



EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral

Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

VERY LARGE TELESCOPE

Reflex KMOS Tutorial

VLT-MAN-ESO-19500-....

Issue 1.2

Date 2015-03-24

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Name Date Signature

Released: –
Name Date Signature

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Change record

Issue/Rev.	Date	Section affected	Reason/Initiation/Documents/Remarks
0.1	25/06/2013	All	Initial Release
0.2	15/07/2013	All	Description of Demo Data
1.0	19/09/2013	All	Revision of product data description and incl. of interactive mode
1.1	29/10/2013	All	Use Reflex 2.5 and Integration in ESO SVN
1.2	19/03/2014	§9	Description of interactive actors (v. 1.3.0), including parameter tables

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1 Introduction And Scope

Reflex is the ESO Recipe Flexible Execution Workbench, an environment to run ESO VLT pipelines which employs a workflow engine to provide a real-time visual representation of a data reduction cascade, called a workflow, which can be easily understood by most astronomers. The basic philosophy and concepts of Reflex have been discussed by Freudling et al. (2013A&A...559A..96F). Please reference this article if you use Reflex in a scientific publication.

Reflex and the data reduction workflows have been developed by ESO and instrument consortia and they are fully supported. If you have any issue, please contact usd-help@eso.org for further support.

This document is a tutorial designed to enable the user to employ the KMOS workflow to reduce his/her data in a user-friendly way, concentrating on high-level issues such as data reduction quality and signal-to-noise (S/N) optimisation.

A workflow accepts science and calibration data, as delivered to PIs in the form of PI-Packs (until October 2011) or downloaded from the archive using the CalSelector tool¹ and organises them into DataSets, where each DataSet contains one science object observation (possibly consisting of several science files) and all associated raw and static calibrations required for a successful data reduction. The data organisation process is fully automatic, which is a major time-saving feature provided by the software. The DataSets selected by the user for reduction are fed to the workflow which executes the relevant pipeline recipes (or stages) in the correct order. Full control of the various recipe parameters is available within the workflow, and the workflow deals automatically with optional recipe inputs via built-in conditional branches. Additionally, the workflow stores the reduced final data products in a logically organised directory structure employing user-configurable file names.

This tutorial deals with the reduction of KMOS IFU observations only via the KMOS Reflex workflow. The user is referred to the KMOS user manual (Cirasuolo ²). More information on the instrument itself as well as a summary of available documentation, recent news, and tools, can be found at the ESO instrument web pages ³. A brief description of the KMOS data flow is given in Davies ²⁴)

The quick start section (see Section 5) describes the minimum effort to get started, and it makes up only two pages of text in this tutorial. User support for this software is available by sending enquiries to usd-help@eso.org.

¹<http://www.eso.org/sci/archive/calselectorInfo.html>

²available at: <http://www.eso.org/sci/facilities/paranal/instruments/kmos/doc>

³<http://www.eso.org/sci/facilities/develop/instruments/kmos.html>

⁴available at: <http://www.mpe.mpg.de/389507/davies-7735-254x.pdf>

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2 Workflow Status

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3 Software Installation

The software pre-requisites for Reflex 2.6 may be found at:

http://www.eso.org/sci/software/pipelines/reflex_workflows

To install the Reflex 2.6 software and demo data, please follow these instructions:

1. From any directory, download the installation script:

```
wget ftp://ftp.eso.org/pub/dfs/reflex/install_esoreflex
```

2. Make the installation script executable:

```
chmod u+x install_esoreflex
```

3. Execute the installation script:

```
./install_esoreflex
```

and the script will ask you to specify three directories: the download directory <download_dir>, the software installation directory <install_dir>, and the directory to be used to store the demo data <data_dir>. If you do not specify these directories, then the installation script will create them in the current directory with default names.

4. You will be asked whether you want to use your Internet connection. Unless you want to reuse already downloaded packages (only advanced users), use the default Yes.
5. You will be given a choice of pipelines (with the corresponding workflows) to install. Please specify the numbers for the pipelines you require, separated by a space, or type “A” for all pipelines.
6. For the pipelines to be installed you will be prompted for the demo data sets to be installed. Type “A” for all demo datasets. Take into account that if you are installing in a directory that already contains data, it won’t be removed.
7. The script will also detect whether previous versions of the workflows or Reflex were installed and in this case you have the option to update links or remove obsolete cache directories. It is advised to use the defaults.
8. To start Reflex, issue the command:

```
<install_dir>/bin/esoreflex
```

It may also be desirable to set up an alias command for starting the Reflex software, using the shell command `alias`. Alternatively, the `PATH` variable can be updated to contain the <install_dir>/bin directory.

