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Paranal Science Operations

VIMOS data reduction cookbook

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1 Introduction

This is a short guide through a VIMOS data reduction performed using the VIMOS ESO pipeline. Some suggestions about quality check of the results is provided. This cookbook refers to the VIMOS pipeline version 2.0.15 .

1.1 Purpose

The purpose of this document is just to provide an example of data reduction for VIMOS MOS data. For any other matter please refer to the full exaustive VIMOS pipeline document available through the WEB.

1.2 Gasgano and Esorex

The recipes can be utilized through two different front-end applications. The reduction process is identical, the differences are only on the interfaces. *Gasgano* is a user friendly graphic user interface, ideal for getting familiar with the data reduction system. *Esorex* is a line command front-end application, useful to reduce a large number of spectral frames using automatic scripts. This guide assumes that you have already installed the VIMOS pipeline and the front-end applications *Gasgano* and *Esorex*, and that you have at hand the "Gasgano User manual" and the "VIMOS pipeline User Manual". It's not the purpose of this guide to describe the complete functionality of *Gasgano* and *Esorex*; only the essential configuration steps, that must be performed before starting the reduction process, will be described here.

1.3 Recipes and Calibration Files

It will be assumed here that PIPEHOME is the directory where the VIMOS pipeline is installed. The MOS calibration files are situated typically in PIPEHOME/calib/vimos-X.Y.Z/mos/cal. The recipes files are in PIPEHOME/ lib/vimos/plugins/vimos-X.Y.Z.

1.4 Configuring Gasgano

Enter the "File" menu and select "Preferences" a new window will open, click on "Add file", navigate to the directory with the calibration files (fig. 1), and select all the files related to the instrument mode you are dealing with (*e.g.*, for a MOS data reduction you don't need the "ifu" files).

In the middle of the same window set the "Classification rule file" to PIPEHOME/gasgano/config /VIMOS.rul. You can also set your filter rule file and other things, please refer *Gasgano* user manual for these settings. Now click on "File Display and Grouping" on the top, and specify the complete path to your favourite fits viewers. It would also be advisable to organise your data by instrument quadrant. If *Gasgano* doesn't already do so, you may configure it to this end: go again to the "File Display and Grouping" panel, and find the "Instrument Specific Grouping" box. Select the line referring to VIMOS, and specify the FITS keyword name indicating the VIMOS quadrant, "OCS.CON.QUAD". Now the input files will be displayed on the main window grouped by quadrant (you can of course group your data according to the values of any set of keywords). Finally click on "Recipe Configuration" on the top of the

window, select "Add recipe", navigate to the directory with the recipes, and select all files with the .so extension. Click OK, now you are ready to start.

1.5 Configuring esorex

Edit the file /.esorex/esorex.rc, find the string with esorex.caller.recipe-dir and modified it in this way:

```
Esorex.caller.recipe-dir=PIPEHOME/lib/vimos/plugins/vimos-X.Y.Z.
```

(where X, Y and Z indicate the VIMOS release in use).

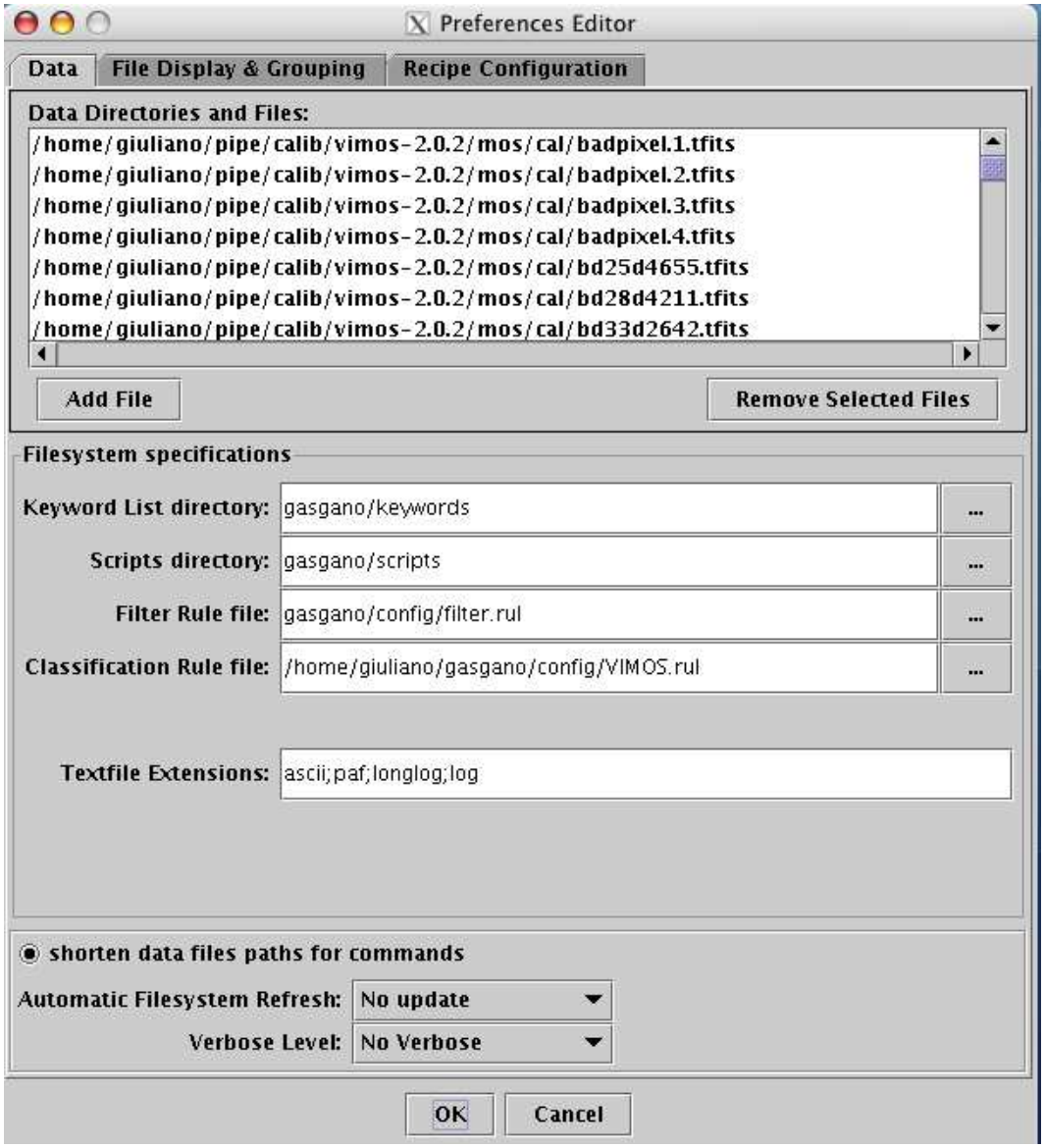


Figure 1: *The Gasgano Preferences window*

2 Reducing MOS data

A typical VIMOS-MOS reduction uses only 6 of the recipes and consists of these 5 steps:

STEP 1: Use *vmbias* to obtain a master bias frame

STEP 2: Use *vmspflat* to obtain the master screen flat and the non-normalised screen flat field

STEP 3: Use *vmspcaldisp* to produce an extraction table

STEP 4: Use *vmmosstandard* to obtain the spectro-photometric table

STEP 5: Use *vmmosobsstare* (*vmmosobsjitter* if you have jittered science exposures) to obtain the final reduced science exposure

These instructions are referred to *Gasgano*, at the end of every step it will be indicated how to execute the same processes using *Esorex*. Select "Add/Remove files" from the file menu, click "add file" and navigate to the directory containing your data. In the illustrated example the data are in the directory "2004-05-15" and its sub-directories "calib", "logs", "raw" and "reduced": selecting the root directory "2005-05-15" *Gasgano* will read all files contained in it and in all its sub-directories. After this step the *Gasgano* main window will look like in figure 2

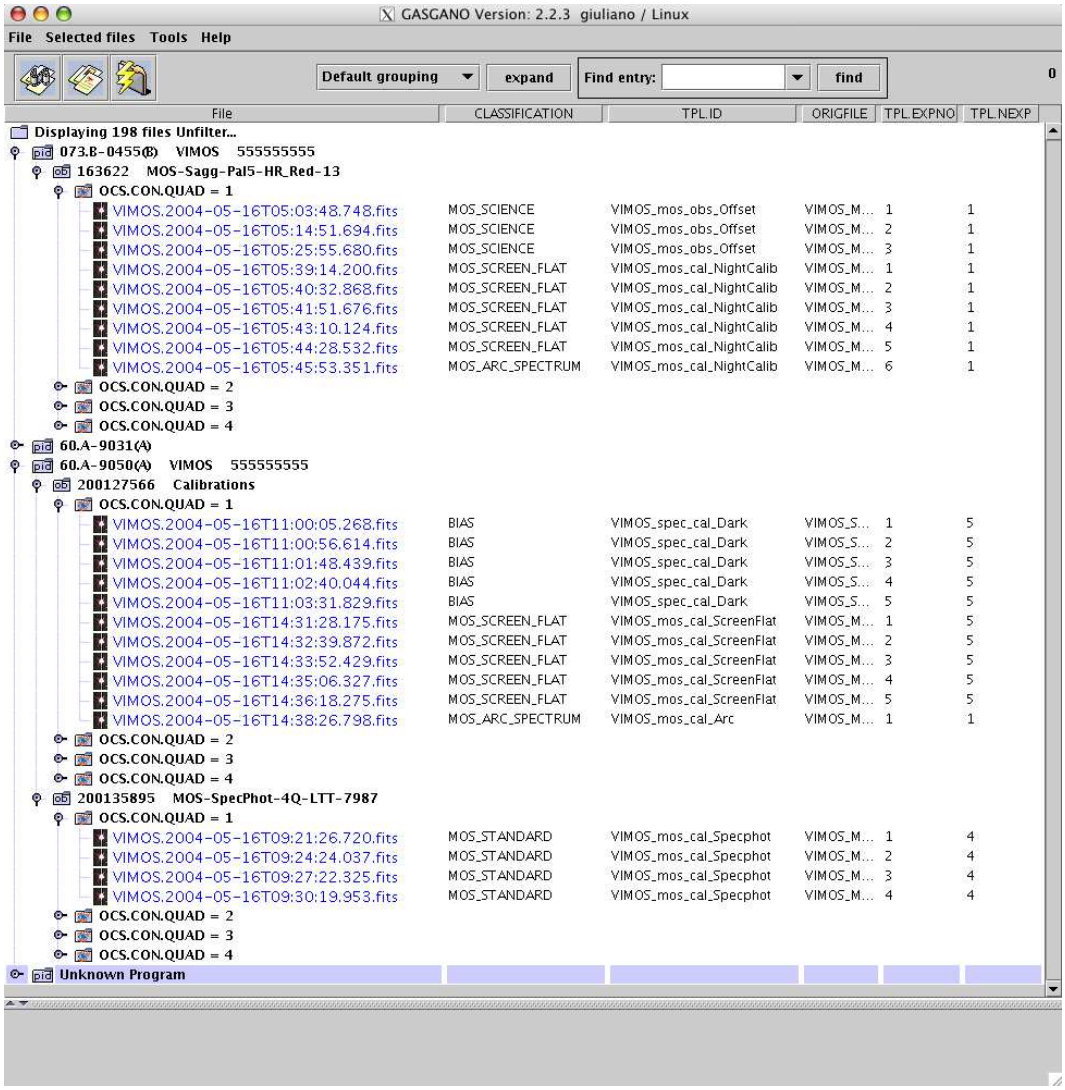


Figure 2: *The Gasgano main window.*

In this example is described the reduction of spectral frames from quadrant 1, obviously the reduction of the other quadrants is conceptually identical. In fig.2 you can see that the example's quadrant 1 data consist in (from top to bottom) :

3 scientific frames,

5 screen flat frames associated with scientific frames,

1 arc spectrum associated with scientific frames,

5 bias frames,

5 screen flat frames associated with standard frames,

1 arc spectrum associated with standard frames,

4 standard frames, but only one must be used.

2.1 Master Bias

Select all the bias files on the *Gasgano*'s window (shift or ctrl + click for multiple selections), click on menu "Selected Files", choose "To recipe" and "vmbias" (look fig.3).

The recipe execution window will appear (fig.4). In the top panel you can find the recipe configuration parameters, in the middle panel the list of input files, and at the bottom the output files and the log box. Typically the creation of the master bias is straightforward: if you want to use "Average" as stacking method, change it by simply clicking on "Median" and select "Average". The other parameters values may also be modified. Read the "VIMOS Pipeline User Manual" to find more information about all the recipe configuration parameters. Now click on "Execute" and wait for the result. When the master bias is created you can close the recipe execution window and return to the *Gasgano*'s main window. You can see the name of the new product (in red) associated to the raw files from which it was derived (in blue).

