one order from the echellogram. In a collapsed échelle image each row of the 2-D image is a single order from the echellogram. Each order has its own wavelength scale, which is stored in an NDF extension. This script will pair up each order with its wavelength scale and output them as individual NDFs with flux data in the main NDF data array and wavelength data in the `AXIS(1)` data array, in other words, an NDF which can be read by DIPSO, FIGARO and so on. Once the orders have been output to their own NDFs, they are read into DIPSO and then saved as a DIPSO stack. The intermediate NDFs are then deleted.

The input image should be one output from ECHOMOP (produced using `ech_result` or `echmenu` Option 14) or FIGARO ECHARC, or one which consists of a 2-dimensional image where each order occupies a single line of the image.

There are two versions of this script available:

- `stackgen_echomop` is specifically for processing ECHOMOP output.
- `stackgen_echarc` is specifically for processing FIGARO ECHARC output.

The scripts expect the wavelength data in the input images to be stored in NDF extensions as follows:

- `.MORE.ECHELLE.ECH_2DWAVES` for ECHOMOP data.
- `.AXIS(1).MORE.FIGARO.DATA_ARRAY.DATA` for ECHARC data.

if this is not the case you can still use the script by modifying the value of the `AXISDATA` variable in the scripts.

The main 2-D order array is expected to be in the NDF main `DATA_ARRAY` (it will be for ECHOMOP or ECHARC data). If you want to take the data from a different location, then set the variable `FLUXDATA` in the scripts to reflect the location. For example, if the data are in the extension `.MORE.ECHELLE.DATA_ARRAY`, then edit the appropriate line in the script to:

```
set FLUXDATA = '.MORE.ECHELLE.DATA_ARRAY';
```

Be sure to include the leading '.' or the extension will not be found.

Usage:

You can simply invoke this script with no arguments and you will be prompted for the required information. Alternatively, you can supply the arguments on the command line. For example, if you have a collapsed échelle spectrum `extobj.sdf` which contains 42 orders and you want the stack to be called `ech_STK.sdf`, which you can then read in DIPSO with the command:

```
> restore ech
```

invoke the script thus:

```
% stackgen extobj 1 42 ech
```

If supplied, command-line arguments must be in this order:

1. **Input image.** Name of the image containing the échelle orders.
2. **Number of first order.** Number of the first échelle order to be extracted.
3. **Number of last order.** Number of the last échelle order to be extracted.
4. **Output stack.** Root name for output stack, e.g. a value `ech` will lead to output DIPSO stack `ech_STK.sdf`. This is also used as the root name for the temporary single-order NDFs.

Missing command-line arguments are prompted for.

Source code:

In a standard Starlink installation the source code for STACKGEN can be found in the:

- `/star/examples/sc3/stackgen_echomop` for ECHOMOP data.
- `/star/examples/sc3/stackgen_echarc` for FIGARO ECHARC data.

Notes:

1. FIGARO V5.0-0 or higher is required.
2. KAPPA V0.9-0 or higher is required.
3. By default, wavelength data in the input file should be in the extension:
   - `.MORE.ECHELLE.ECH_2DWAVES` for ECHOMOP data.
   - `.AXIS(1).MORE.FIGARO.DATA_ARRAY.DATA` for ECHARC data.

   Use HDSTRACE to check this.
4. By default, the flux array is assumed to be in the main

   ```
   .DATA_ARRAY
   ```

   of the input file. Use HDSTRACE to check this.
5. This script performs a Starlink login, setup for FIGARO commands, setup for KAPPA commands and DIPSO setup. This is so that the script need not be 'source'd to use. You can reduce the script set up time (and get rid of the login/setup messages) if you have already done a Starlink login, setup for FIGARO, KAPPA, and DIPSO. Edit out the lines as indicated in the script then, to use this script, you **must** source it. For example:

   ```
   % source stackgen extobj 1 42 ech
   ```

4.4 TRACEPOLY & ARCPOLY

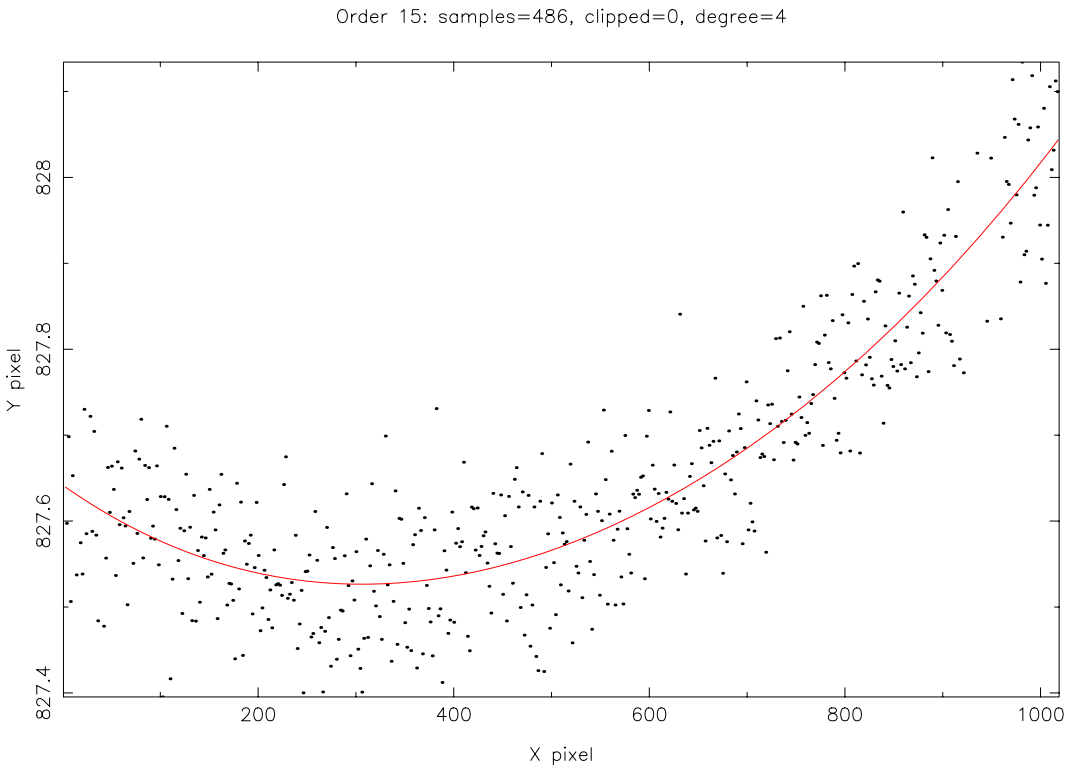


Figure 4: Curve fitted to the trace of an échelle order using ECHOMOP ech_fitord. This is a fourth-order polynomial. The parameters of the fit could be listed using the TRACEPOLY script.

Purpose:

TRACEPOLY is a script to extract trace polynomial coefficients from an ECHOMOP data reduction structure file. ARCPOLY is a similar script which extracts wavelength polynomial coefficients from an ECHOMOP data reduction structure file.

Language:

C shell script.

Description:

TRACEPOLY uses the Starlink HDSTRACE utility to look for the object

```
<file>.MORE.ECHELLE.TRC_POLY
```

in the ECHOMOP reduction structure file `<file>.sdf` which holds the coefficients of order trace polynomials as determined by the ECHOMOP task `ech_trace`. This allows easy access to the trace polynomials outside of ECHOMOP tasks. The script can be modified to display other information from ECHOMOP reduction structures. An example of this is ARCPOLY which looks for the object

```
<file>.MORE.ECHELLE.W_POLY
```

which holds the wavelength-scale polynomials for the reduction.

Usage:

You can simply invoke the scripts with no arguments and you will be prompted for the required information. Alternatively, you can supply the arguments on the command line. For example:

```
% tracepoly rdf68 4 7
```

will display the first seven polynomial coefficients for order 4 of the data in the reduction structure file `rdf68.sdf`.

If supplied, command-line arguments must be in this order:

1. **Reduction structure.** Name of the ECHOMOP reduction structure file.
2. **Number of the order.** Number of the order trace or wavelength scale to be displayed.
3. **Maximum coefficients.** (Default value 8.) Number of polynomial coefficients to be displayed.

Arguments 1–2 will be prompted for if not given on the command line.
Argument 3 defaults to the value 8 if not given on the command line.

Source code:

In a standard Starlink installation the source codes for TRACEPOLY and ARCPOLY can be found in the files:

```
/star/examples/sc3/tracepoly
```

and

```
/star/examples/sc3/arcpoly
```

4.5 Automated ECHOMOP reductions

This family of scripts can be used to manage the automatic reduction of échelle data based upon a single template reduction performed manually. The scripts are as follows:

PREPRUN1 Driver script for an automated reduction run. Prompts for details of the dataset.

PREPRUN2 Driver script for an automated reduction run. Should be edited to contain details of the dataset.

PREPBIAS A bias frame is created using FIGARO MEDSKY to produce the median of the input images.

PREPFLAT Uses the bias frame produced by PREPBIAS and a series of input images to create a flat field using FIGARO MEDSKY. Rotates the images (if needed) to give horizontal orders.

PREPARCS Uses the bias frame produced by PREPBIAS and the flat field from PREPFLAT to prepare the input arc images for ECHOMOP. Images clipped and rotated.

PREPOBJS Uses the bias frame produced by PREPBIAS and the flat field from PREPFLAT to prepare the input object images for ECHOMOP. Images clipped and rotated.

ECHRDARC Extracts the arc spectra using an appropriate object image to determine channels.

ECHRDUCE Extracts the object spectra.

The PREPBIAS, PREPFLAT, PREPARCS and PREPOBJS scripts use FIGARO commands to prepare the raw CCD image frames for use by ECHOMOP. By default, these scripts **do not** perform **rotation** of the images. ECHOMOP requires that the orders of the spectrum should run roughly parallel to the rows of the image (*i.e.* horizontally). If your input frames contain échelle spectra with the dispersion running roughly along the columns you should uncomment the parts of the scripts which deal with image rotation. See the individual scripts for details.

As FIGARO is used for the data preparation, there is no automatic handling of error values. The scripts might be adapted to use CCDPACK to perform the CCD-related preprocessing if variances are required, e.g. for optimal extractions.