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4 Demo Data

Together with the pipeline you will also receive a demo data set, that allows you to run the Reflex KMOS workflow without any changes in parameters. This way you have a data set to experiment with before you start to work on your own data.

Note that you will need a minimum of ~ 5 GB, ~ 9 GB and ~ 2.5 GB of free disk space for the directories `<download_dir>`, `<install_dir>` and `<data_dir>`, respectively.

The raw input consists of a single SCIENCE OB of the HII, star-formation region Gum 43 (RCW 65) executed in NOD to SKY mode, and includes the raw calibration frames: darks, lamp flats, arc lamps, and flux standards. The static calibration files (arc line lists, atmosphere model, OH spectral lines, and arc reference lines) are included in the pipeline distribution. The raw tutorial data set is summarized in table 4.1.

Table 4.1: The KMOS Reflex workflow tutorial data set

File	DPR.CATG	DPR.TYPE	INS.GRAT1.ID	DET.SEQ1.DIT
KMOS.2013-06-27T02:30:02.036.fits	CALIB	FLAT.OFF	K	3.0000000
KMOS.2013-06-27T02:30:13.935.fits	CALIB	FLAT.OFF	K	3.0000000
KMOS.2013-06-27T02:30:26.009.fits	CALIB	FLAT.OFF	K	3.0000000
KMOS.2013-06-27T02:33:25.442.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:33:37.272.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:33:49.244.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:34:42.585.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:34:54.500.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:35:06.539.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:35:59.909.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:36:11.744.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:36:23.588.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:37:17.002.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:37:27.878.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:37:40.018.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:38:33.399.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:38:45.321.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:38:57.219.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:39:50.556.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:40:02.535.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:40:14.442.fits	CALIB	FLAT.LAMP	K	3.0000000
KMOS.2013-06-27T02:42:34.927.fits	CALIB	WAVE.OFF	K	4.0000000
KMOS.2013-06-27T02:45:31.613.fits	CALIB	WAVE.LAMP	K	4.0000000
KMOS.2013-06-27T02:46:24.832.fits	CALIB	WAVE.LAMP	K	4.0000000
KMOS.2013-06-27T02:47:18.086.fits	CALIB	WAVE.LAMP	K	4.0000000
KMOS.2013-06-27T02:48:12.603.fits	CALIB	WAVE.LAMP	K	4.0000000
KMOS.2013-06-27T02:49:06.959.fits	CALIB	WAVE.LAMP	K	4.0000000
KMOS.2013-06-27T02:50:01.906.fits	CALIB	WAVE.LAMP	K	4.0000000
KMOS.2013-06-28T22:21:22.894.fits	CALIB	FLAT.SKY	K	5.0000000
KMOS.2013-06-28T22:21:57.131.fits	CALIB	FLAT.SKY	K	30.0000000
KMOS.2013-06-28T22:22:36.403.fits	CALIB	FLAT.SKY	K	30.0000000
KMOS.2013-06-28T22:23:14.587.fits	CALIB	FLAT.SKY	K	30.0000000
KMOS.2013-06-29T05:25:36.594.fits	CALIB	OBJECT.SKY,STD,FLUX	K	10.0000000
KMOS.2013-06-29T05:26:08.050.fits	CALIB	OBJECT.SKY,STD,FLUX	K	10.0000000
KMOS.2013-06-29T05:26:34.039.fits	CALIB	OBJECT.SKY,STD,FLUX	K	10.0000000
KMOS.2013-06-30T14:52:42.168.fits	CALIB	DARK	YJ	100.0000000
KMOS.2013-06-30T14:54:30.888.fits	CALIB	DARK	YJ	100.0000000
KMOS.2013-06-30T14:56:19.580.fits	CALIB	DARK	YJ	100.0000000
KMOS.2013-06-30T14:58:08.242.fits	CALIB	DARK	YJ	100.0000000
KMOS.2013-06-30T14:59:56.907.fits	CALIB	DARK	YJ	100.0000000
KMOS.2013-06-30T23:48:06.049.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-06-30T23:53:23.571.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-06-30T23:59:09.586.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-07-01T00:04:22.390.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-07-01T00:09:35.560.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-07-01T00:14:52.379.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-07-01T00:20:10.285.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-07-01T00:25:24.507.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-07-01T00:30:37.274.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-07-01T00:35:55.867.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-07-01T00:41:13.785.fits	SCIENCE	OBJECT.SKY	K	300.0000000
KMOS.2013-07-01T00:46:26.588.fits	SCIENCE	OBJECT.SKY	K	300.0000000