To accomplish the same operation with *Esorex* you must first create an ASCII file with the names of the input raw frame with their classification tag. In this example this file is named bias.sof, but you can call it any way you want: File: *bias.sof*

```
VIMOS.2004-05-16T11:00:05.268.fits     BIAS
VIMOS.2004-05-16T11:00:56.614.fits     BIAS
VIMOS.2004-05-16T11:01:48.439.fits     BIAS
VIMOS.2004-05-16T11:02:40.044.fits     BIAS
VIMOS.2004-05-16T11:03:31.829.fits     BIAS
```

Then issue the following command to the shell prompt:

```
esorex vmbias -StackMethod=Average bias.sof
```

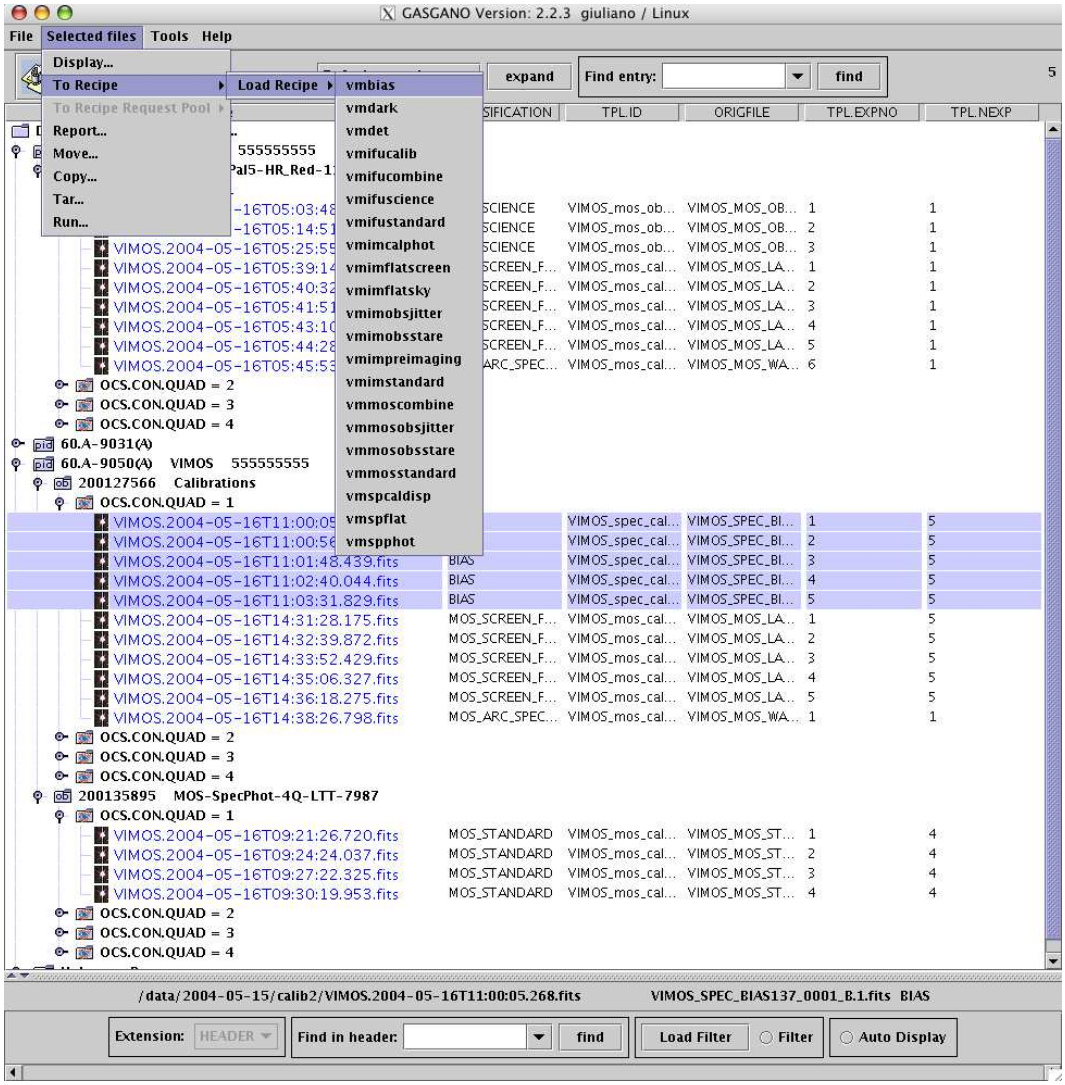


Figure 3: *Launching vmbias recipe.*

2.2 Flat

The creation of master and combined screen flats is equally simple. Select from the *Gasgano*'s main window the MOS_SCREEN_FLAT files you want to use, the MASTER_BIAS file, and the appropriate GRISM_TABLE. You may find the GRISM_TABLE at the bottom, among the files classified under the "Unknown Program" group. In this example the data are obtained with the HR_RED grism, so the file "grs_HR_red.1.tfits" will be selected (1 is the number of quadrant used). Now choose "Selected File" - "To recipe" - "vmspflat", and a new recipe execution window will appear. The default parameters are appropriate for most cases, so choose "Execute" and wait that for the files "mos_master_screen_flat.fits" and "mos_combined_screen_flat.fits" to be produced.

Using *Esorex* you must create the ASCII file with the inputs: File: *mosflat.sof*

```
VIMOS.2004-05-16T05:39:25.956.fits      MOS_SCREEN_FLAT
VIMOS.2004-05-16T05:40:25.956.fits      MOS_SCREEN_FLAT
VIMOS.2004-05-16T05:41:09.806.fits      MOS_SCREEN_FLAT
```