The script PREPRUN1 is provided as an example of a driver script for the other tasks. It may be more convenient to use a non-interactive driver script which you should edit to contain the details of the dataset. PREPRUN2 is a template for this purpose.

In use, at least a single object and arc should be reduced manually using `echmenu` to ensure that correct general parameters are used to build an ECHOMOP *reduction file* which can be re-used in subsequent reductions. The scripts ECHRDARC and ECHRDUCE should be edited to reflect the sequence of operations required for your particular data.

Which parts of a reduction can be fully automated, which parts need to be done only once in the template manual reduction, which parts must be done manually for every dataset, will depend entirely on your data. If you are in any doubt, you should study the *Introduction to Echelle Spectroscopy* to get an idea of which parts of the reduction are tricky. In theory,

ECHOMOP can be used to perform fully-automated reductions in most cases. In practice, there is no substitute for carefully investigating your data before trying to 'pipeline' process it. Even if you are confident of successful automated reduction, you will still have to review the results carefully.

In the scripts included, the `echmenu` option sequence:

4.2 `ech_object` Get the object channel.

22 `ech_mdlbck` Model the background as scattered light.

7 `ech_profile` Model the object profile.

8 `ech_extrct` Extract the orders.

14 `ech_result` Write the results to an output NDF.

EXIT Exit `echmenu`.

is executed. See SUN/152 for details of ECHOMOP reductions. The EXIT option **must** be included otherwise `echmenu` will revert to interactive mode when the sequence of options is completed. The reduction sequence is specified via the parameter `tune_automate`. Other parameters, *e.g.* which extraction object to output (parameter `result_type`), are also given in the `echmenu` command line. As the above sequence does not perform order tracing, the order trace polynomials must be provided in the manually-prepared reduction structure file. This is an example of an automated reduction sequence where one aspect of the reduction – the order tracing – has been done only once manually and reused in the subsequent automatic reductions.

4.5.1 PREPRUN1 & PREPRUN2 – Set up automated run

These are example master driver scripts for an automated run.

If you want to perform optimal extractions or need variance data with from reduction, you'll need to know the noise and gain details of the detector used.

Some sort of image display and interrogation programs (*e.g.* FIGARO IMAGE and ICUR) to work out which part of the overscan to use for 'zero-offset correction' and which part of the frames you want to keep for extracting the spectra.

Two examples are provided, PREPRUN1 prompts for all the parameters required – in practice you'll be better off using PREPRUN2 as there are rather a lot of parameters. The best way to manage reductions is to take a copy of PREPRUN2 and enter in the script the various trimming numbers, CCD gain and output noise, and object & arc lists and so on. The whole reduction can then be done by running the script without any prompts.

Here is the prologue for PREPRUN2:

Purpose:
Driver script to set up for an automated échelle data reduction run.

Language:
C shell script.

Description:

This script can be used to coordinate the relatively complex series of operations required for reducing a large number of similar échelle spectrograms. Before using the script, you should be familiar with the use and parameters of the ECHOMOP package. (You can try this out without being familiar with ECHOMOP – but it is a complex package!)

Essentially the procedure is to 'prototype' the reduction manually using ECHOMOP and then, once you have determined suitable parameter settings, to use the manually-generated reduction structure file as a template with which to reduce the complete dataset.

Which parts of the reduction procedure need to be done for every frame, and which parts can be copied 'as-is' from the manual template will depend on your data. For example, you might use the order traces from the manual reduction for all the frames. This will be fine as long as the image of the echellogram remains stable over the full time period which covers your dataset. One way to check this sort of thing is to perform two manual reductions – one from early in the time period covered, one from late – and then compare the two. Plotting orders from the reduced arcs is a good way to spot shifts in the dispersion direction. Detecting shifts in the spatial direction can be more difficult; however, you might use the `tracepoly` script to extract the parameters of the order traces from the ECHOMOP reduction structure files. You can then compare the parameters and look for shifts – for POLY fits checking that the low-order parameters closely match and that higher-order parameters are small should be enough.

This script calls a set of shortish scripts to perform each of the data preparation tasks – debiasing, flat fielding, clipping and so on. You should review the descriptions in these scripts so that you are happy you understand what each one is doing with your data. You may also need to edit the scripts in some places, particularly if your echellograms have orders which run roughly vertically.

The output of the automated reduction process is a series of files `ob_`'file' where 'file' is the name of the source object frame. Arc frames `ar_`'file' are similarly created.

Usage:

You need to know the true detection area of the CCD used to acquire your data – if you don't, display an image with FIGARO IMAGE and look for empty parts of the frame at the edges of the image. These are not used by ECHOMOP and should be cut off by setting suitable values for the trim parameters. You should select a part of the overscan ('dark' area) to be used for measurement of the electronic bias level. Use FIGARO ICUR to measure the coordinates of the various areas.

The following in this script should be edited to suit your data:

1. Detector overscan sample region – for bias-level determination.
2. Detector clipping region (to remove overscan) – to remove non-science data areas of the input images.
3. Detector output details (noise, gain).
4. List of bias frames.
5. List of flat-field frames.
6. List of arc frames.
7. List of arc mask frames (paired with arcs) – these are used to configure the processing of arcs so that they are extracted in the same way as objects.