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5 Quick Start: Reducing The Demo Data

For the user who is keen on starting reductions without being distracted by detailed documentation, we describe the steps to be performed to reduce the science data provided in the KMOS demo data set supplied with the Reflex 2.6 release. By following these steps, the user should have enough information to attempt a reduction of his/her own data without any further reading:

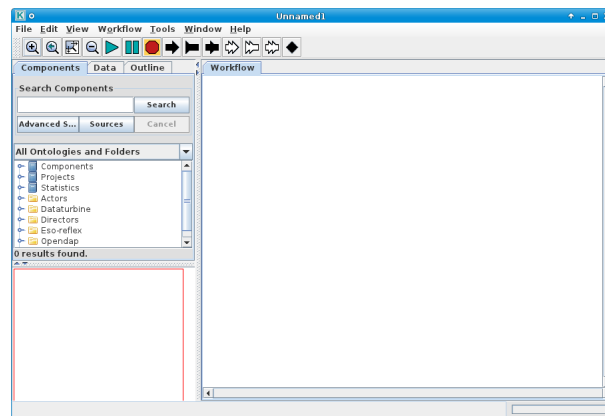


Figure 5.1: *The empty Reflex canvas.*

1. Start the Reflex application:


```
reflex &
```

The empty Reflex canvas as shown in Figure 5.1 will appear.

2. Now open the KMOS workflow by clicking on File -> Open File, selecting first `kmos-1.3.11` and then the file `kmos.xml` in the file browser. You will be presented with the workflow canvas shown in Figure 5.2. Note that the workflow will appear as a canvas in a new window.
3. To aid in the visual tracking of the reduction cascade, it is advisable to use component (or actor) highlighting. Click on Tools -> Animate at Runtime, enter the number of milliseconds representing the animation interval (100 ms is recommended), and click .
4. Under “Setup Directories” in the workflow canvas there are seven parameters that specify important directories (green dots). Setting the value of `ROOT_DATA_DIR` is the only necessary modification if you want to process data other than the demo data⁵, since the value of this parameter specifies the working directory within which the other directories are organised. Double-click on the parameter `ROOT_DATA_DIR` and a pop-up window will appear allowing you to modify the directory string, which you may either edit directly, or use the button to select the directory from a file browser. When you have finished, click to save your changes.

⁵If you used the install script `install_reflex`, then the value of the parameter `ROOT_DATA_DIR` will already be set correctly to the directory where the demo data was downloaded.

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5. Click the  button to start the workflow
6. The workflow will highlight the `Data Organiser` actor which recursively scans the raw data directory (specified by the parameter `RAWDATA_DIR` under “Setup Directories” in the workflow canvas) and constructs the `DataSets`. Note that the raw and static calibration data must be present either in `RAWDATA_DIR` or in `CALIB_DATA_DIR`, otherwise `DataSets` may be incomplete and cannot be processed. However, if the same reference file was downloaded twice in different places this creates a problem as `Reflex` cannot decide which one to use.
7. The `Data Set Chooser` actor will be highlighted next and will display a “Select Datasets” window (see Figure 5.3) that lists the `DataSets` along with the values of a selection of useful header keywords⁶. The first column consists of a set of tick boxes which allow the user to select the `DataSets` to be processed, and by default all complete `DataSets` are selected.
8. Click the `Continue` button and watch the progress of the workflow by following the red highlighting of the actors. A window will show which `DataSet` is currently being processed.
9. When the reduction of the current `DataSet` finishes, a pop-up window called *Provenance Explorer* will appear showing the datasets which have been so far reduced together with the list of final products. This actor allows the user to inspect the final data products, as well as to search and inspect the input data used to create any of the products of the workflow. Figure 5.4 shows the *Provenance Explorer* window.
10. The workflow will continue with the remaining `DataSets` following the same steps described above.
11. After the workflow has finished, all the products from all the `DataSets` can be found in a directory under `END_PRODUCTS_DIR` with the named with the workflow start timestamp. Further subdirectories will be found with the name of each `DataSet`.