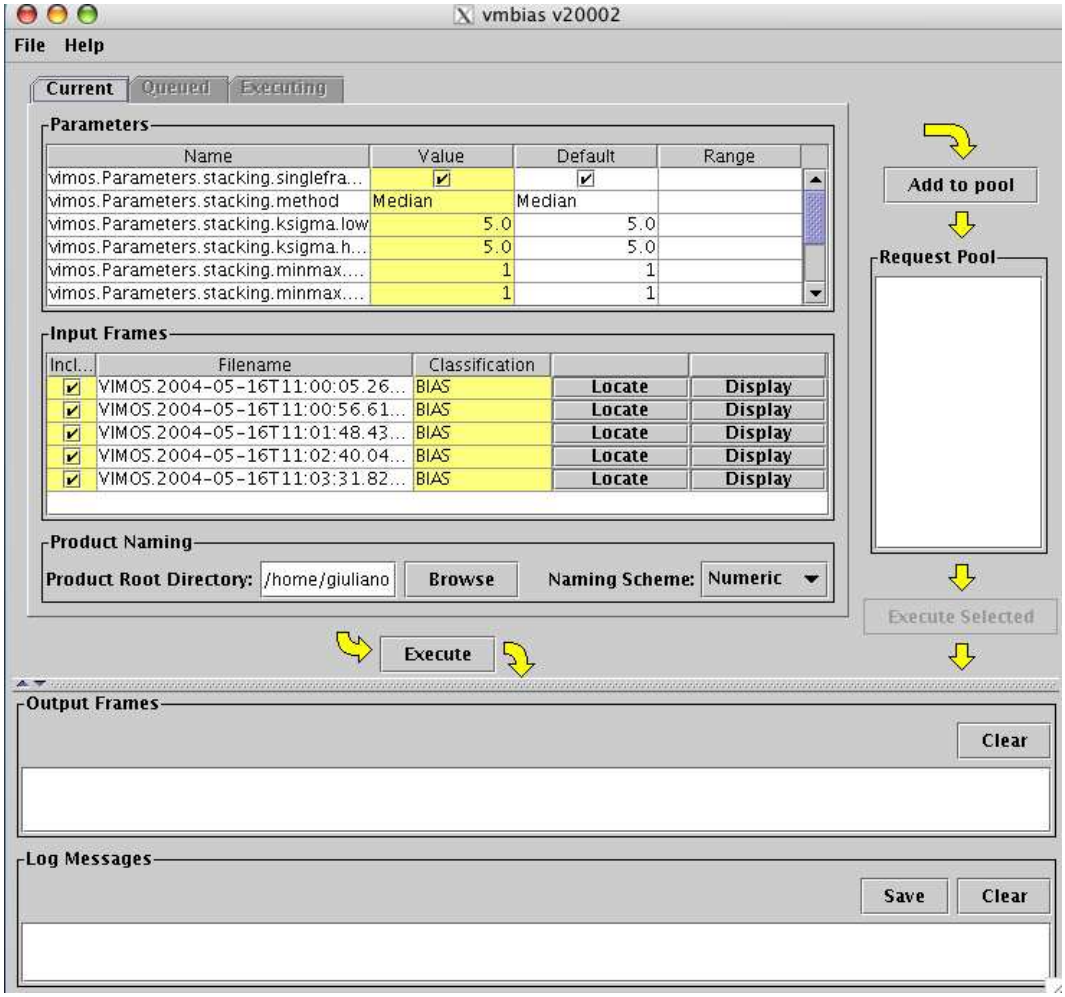


Figure 4: *The Gasgano recipe window.*

```
VIMOS.2004-05-16T05:43:51.246.fits      MOS_SCREEN_FLAT
VIMOS.2004-05-16T05:44:13.433.fits      MOS_SCREEN_FLAT
master_bias.fits                        MASTER_BIAS
/cal/vimos/mos/cal/grs_HR_red.1.tfits   GRISM_TABLE
```

Then use the following command:

```
esorex vmspflat mosflat.sof
```

You must repeat this passage twice. Once to obtain the screen flat files for the scientific frames, and once to obtain the same files for standard frames. Typically *Gasgano* puts the MOS_SCREEN_FLAT files for the scientific frames close to the scientific frames, and the MOS_SCREEN_FLAT files for the standard frames close to the bias frames. If you have some doubts you can check the header keyword INS.MASK1.ID (1 if you are working with quadrant 1): this keyword must have the same value in MOS_SCREEN_FLAT files and in all the associated frames.

2.3 Extraction table

The creation of a good extraction table is the most difficult task of the reduction process. A bad extraction table means a bad wavelength calibration and a bad spectral tracing. It's important to carefully examine the results. Select the file MOS_ARC_SPECTRUM, and the products MASTER_BIAS and MOS_COMBINED_SCREEN_FLAT created in the previous steps. Select also the appropriate GRISM_TABLE and LINE_CATALOG files associated to your grism (in this example the file is lcat_HR_red.1.tfits). You are of course free to modify the entries in the line catalog, if you think that a better choice of reference lines could be used. You may also modify the GRISM_TABLE to specify different spectral intervals to calibrate and extract.

Begin with the arc spectrum and the screen flat associated to the scientific frames (*i.e.*, obtained with the same slits). Start the recipe *vmspcaldisp* and try to click "Execute" with the default parameters values. This recipe will produce the file extract_table.tfits, that will be useful for the next steps, and the calibrated arc lamp spectrum. At the bottom of the log box find the string "Global IDS RMS" and check the corresponding value (see fig. 5). If it is around 0.3-0.4 pixels, or less, the solution is probably acceptable. But more likely higher values are reported: in this example the value 2.805 pixel has been obtained (see fig. 5). The quality of the calibration can also be appreciated by viewing the extracted arc lamp slit spectra, by just clicking the corresponding "Display" button in the products window. In case of high RMS values something similar to fig.6 might have been obtained: the spectral emission lines are not aligned, and in some cases the spectra are apparently distorted.