8. List of object frames.
9. Name of prototype ECHOMOP reduction structure file.

See comments in the script for details. Example values have been given for some of these items.

Source code:

In a standard Starlink installation the source code for the PREPRUN scripts can be found in these files:

- `/star/examples/sc3/preprun1`.
- `/star/examples/sc3/preprun2`.

4.5.2 PREPBIAS – Prepare bias frame

Purpose:
Script to prepare a single biasframe from a series of frames.

Language:
C shell script.

Description:
This script produces a single median image from a series of 'raw' CCD bias frames. The median bias frame is created using FIGARO MEDSKY. The output image is called `biasframe`, this can be altered by editing the appropriate line in the script.

Usage:
This script can simply be invoked from the shell; in this case the script will prompt for a list of the input bias images. Alternatively, the list of bias frames can be supplied on the command line, for example:

```
% prepbias run0800 run0801 run0802 run0856 run0857 run0858
```

If wildcarding facilities are available in your shell, you can use them to simplify the command line, for example, the above would become:

```
% prepbias run080[012] run085[678]
```

in the C shell. This wildcarding facility is available when the script prompts for a list of input images.

Source code:
In a standard Starlink installation the source code for PREPBIAS can be found in the file:

```
/star/examples/sc3/prepbias
```

Notes:

1. If needed, the input parameters can be input at the command line thus:

   ```
   % nohup prepbias filename [filename...] &
   ```

   the `nohup` command will ensure that the script continues to run even when you have logged off the system. The `&` at the end of the line will run the script in the background.
2. This script is designed to be used as part of an automated échelle data reduction package. If you intend to use it for this purpose, you should not change the name of the output median bias frame `biasframe`. See the comments in the script for changes which can be made if it is to be used stand-alone.
3. This script will work with FIGARO v5.0-0 or later.
4. This script is designed to be called by a master reduction script. See the example scripts `preprun1` and `preprun2` for details.

4.5.3 PREPFLAT – Prepare Flat-field frame

Purpose:

Script to prepare a median flat-field for use by ECHOMOP.

Language:

C shell script.

Description:

This script takes a list of 'raw' CCD flat-field frames and produces a single median flat-field image suitable for use as the FFIELD file in ECHOMOP.

Be advised that flat-fielding in échelle data reduction is not easy – sometimes it's not even possible. Refer to the *Introduction to Echelle Spectroscopy* (SG/9) if in any doubt.

The script performs the basic CCD data processing steps of bias subtraction and trimming. Bias subtraction removes the zero-point bias introduced by the camera electronics. Trimming removes the pre-scan and over-scan regions of the CCD image which contain no science data and can confuse the algorithms in échelle data reduction software.

If required, the CCD frames can be rotated so that the dispersion direction of the échelle orders runs horizontally as required by ECHOMOP.

The median flat-field is calculated using FIGARO MEDSKY.

Usage:

This script can simply be invoked from the shell; in this case the script will prompt for a list of the input flat-field images. Alternatively, the list of frames can be supplied on the command line, for example:

```
% prepflat run0800 run0801 run0802 run0856 run0857 run0858
```

If wildcarding facilities are available in your shell, you can use them to simplify the command line, for example, the above would become:

```
% prepflat run080[012] run085[678]
```

in the C shell. This wildcarding facility is available when the script prompts for a list of input images.

In practice, invocation from your shell is unlikely to be a good method of using this script as 8 environment variables defining the region of the image to be kept and the region of the overscan to be used for debiasing are required. Use of these variables is summarised below.

Source code:

In a standard Starlink installation the source code for PREPFLAT can be found in the file:

```
/star/examples/sc3/prepflat
```

Notes:

1. If needed, the input parameters can be input at the command line thus:

   ```
   % nohup prepflat filename [filename...] &
   ```

   the `nohup` command will ensure that the script continues to run even when you have logged off the system. The `&` at the end of the line will run the script in the background.

2. This script is designed to be used as part of an automated échelle data reduction package. If you intend to use it for this purpose, you should not change the name of the output median flat-field frame `flatfield`. See the comments in the script for changes which can be made if it is to be used stand-alone.

3. This script will work with FIGARO v5.0-0 or later.

4. When this script is invoked, 8 environment variables defining the overscan region to be used for debiasing, and the region of the images containing science data must be defined. These environment variables are used:

   `$xbimin` X-start of overscan region to use for bias subtract.

   `$xbimax` X-end of overscan region to use for bias subtract.

   `$ybimin` Y-start of overscan region to use for bias subtract.

   `$ybimax` Y-end of overscan region to use for bias subtract.

   `$xtrmin` X-start of region of image to be retained.

   `$xtrmax` X-end of region of image to be retained.

   `$ytrmin` Y-start of region of image to be retained.

   `$ytrmax` Y-end of region of image to be retained.

5. A file `biasframe` containing a bias frame prepared by the script `prepbias` should exist in the working directory. You can alter the name of this file, see comments in the script.