Well done! You have successfully completed the quick start section and you should be able to use this knowledge to reduce your own data. However, there are many interesting features of `Reflex` and the `KMOS` workflow that merit a look at the rest of this tutorial.

⁶The keywords listed can be changed by right-clicking on the `DataOrganiser Actor`, selecting `Configure Actor`, and then changing the list of keywords in the second line of the pop-up window.

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KMOS Workflow (v. 1.3.0b1)

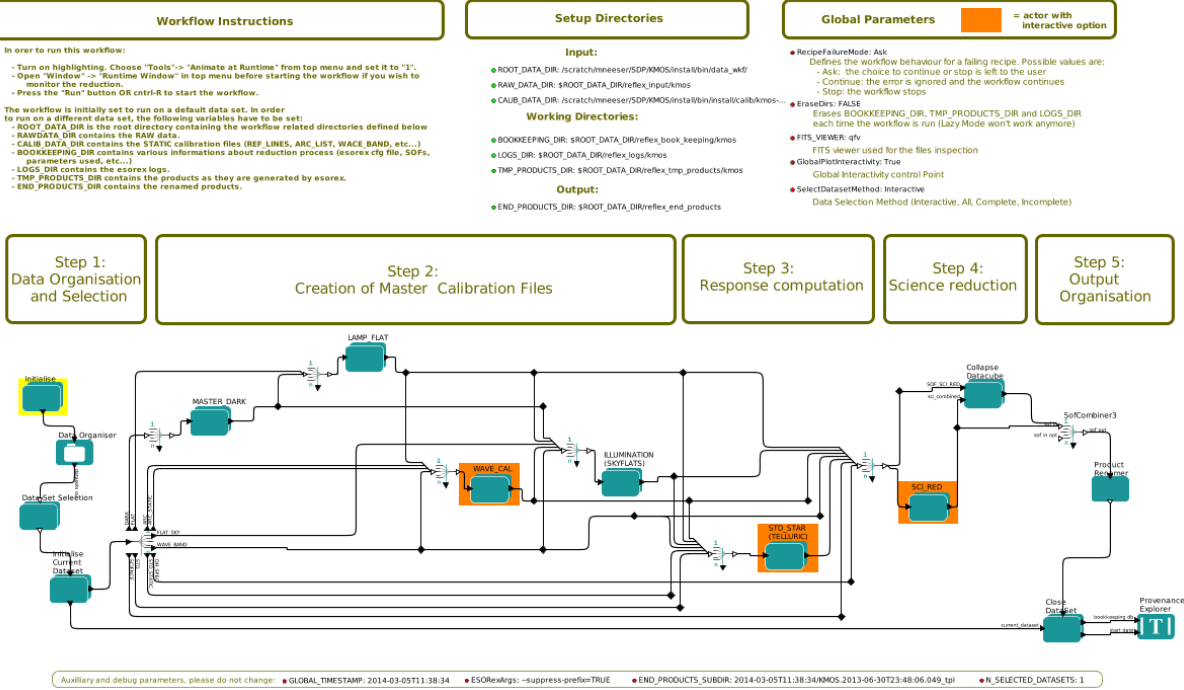


Figure 5.2: KMOS workflow general layout.



Figure 5.3: The “Select Datasets” pop-up window.