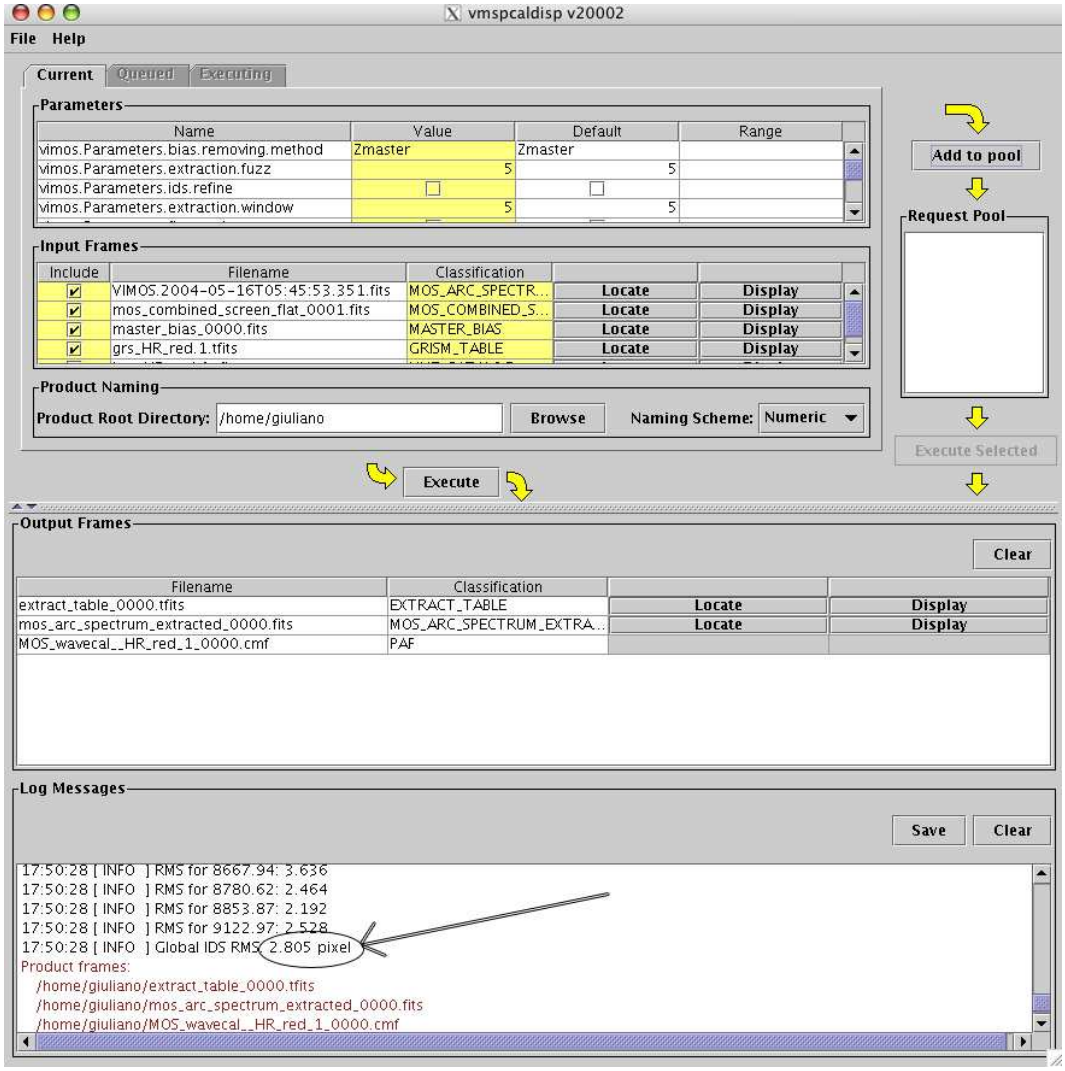


Figure 5: *Vmspcaldisp window with RMS value.*

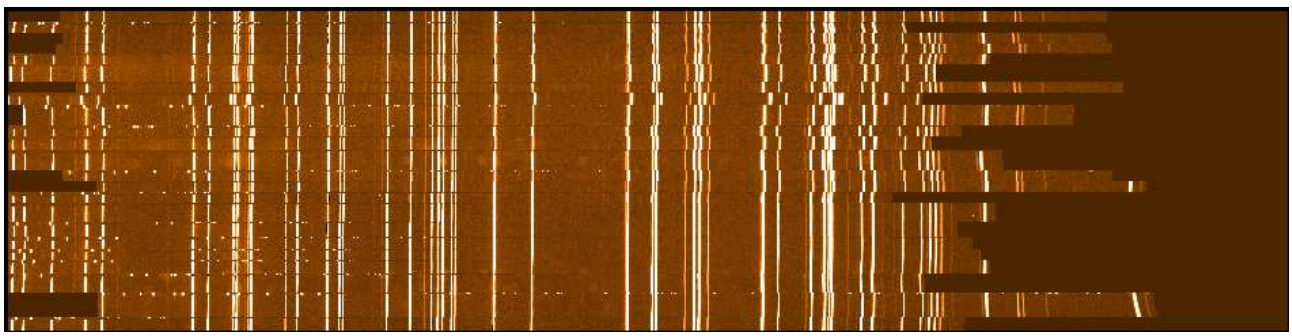


Figure 6: *Arc spectrum extracted, example of bad result*

The main reason of such failures is that the spectral distortions models, described in the input FITS files headers, are typically not accurate enough to guarantee a safe identification of the reference arc lamp lines and of the flat field spectra edges. For this reason different identification strategies need to be applied in the search of a good wavelength calibration for your data. From a practical point of view, you would need to play a bit with the recipe parameter values. The good new is that spectral frames obtained in the same night and with the same mask will probably have the same problems, and therefore the same solutions. The key parameters to play with are the following:

```
Vimos.Parameters.extraction
Vimos.Parameters.slit.model
Vimos.Parameters.ids.refine
Vimos.Parameters.extraction.fuzz
Vimos.Parameters.extraction.window
```

For a complete decription of the meanings of these parameters please refer to "VIMOS Pipeline User Manual".

First of all, try to change the parameter "Vimos.Parameters.extraction" from Global to Local, flag on "Vimos.Parameters.ids.refine" and "Vimos.Parameters.slit.model", run the recipe and check the result. In this example the value 0.413 has been obtained. If your arc lamp spectrum is not too crowded with emission lines, it may be possible to further improve the result by specifying a larger line search interval (parameter "Vimos.Parameters.extraction.window"). Similarly, in case the slit spectra do not seem to be properly traced, the search interval for flat field spectral edges may be extended (parameter "Vimos.Parameters.extraction.fuzz").

Once having determined the parameters values corresponding to an acceptable RMS value, change the parameter "Vimos.Parameters.extraction" back to Global. If the result doesn't improve, return to Local. If despite all further attempts you cannot improve the solution, you may try to improve it by iteration: select the best obtained extraction table and drag it with the mouse from the *Gasgano* main window to the "Input Frames" panel of the recipe execution window. In this way the extraction table created in your best attempt will be used as first-guess, instead of those carried in the input arc lamp exposure FITS header. There is no need to modify the configuration parameters, leave the best settings you have found and click "execute". Probably you will obtain a better result. If despite all attempts you still have a bad result, it's time to attempt a completely different strategy, consisting of completely ignoring any first-guess model found in the input data headers, or in an iterated extraction table. For this you need to change the parameter "vimos.Parameters.line.ident.method" from "FirstGuess" to "Blind", and try different values of the peak identification threashold, "vimos.Parameters.line.ident.level". This method, based on pattern-matching, is the last resort to reduce data with very inaccurate first-guess distorsion model. If not even this solution works, send an e-mail to ESO-Support and explain your problem and the attempts you have made.

The best result obtained for this example, with a Global IDS RMS equal to 0.286 pixels, is shown in fig.7.

The same procedure should now be repeated with the standard star exposure, that is normally made using a different mask. In this case however it's not important to obtain very high accuracies: a Global IDS RMS 0.8 or 0.9 pixels is generally acceptable for a good spectrophotometric calibration.