6. The input frames are **not** rotated by this script. You may have images in which the orders run roughly vertically, in which case you should uncomment the line using FIGARO IROT90 as in the script. Approximately horizontal orders are required by ECHOMOP. If you do rotate the flat field, note that the script only rotates the final median frame, not the individual input frames (saves time).

7. This script is designed to be called by a master reduction script. See the example scripts `preprun1` and `preprun2` for details.

4.5.4 PREPARCS – Prepare arc frames

Purpose:

Script to prepare a set of arc frames for use by ECHOMOP.

Language:

C shell script.

Description:

This script takes a list of 'raw' CCD arc-lamp frames and performs the basic CCD data processing steps of bias subtraction and trimming on the images. Bias subtraction removes the zero-point bias introduced by the camera electronics. Trimming removes the pre-scan and over-scan regions of the CCD image which contain no science data and can confuse the algorithms in échelle data reduction software.

If required, the CCD frames can be rotated so that the dispersion direction of the échelle orders runs horizontally as required by ECHOMOP.

The script produces a series of files `a_`'file' where 'file' is the name of the source frame.

Usage:

This script can simply be invoked from the shell; in this case the script will prompt for a list of the input arc-lamp images. Alternatively, the list of frames can be supplied on the command line, for example:

```
% preparcs run0800 run0801 run0802 run0856 run0857 run0858
```

If wildcarding facilities are available in your shell, you can use them to simplify the command line, for example, the above would become:

```
% preparcs run080[012] run085[678]
```

in the C shell. This wildcarding facility is available when the script prompts for a list of input images.

In practice, invocation from your shell is unlikely to be a good method of using this script as 8 environment variables defining the region of the image to be kept and the region of the overscan to be used for debiasing are required. Use of these variables is summarised below.

Source code:

In a standard Starlink installation the source code for PREPARCS can be found in the file:

```
/star/examples/sc3/preparcs
```

Notes:

1. If needed, the input parameters can be input at the command line thus:

   ```
   % nohup preparcs filename [filename...] &
   ```

the `nohup` command will ensure that the script continues to run even when you have logged off the system. The `&` at the end of the line will run the script in the background.

2. This script is designed to be used as part of an automated échelle data reduction package. If you intend to use it for this purpose, you should not change the name of the output frames from `a_`'file' where 'file' is an input frame. See the comments in the script for changes which can be made if it is to be used stand-alone.
3. This script will work with FIGARO v5.0-0 or later.
4. When this script is invoked, 8 environment variables defining the overscan region to be used for debiasing, and the region of the images containing science data must be defined. These environment variables are used:

   `$xbimin` X-start of overscan region to use for bias subtract.

   `$xbimax` X-end of overscan region to use for bias subtract.

   `$ybimin` Y-start of overscan region to use for bias subtract.

   `$ybimax` Y-end of overscan region to use for bias subtract.

   `$xtrmin` X-start of region of image to be retained.

   `$xtrmax` X-end of region of image to be retained.

   `$ytrmin` Y-start of region of image to be retained.

   `$ytrmax` Y-end of region of image to be retained.

5. A file `biasframe` containing a bias frame prepared by the script `prepbias` should exist in the working directory. You can alter the name of this file, see comments in the script.
6. The input frames are **not** rotated by this script. You may have images in which the orders run roughly vertically, in which case you should uncomment the line using FIGARO IROT90 as indicated in the script. Approximately horizontal orders are required by ECHOMOP.
7. This script is designed to be called by a master reduction script. See the example scripts `preprun1` and `preprun2` for details.

4.5.5 PREPOBJS – Prepare object frames

Purpose:

Script to prepare a set of object frames for use by ECHOMOP.

Language:

C shell script.

Description:

This script takes a list of 'raw' CCD object frames and performs the basic CCD data processing steps of bias subtraction and trimming on the images. Bias subtraction removes the zero-point bias introduced by the camera electronics. Trimming removes the pre-scan and over-scan regions of the CCD image which contain no science data and can confuse the algorithms in échelle data reduction software.

If required, the CCD frames can be rotated so that the dispersion direction of the échelle orders runs horizontally as required by ECHOMOP.

The script produces a series of files `o_file` where `file` is the name of the source frame.

Usage:

This script can simply be invoked from the shell; in this case the script will prompt for a list of the input object images. Alternatively, the list of frames can be supplied on the command line, for example:

```
% prepobjs run0800 run0801 run0802 run0856 run0857 run0858
```

If wildcarding facilities are available in your shell, you can use them to simplify the command line, for example, the above would become:

```
% prepobjs run080[012] run085[678]
```

in the C shell. This wildcarding facility is available when the script prompts for a list of input images.

In practice, invocation from your shell is unlikely to be a good method of using this script as 8 environment variables defining the region of the image to be kept and the region of the overscan to be used for debiasing are required. Use of these variables is summarised below.

Source code:

In a standard Starlink installation the source code for PREPOBJS can be found in the file:

```
/star/examples/sc3/prepobjs
```

Notes:

1. If needed, the input parameters can be input at the command line thus:

   ```
   % nohup prepobjs filename [filename...] &
   ```

the `nohup` command will ensure that the script continues to run even when you have logged off the system. The `&` at the end of the line will run the script in the background.