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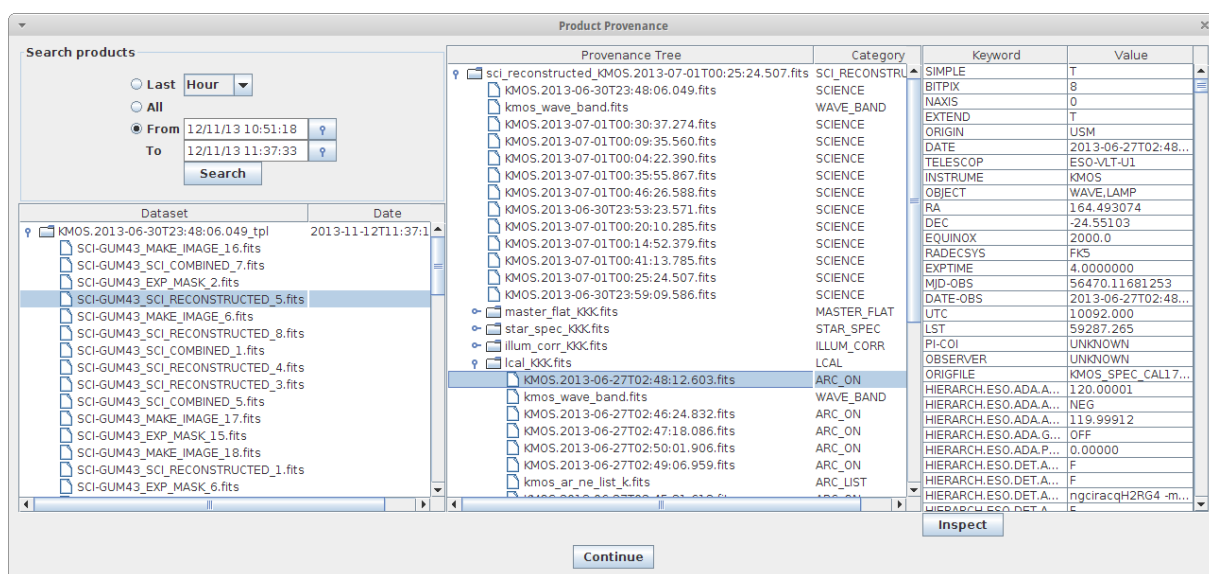


Figure 5.4: The KMOS provenance explorer.

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6 Reducing Science Verification Data

To reduce science verification data, simply change the path to the raw data directory defined at the top of the workflow labelled `Setup Directories` by double clicking on `RAW_DATA_DIR`. Then just re-run the workflow as for the tutorial demo data.

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7 KMOS Reduced Data Description

A number of intermediate pipeline products from the tutorial data set can be found in subdirectories of the `TMP_PRODUCT_DIR`. These master calibration files are summarized in table 7.1.

Table 7.1: The KMOS Reflex workflow tutorial data set: calibration products

File	PRO.CATG	Description
kmoss_dark: badpixel_dark.fits master_dark.fits	BADPIXEL_DARK MASTER_DARK	preliminary bad pixel map (hot pixels) master dark frame including a noise map
kmoss_flat: badpixel_flat_KKK.fits flat_edge_KKK.fits master_flat_KKK.fits xcal_YJYJYJ.fits ycal_YJYJYJ.fits	BADPIXEL_FLAT FLAT_EDGE MASTER_FLAT XCAL YCAL	master bad pixel map (hot + cold pixels) fits table defining the edges of each IFU pseudo slit as derived from the screen flat frames master flat-field frame including noise map spatial solution lookup frame spatial solution lookup frame
kmoss_wave: det_img_wave_KKK.fits lcal_KKK.fits	DET_IMG_WAVE LCAL	resampled image of reconstructed arc frame wavelength solution lookup frame
kmoss_illum: illum_corr_KKK.fits skyflat_edge_KKK.fits	ILLUM_CORR SKYFLAT_EDGE	illumination correction to flat-filed fits table defining the edges of each pseudo slit IFU as derived from the sky flat frames
kmoss_std: star_spec_KKK.fits std_image_KKK.fits std_mask_KKK.fits telluric_KKK.fits	STAR_SPEC STD_IMAGE STD_MASK TELLURIC	extracted star spectrum collapsed standard star cube image masked pixels within the collapsed standard star cube image normalized telluric spectrum including noise map

The final products of the reduction pipeline can be found in the directory `END_PRODUCT_DIR` that is defined in the “Setup Directories” section at the top of the workflow.

The science data products from the tutorial data set are summarized in table 7.2.