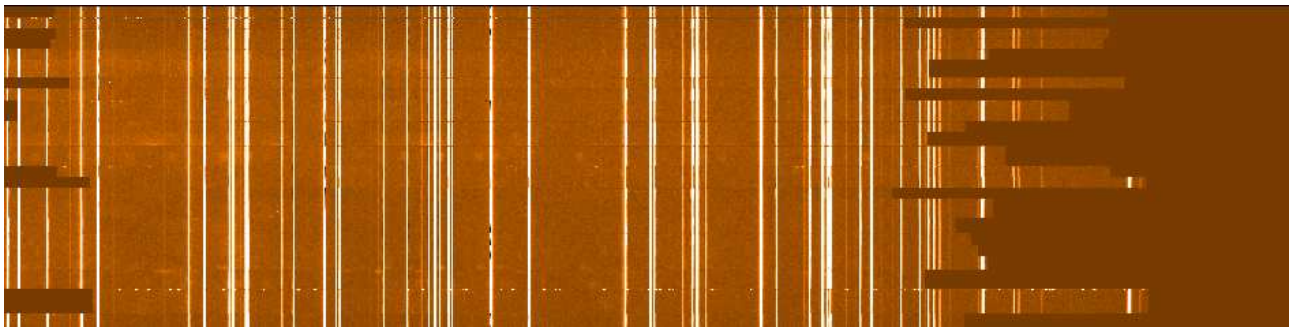


Figure 7: *Arc spectrum extracted, example of good result*

In case you are using *Esorex* you must create an input set-of-frames file, that in this example we call distorsions.sof:

File: *distortions.sof*

```
VIMOS.2004-05-16T05:45:53.351.fits      MOS_ARC_SPECTRUM
master_bias.fits                        MASTER_BIAS
mos_combined_screen_flat.fits           MOS_COMBINED_SCREEN_FLAT
/cal/vimos/mos/cal/grs_HR_red.1.tfits   GRISM_TABLE
/cal/vimos/mos/cal/lcat_HR_red.1.tfits LINE_CATALOG
```

and specify all the parameters in the command line: for example if in *Gasgano* you flagged on "Vimos.Parameters.ids.refine" and "Vimos.Parameters.slit.model", and you specified the "Local" modeling, you must use the command:

```
esorex vmspcaldisp -RefineIDS=true -ArcExtraction=Local
                   -ModelSlit=true distorsions.sof
```

2.4 Spectrophotometric table

In this section is described how to obtain a spectral response curve from your spectrophotometric standard star observation.

Select in the *Gasgano* main window the MOS_STANDARD spectral frame. In this example there are four files for each quadrant, but only one contains the standard star. Check the header keyword TPL.EXPNO: if you are in the first quadrant the frame with TPL.EXPNO=1 is the right frame; if you are in the quadrant X the right frame is the one with TPL.EXPNO=X. To be sure, display the frame and check if it contains the (typically bright) standard star spectrum: it should look like fig.7, where the standard star is the white line on the central slit spectrum.

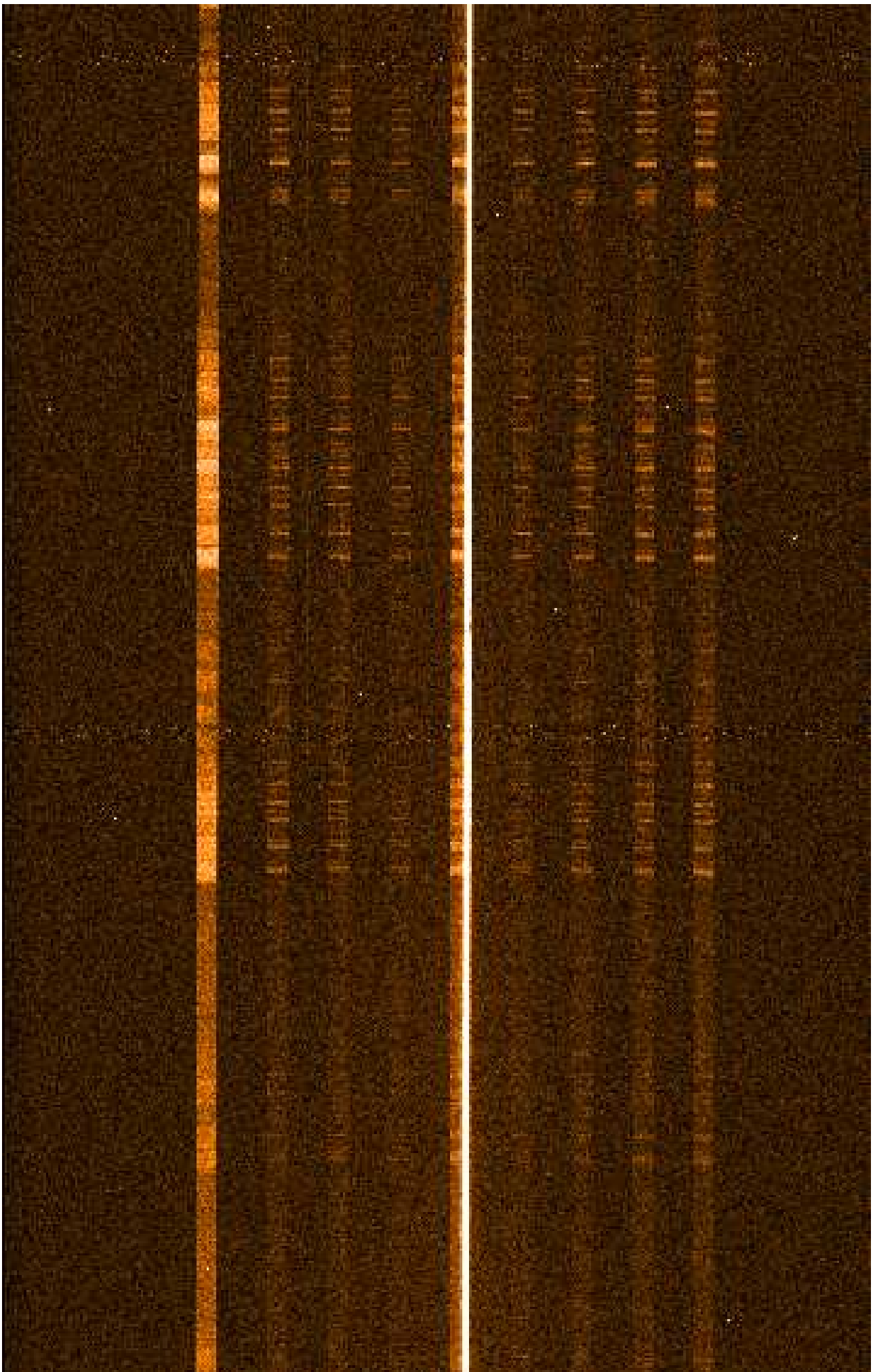
After selecting the MOS_STANDARD frame, select the MASTER_BIAS, the EXTRACT_TABLE computed for the standard star observation (*not* the extraction table associated to the scientific frames). From the static calibration files select also the GRISM_TABLE, the atmospheric extinction table EXTINCT_TABLE (extinct_table.tfits), and the corresponding STD_FLUX_TABLE containing the standard star spectrum in physical units. The standard flux table to use should correspond to the observed standard star: search in the header of the standard star exposure the keyword "OBS.TARG.NAME". In this example the standard star is LTT-7987, so the file ltt7987.tfits must be used (note that the FITS header of this file contains a keyword "OBS.TARG.NAME" with exactly the same content, so this keyword can be used for association). You may also need a bad pixel map, so find the file badpixel.1.tfits, or badpixel.X.tfits if you are in quadrant X. Runnig the recipe *vmmosstandard*, you will in general not encounter any problem, but sometimes you may obtain this error message:

```
[ ERROR ] vmmosstandard: More than one object found! Use parameter
          SelectSlit to indicate the slit with the standard star.
```