2. This script is designed to be used as part of an automated échelle data reduction package. If you intend to use it for this purpose, you should not change the name of the output frames from `o_`'file' where 'file' is an input frame. See the comments in the script for changes which can be made if it is to be used stand-alone.
3. This script will work with FIGARO v5.0-0 or later.
4. When this script is invoked, 8 environment variables defining the overscan region to be used for debiasing, and the region of the images containing science data must be defined. These environment variables are used:

   `$xbimin` X-start of overscan region to use for bias subtract.

   `$xbimax` X-end of overscan region to use for bias subtract.

   `$ybimin` Y-start of overscan region to use for bias subtract.

   `$ybimax` Y-end of overscan region to use for bias subtract.

   `$xtrmin` X-start of region of image to be retained.

   `$xtrmax` X-end of region of image to be retained.

   `$ytrmin` Y-start of region of image to be retained.

   `$ytrmax` Y-end of region of image to be retained.

5. A file `biasframe` containing a bias frame prepared by the script `prepbias` should exist in the working directory. You can alter the name of this file, see comments in the script.
6. The input frames are **not** rotated by this script. You may have images in which the orders run roughly vertically, in which case you should uncomment the line using FIGARO IROT90 as indicated in the script. Approximately horizontal orders are required by ECHOMOP.
7. This script is designed to be called by a master reduction script. See the example scripts `preprun1` and `preprun2` for details.

4.5.6 ECHRDARC – Reduce arc frames

Purpose:
Script to reduce an arc frame with ECHOMOP.

Language:
C shell script.

Description:
This script reduces a wavelength-scale reference arc frame using ECHOMOP. An object or flat-field frame to be used for order profiling must be available. (You could use an arc frame – this is fine as long as the same frame is used by the script `echrduce` for reducing the object frames for which this is the arc reference.)

The output file is named `ar_ArcFile` where `ArcFile` is the name of the input arc frame.

Usage:
This script can simply be invoked from the shell; in this case the script will prompt for the arc frame to be processed and the object frame to be used for order profiling. Alternatively, the input frame names can be supplied on the command line, for example:

```
% echrdarc arc004 obj012
```

In practice, invocation from your shell is unlikely to be a good method of using this script as 3 environment variables defining the CCD output characteristic and ECHOMOP reduction structure file name are required. Use of these variables is summarised below.

Arguments:
If supplied, command-line arguments must be in this order:

1. **Arc Frame.** Name of the Arc frame to be processed.
2. **Object Frame.** Name of the Object frame to be processed.

Missing command-line arguments are prompted for.

Source code:
In a standard Starlink installation the source code for ECHRDARC can be found in the file:

```
/star/examples/sc3/echrdarc
```

Notes:

1. If needed, the input parameters can be input at the command line thus:

   ```
   % nohup echrdarc arcfilename objectfilename &
   ```

   the `nohup` command will ensure that the script continues to run even when you have logged off the system. The `&` at the end of the line will run the script in the background.

2. This script is designed to be used as part of an automated échelle data reduction package. If you intend to use it for this purpose, you should not change the name of the output arc frame, `ar_`'ArcFile'.
3. When this script is invoked, 3 environment variables defining the output characteristics of the CCD used, and the ECHOMOP reduction structure file used must be defined. These environment variables are used:

   `$EchFile` Name of the ECHOMOP reduction structure file.

   `$Gain` CCD output transfer function in photons per ADU.

   `$RDN` CCD readout noise in electrons.
4. A file `flatfield` containing a flat-field frame prepared by the script `prepflat` should exist in the working directory. You can alter the name of this file, see comments in the script.
5. The scripts `preparcs`, `prepbias` and `prepflat` should be used to prepare data for processing with this script.
6. This script is designed to be called by a master reduction script. See the example scripts `preprun1` and `preprun2` for details.

4.5.7 ECHRDUCE – Reduce object frames

Purpose:
Script to reduce a set of object frames with ECHOMOP.

Language:
C shell script.

Description:
This script reduces a series of object frames using ECHOMOP.

The output files are named `ob_File` where `File` is the name of the input object frame.

Usage:
This script can simply be invoked from the shell; in this case the script will prompt for a list of object frames to be processed Alternatively, the input frame names can be supplied on the command line, for example:

```
% echrduce run0800 run0801 run0802 run0856 run0857 run0858
```

If wildcarding facilities are available in your shell, you can use them to simplify the command line, for example, the above would become:

```
% echrduce run080[012] run085[678]
```

in the C shell. This wildcarding facility is available when the script prompts for a list of input images.

In practice, invocation from your shell is unlikely to be a good method of using this script as 3 environment variables defining the CCD output characteristic and ECHOMOP reduction structure file name are required. Use of these variables is summarised below.

Arguments:
If supplied, command-line arguments must be in this order:

1. **List of files.** List of files to be processed.

Missing command-line arguments are prompted for.

Source code:
In a standard Starlink installation the source code for ECHRDUCE can be found in the file:

```
/star/examples/sc3/echrduce
```

Notes:

1. If needed, the input parameters can be input at the command line thus:

   ```
   % nohup echrduce filename [filename...] &
   ```

the `nohup` command will ensure that the script continues to run even when you have logged off the system. The `&` at the end of the line will run the script in the background.