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Table 7.2: The KMOS Reflex workflow science products from the tutorial data set (all K-band)

File	PRO.CATG	Description
SCI-GUM43_MAKE_IMAGE.fits	MAKE_IMAGE	the median collapse of the IFU #1 data cube along the wavelength direction.
SCI-GUM43_MAKE_IMAGE_1.fits	MAKE_IMAGE	the median collapse of the IFU #2 data cube along the wavelength direction.
SCI-GUM43_MAKE_IMAGE_2.fits	MAKE_IMAGE	the median collapse of the IFU #3 data cube along the wavelength direction.
SCI-GUM43_MAKE_IMAGE_3.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_4.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_5.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_6.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_7.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_8.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_9.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_10.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_11.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_12.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_13.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_14.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_15.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_16.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_17.fits	MAKE_IMAGE	"
SCI-GUM43_MAKE_IMAGE_18.fits	MAKE_IMAGE	". Only 19 IFU's were active in this OB.
SCI-GUM43_SCI_COMBINED.fits	SCI_COMBINED	reconstructed science cube (coadded dithers) including noise map created from IFU #1.
SCI-GUM43_SCI_COMBINED_1.fits	SCI_COMBINED	reconstructed science cube (coadded dithers) including noise map created from IFU #2.
SCI-GUM43_SCI_COMBINED_2.fits	SCI_COMBINED	reconstructed science cube (coadded dithers) including noise map created from IFU #3.
SCI-GUM43_SCI_COMBINED_3.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_4.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_5.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_6.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_7.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_8.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_9.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_10.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_11.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_12.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_13.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_14.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_15.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_16.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_17.fits	SCI_COMBINED	"
SCI-GUM43_SCI_COMBINED_18.fits	SCI_COMBINED	". Only 19 IFU's were active in this OB.
SCI-GUM43_SCI_RECONSTRUCTED.fits	SCI_RECONSTRUCTED	intermediate reconstructed and combined science cube including noise map for pointing #1.
SCI-GUM43_SCI_RECONSTRUCTED_1.fits	SCI_RECONSTRUCTED	intermediate reconstructed and combined science cube including noise map for pointing #2.
SCI-GUM43_SCI_RECONSTRUCTED_2.fits	SCI_RECONSTRUCTED	intermediate reconstructed and combined science cube including noise map for pointing #3.
SCI-GUM43_SCI_RECONSTRUCTED_3.fits	SCI_RECONSTRUCTED	"
SCI-GUM43_SCI_RECONSTRUCTED_4.fits	SCI_RECONSTRUCTED	"
SCI-GUM43_SCI_RECONSTRUCTED_5.fits	SCI_RECONSTRUCTED	"
SCI-GUM43_SCI_RECONSTRUCTED_6.fits	SCI_RECONSTRUCTED	"
SCI-GUM43_SCI_RECONSTRUCTED_7.fits	SCI_RECONSTRUCTED	"
SCI-GUM43_SCI_RECONSTRUCTED_8.fits	SCI_RECONSTRUCTED	"

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8 About The Reflex Canvas

8.1 Saving And Loading Workflows

In the course of your data reductions, it is likely that you will customise the workflow for various data sets, even if this simply consists of editing the `ROOT_DATA_DIR` to a different value for each data set. Whenever you modify a workflow in any way, you have the option of saving the modified version to an XML file using `File -> Export As` (which will also open a new workflow canvas corresponding to the saved file). The saved workflow may be opened in subsequent Reflex sessions using `File -> Open`. Saving the workflow in the default format (.kar) is only advised if you do not plan to use the workflow in another computer.

8.2 Buttons

At the top of the Reflex canvas are a set of buttons which have the following useful functions:

-  - Zoom in.
-  - Reset the zoom to 100%.
-  - Zoom the workflow to fit the current window size (Recommended).
-  - Zoom out.
-  - Run (or resume) the workflow.
-  - Pause the workflow execution.
-  - Stop the workflow execution.

The remainder of the buttons (not shown here) are not relevant to the workflow execution.

8.3 Workflow States

A workflow may only be in one of three states: executing, paused, or stopped. These states are indicated by the yellow highlighting of the , , and  buttons, respectively. A workflow is executed by clicking the  button. Subsequently the workflow and any running pipeline recipe may be stopped immediately by clicking the  button, or the workflow may be paused by clicking the  button which will allow the current actor/recipe to finish execution before the workflow is actually paused. After pausing, the workflow may be resumed by clicking the  button again.