Before going to specify in what slit the standard star spectrum is to be found, you may simply try to increase the value of the parameter "vimos.Parameters.detection.sigma". Its default value (10.0 sigma) is generally OK, but if the recipe finds more than one object we can safely assume that the brighter one is the standard star spectrum. Naturally, if you increase this threshold too much you may risk not to detect any object, obtaining the error message:

```
[ ERROR ] vmmosstandard: No objects found!
```

If you cannot find the appropriate threshold capable of selecting the standard star spectrum, try to indicate the slits where the spectrum can be found. Typically the standard star is observed with slit 1 (the sequence number of the slits can be found in the header): display the standard frame, and if you see the spectrum in the central slit, like in fig.8, then the standard star is in slit number 1. In this case set "vimos.Parameters.slit.select"=1.



In case you are using *Esorex* you must create the input set-of-frames file, named standard.sof in this example:

File: *standard.sof*

```
VIMOS.2004-05-16T09:21:26.720.fits      MOS_STANDARD
master_bias.fits                        MASTER_BIAS
extract_table_std.tfits                 EXTRACT_TABLE
/cal/vimos/mos/cal/grs_LR_red.1.tfits   GRISM_TABLE
/cal/vimos/mos/cal/extinct_table.tfits EXTINCT_TABLE
/cal/vimos/mos/cal/ltt7987.tfits        STD_FLUX_TABLE
```

Curiously, the parameter "vimos.Parameters.detection.sigma" became in *Esorex* "Detection-Level" (that is *different* from parameter "vimos.Parameters.detection.levels" of *Gasgano*). So if you want to use the slit number one you can use the following command:

```
esorex vmmosstandard --DetectionLevel=1 --SelectSlit=1 standard.sof
```

2.5 Scientific frames reduction

If all the previous steps were accomplished with good results, you will normally not encounter further problems to complete the reduction. Select one of the scientific frames, the MASTER_BIAS, the EXTRACT_TABLE associated to the scientific frames (not the one associated to the standard star exposure), the GRISM_TABLE (grs_HR_red.1.tfits in this example), the EXTINCT_TABLE and the MOS_SPECPHOT_TABLE produced in the previous step. Select the recipe *vmmosobsstare*, flag on the parameter "vimos.Parameters.flux.calibration", and click "Execute". If you have more than one scientific frame obtained with the same mask in the same night, select all of them, then select all the files listed before and run the recipe *vmmosobsjitter* instead of *vmmosobsstare*. Also in this case flag on the parameter "vimos.Parameters.flux.calibration". When a set of jittered exposures is processed, it can also be attempted the removal of the sky spectral fringing. Two methods are available, "Raw" or "Resampled" (indicated with the parameter "vimos.Parameters.fringing.removing.method"). Don't expect great results: both methods are just aimed at removing the *sky* fringing, and not the fringing inherent to the objects spectra. This can only be helpful for very weak objects, where the sky brightness is much higher than the objects signal, but the fringing of the object spectra will remain.

2.6 Quality check

To check the quality of your result display the MOS_SCIENCE_SKY frame, containing the sky modeled for each slit spectrum, and ensure that the skylines are all well aligned. See the example in fig.9, you should obtain something similar.

Figure 9: *Sky Frame*

You need however something more than a visual check to estimate the real accuracy in wavelength of your data. In general a number of bright and unblended sky lines may be used to evaluate the reached accuracy. In our example, using HR_RED data, the following sky lines may be used:

SKY1 = 7821.503 Å

SKY2 = 8344.6152 Å

SKY3 = 8399.1963 Å

SKY4 = 8430.2002 Å

SKY5 = 8465.3926 Å

Now find the value of

```
diff = (observed wavelength) - (expected wavelength) / (resampling step)
```

for each line, and for each slit, and plot this value as a function of the skylines wavelengths. A typical result is in fig.10.

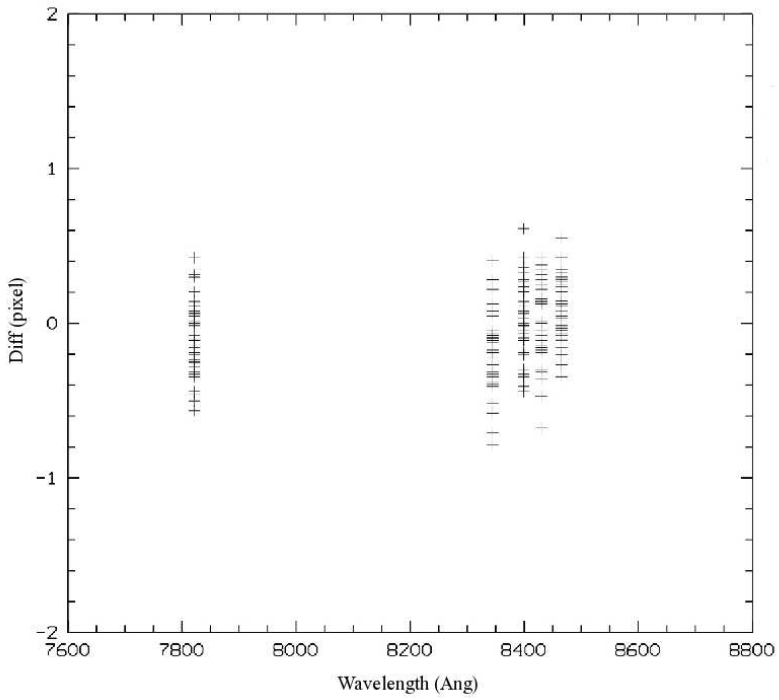


Figure 10: *Sky lines residuals (in pixel)*

You should obtain something similar, (or better). If you obtain a higher scatter of the residuals, or observe some systematic trends, something has gone wrong during the previous reduction steps. If you observe some systematic trends, similar to fig.11, probably the arc spectrum and the scientific exposure were obtained at very different air temperatures. Check if another arc spectrum was taken during the same night, otherwise you will probably need to align the arc-based wavelength calibration to the sky lines positions by yourself.