2. This script is designed to be used as part of an automated échelle data reduction package. If you intend to use it for this purpose, you should not change the name of the output frames, `ob_`'File'.
3. When this script is invoked, 3 environment variables defining the output characteristics of the CCD used, and the ECHOMOP reduction structure file used must be defined. These environment variables are used:

   `$EchFile` Name of the ECHOMOP reduction structure file.

   `$Gain` CCD output transfer function in photons per ADU.

   `$RDN` CCD readout noise in electrons.
4. A file `flatfield` containing a flat-field frame prepared by the script `prepflat` should exist in the working directory. You can alter the name of this file, see comments in the script.
5. The scripts `prepobjs`, `prepbias` and `prepflat` should be used to prepare data for processing with this script.
6. This script is designed to be called by a master reduction script. See the example scripts `preprun1` and `preprun2` for details.

5 IRAF

These scripts are designed for use with data processed using the IRAF packages and scripts for handling échelle data (echelle, doecslit). They provide simple utilities which could also be used as templates for other actions.

5.1 ECHIMDIVIDE

Purpose:

Script to divide a series of extracted échelle spectra by an extracted flat-field and then rescale to the original means of the spectra.

Language:

IRAF cl script.

Description:

This script is for removing the blaze function of an extracted échelle spectrum. In this particular case an extracted flat-field spectrum is used to divide-out the blaze function. The script proceeds by dividing the échelle image by the flat field. This will lead to some change in the mean flux level in the orders of the spectrum. To remove the level shift, the mean value of each order in the input image and in the flat-field-divided image is found. A 'correction' ratio for each order can then be calculated and used to rescale the output image so that the resulting blaze-corrected image retains the same per-order mean level as the input. By calculating a per-order mean, rather than rescaling the image by a single factor, the order-to-order blaze corrections are retained.

Usage:

The `flat` parameter is the name of an extracted flat field.

The `input` and `output` lists of spectra may be the same.

To install and use:

1. Place script in your IRAF home$ directory as echimdivide.cl.
2. Interactively type:

   ```
   cl> task echimdivide=home$echimdivide.cl
   ```

3. Or, in your login.cl or loginuser.cl place the following before the keep:

   ```
   task echimdivide = home$echimdivide.cl
   ```

4. Run the task by typing:

   ```
   cl> echimdivide
   ```

   You will be prompted to enter values for the parameters. Alternatively, set values using the parameter editor and then run the task.

Source code:

In a standard Starlink installation the source code for ECHIMDIVIDE can be found in the file:

```
/star/examples/sc3/echimdivide.cl
```

5.2 ECHMKV

Purpose:

Script to extract orders from a dispersion-calibrated échelle spectrum and convert to velocity at the specified wavelength.

Language:

IRAF cl script.

Description:

The problem: One has échelle data with a series of lines, say Lyman series lines, which one wants to compare or combine in velocity space; that is the center of each line is zero velocity and the profile is in relative velocity. The following script takes a list of échelle aperture (order) numbers and central wavelengths and extracts the orders from échelle wavelength-calibrated images and modifies the header to place each order in relative velocity. The individual 1-D orders can than be stacked with SPECPLOT or combined in velocity with SCOMBINE.

This script is useful for comparing sets of lines at different wavelengths, for example, Lyman lines.

Usage:

The `input` parameter is the name of a multiorder échelle spectrum.

The `lines` parameter is a two-column text file containing the aperture number for the desired feature and the wavelength for zero velocity.

The `output` parameter is a root filename. A set of 1-D spectra with the root name and an appended integer will be produced, one for every line in the `lines` file.

To install and use:

1. Place script in your IRAF home$ directory as file echmkv.cl.
2. Interactively, load the onedspec package and type:

   ```
   on> task echmkv=home$echmkv.cl
   ```

3. Or, in your login.cl or loginuser.cl place the following before the 'keep':

   ```
   task echmkv=home$echmkv.cl
   ```

4. Run the task by typing:

   ```
   cl> echmkv
   ```

   You will be prompted to enter values for the parameters. Alternatively, set values using the parameter editor and then run the task.

Source code:

In a standard Starlink installation the source code for ECHMKV can be found in the file:

```
/star/examples/sc3/echmkv.cl
```

Notes:

1. This works in all versions of IRAF V2.10.
2. The script requires the ONEDSPEC package or other spectral package containing SCOPY.
3. Plots will have X-axes labeled as wavelength even though the value is velocity.

5.3 ECHTRIM

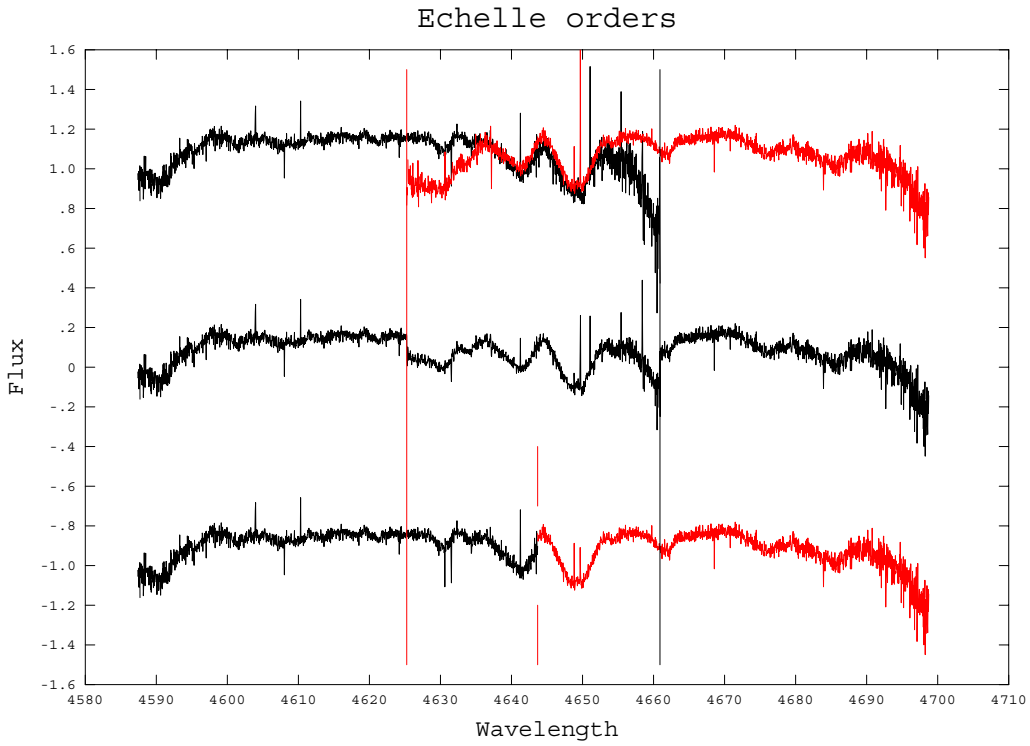


Figure 5: Two overlapping echelle orders. The upper plot shows the two individual orders after blaze correction. The correction is not perfect, and as a result the signal level falls off at the ends of the orders. The middle plot shows the merged spectrum of the orders, using their mean in the overlap. There are two discontinuities present at about 4625Å and 4661Å. The lower plot shows how these discontinuities can be removed by selecting a clip point to change from one order to the next; this is at about 4643Å. In this case, the overlap between the orders at the selected cut-off point is good and no discontinuity is present in the merged spectrum.

Purpose:

Script to trim individual échelle orders.

Language:

IRAF cl script.

Description:

When the orders of a collapsed echellogram are merged it is often the case that regions of overlap between two adjacent orders have quite different signal levels. This can be for several reasons, most notably the blaze function. When merging the orders a weighted sum of some kind is often used, however, there are almost always one or two discontinuities in the single spectrum produced. One way of ensuring that there is only one discontinuity per-order, and this is at a known position, is to trim the wavelength range of each of the

orders of the echellogram so that there is precisely no overlap. Instead, the orders each cover an adjacent region of the spectrum.

This script allows the specification of sections of the orders of an echellogram to be used to produce a single spectrum. A file listing the order numbers and required sections of the orders is read and the selected regions of each order are then trimmed into the output échelle image. Several similar échelle images can be processed at the same time by specifying a list of input images.

Usage:

The `input` parameter is a list of IRAF échelle format images.

The `orders` parameter is a text file containing lines with order number and 1-D image section for trimming. See the example below for the format of the file. Basically, you should use the standard IRAF syntax for specifying a section of an image, one order per line of the file.

Each specified order is trimmed and merged into the `output` image.

The `input` and `output` images may be the same.

To install and use:

1. Place script in your IRAF home$ directory as file echtrim.cl.
2. Interactively, load the échelle package and type:

   ```
   ec> task echtrim=home$echtrim.cl
   ```

3. Or, in your login.cl or loginuser.cl place the following before the 'keep':

   ```
   task echtrim=home$echtrim.cl
   ```

4. Run the task by typing:

   ```
   cl> echtrim
   ```

   You will be prompted to enter values for the parameters. Alternatively, set values using the parameter editor and then run the task.

Source code:

In a standard Starlink installation the source code for ECHTRIM can be found in the file:

```
/star/examples/sc3/echtrim.cl
```

Notes:

1. This works with IRAF V2.10.2 through V2.10.4.
2. The script requires the ECHELLE package or other spectral package containing SCOPY.

Example:

```
ec> imhead test.ec l-
test.ec[512,10][real]: Artificial Echelle Spectrum
ec> type sec.dat
[1:100,1]
[101:200,2]
[201:300,3]
[301:400,4]
[401:500,5]
[101:300,6]
[101:400,7]
ec> echtrim test.ec test1.ec sec.dat
test.ec -> test1.ec
test.ec[1:100,1](1)  -->  test1.ec[*,1](1)
test.ec[101:200,2](2)  -->  test1.ec[*,2](2)
test.ec[201:300,3](3)  -->  test1.ec[*,3](3)
test.ec[301:400,4](4)  -->  test1.ec[*,4](4)
test.ec[401:500,5](5)  -->  test1.ec[*,5](5)
test.ec[101:300,6](6)  -->  test1.ec[*,6](6)
test.ec[101:400,7](7)  -->  test1.ec[*,7](7)
```