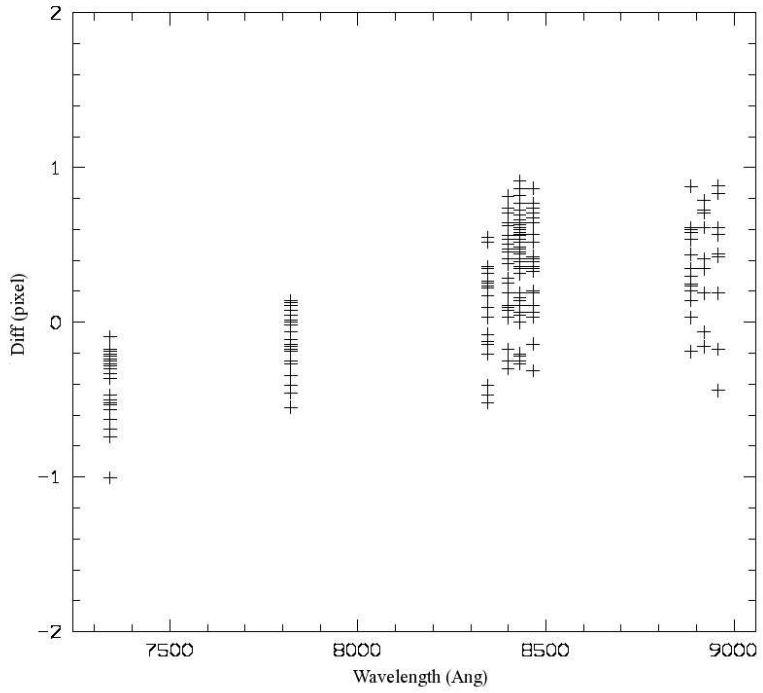


Figure 11: *Systematic trends in sky lines residuals*

The accuracy in wavelength for each slit spectrum can be estimated from the distribution of the residuals, applying the usual

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^{n} \Delta p_{ij}^2}{n}}$$

where Δp_{ij} is the residual of the j-th line in slit i, and n is the number of sky lines used. You must obtain a typical value of about 0.2 pixels. In this example the result is shown in fig.12, where even if some of the slit spectra display a relatively high RMS (up to 0.5 pixels) most of them are good.

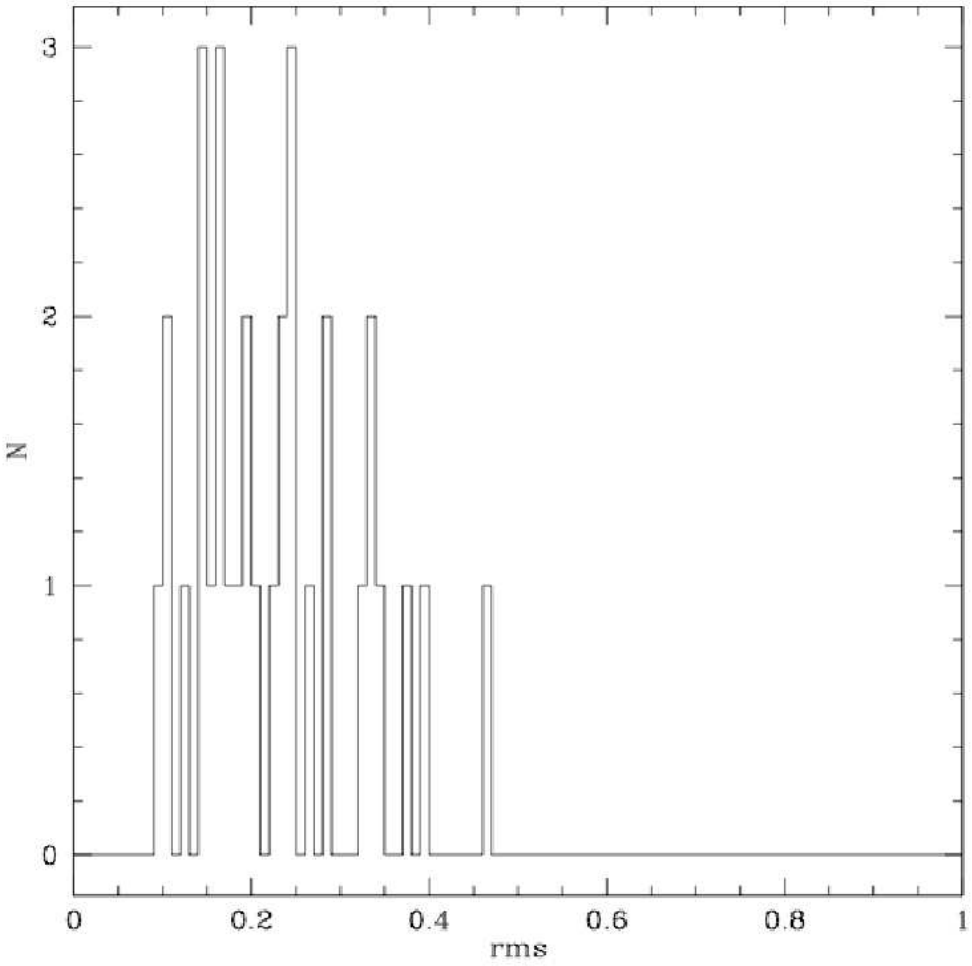


Figure 12: *Plot of the obtained RMS for each slit*

2.7 Reference documents

1 ESO DICB - Data Interface Control Document - GEN-SPE-ESO-00000-0794
2 VIMOS Calibration Plan - VLT-PLA-ESO-14610-3556
3 VIMOS User Manual - VLT-PLA-ESO-14610-3509

2.8 Abbreviations and acronyms

The following abbreviations and acronyms are used in this document:

SciOp	Science Operations
ESO	European Southern Observatory
Dec	Declination
eclipse	ESO C Library Image Processing Software Environment
ESO-MIDAS	ESO's Munich Image Data Analysis System
FITS	Flexible Image Transport System
IRAF	Image Reduction and Analysis Facility
PAF	PArameter File
RA	Right Ascension
UT	Unit Telecope
VLT	Very Large Telescope

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