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9 The KMOS Workflow

The KMOS workflow canvas is organised into a number of areas. From top-left to top-right you will find general workflow instructions, directory parameters, and global parameters. In the middle row you will find five boxes describing the workflow general processing steps in order from left to right, and below this the workflow actors themselves are organised following the workflow general steps.

9.1 Workflow Canvas Parameters

The workflow canvas displays a number of parameters that may be set by the user. Under “Setup Directories” the user is only required to set the `RAWDATA_DIR` to the working directory for the `DataSet(s)` to be reduced, which, by default, is set to the directory containing the demo data. The `RAWDATA_DIR` is recursively scanned by the `Data Organiser` actor for input raw data. The directory `CALIB_DATA_DIR`, which is by default within the pipeline installation directory, is also scanned by the `Data Organiser` actor to find any static calibrations that may be missing in your `DataSet(s)`. If required, the user may edit the directories `BOOKKEEPING_DIR`, `LOGS_DIR`, `TMP_PRODUCTS_DIR`, and `END_PRODUCTS_DIR`, which correspond to the directories where book-keeping files, logs, temporary products and end products are stored, respectively (see the Reflex User Manual for further details; [4]).

Under the “Global Parameters” area of the workflow canvas, the user may set the `FITS_VIEWER` parameter to the command used for running his/her favourite application for inspecting FITS files. Currently this is set by default to `fv`, but other applications, such as `ds9`, `skycat` and `gaia` for example, may be useful for inspecting image data.

By default the `EraseDirs` parameter is set to `false`, which means that no directories are cleaned before executing the workflow, and the recipe actors will work in Lazy mode (see Section 9.2.2), reusing the previous pipeline recipe outputs where input files and parameters are the same as for the previous execution, which saves considerable processing time. Sometimes it is desirable to set the `EraseDirs` parameter to `true`, which forces the workflow to recursively delete the contents of the directories specified by `BOOKKEEPING_DIR`, `LOGS_DIR`, and `TMP_PRODUCTS_DIR`. This is useful for keeping disk space usage to a minimum and will force the workflow to fully rereduce the data each time the workflow is run.

The parameter `RecipeFailureMode` controls the behaviour in case that a recipe fails. If set to `Continue`, the workflow will trigger the next recipes as usual, but without the output of the failing recipe, which in most of the cases will lead to further fails of other recipes without the user actually being aware of it. This mode might be useful for unattended processing of large number of datasets. If set to `Ask`, a pop-up window will ask whether the workflow should stop or continue. This is the default. Additionally, the `Stop` mode will stop the workflow execution immediately.

The parameter `GlobalInteractivity` controls whether the interactive windows will appear for those windows which are *enabled* by default. The possible values are `true`, `false`. Take into account that some windows are disabled in the default configuration and therefore are not affected by this parameter.



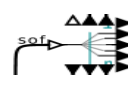
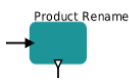

The parameter `ProvenanceExplorerEnabled` controls whether the `ProvenanceExplorer` actor will show its window or not. The possible values are `true`, `false`.

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9.2 Workflow Actors

9.2.1 Simple Actors

Simple actors have workflow symbols that consist of a single (rather than multiple) green-blue rectangle. They may also have a logo within the rectangle to aid in their identification. The following actors are simple actors:

-  - The Data Organiser actor.
-  - The Data Set Chooser actor.
-  - The Fits Router actor
-  - The Product Renamer actor.
-  - The Provenance Explorer actor.

Access to the parameters for a simple actor is achieved by right-clicking on the actor and selecting `Configure Actor`. This will open an “Edit parameters” window. Note that the `Product Renamer` actor is a jython script (Java implementation of the Python interpreter) meant to be customised by the user (by double-clicking on it).

9.2.2 Lazy Mode

By default, all recipe executer actors in a pipeline workflow are “Lazy Mode” enabled. This means that when the workflow attempts to execute such an actor, the actor will check whether the relevant pipeline recipe has already been executed with the same input files and with the same recipe parameters. If this is the case, then the actor will not execute the pipeline recipe, and instead it will simply broadcast the previously generated products to the output port. The purpose of the Lazy mode is therefore to minimise any reprocessing of data by avoiding data rereduction where it is not necessary.

One should note that the actor Lazy mode depends on the contents of the directory specified by `BOOKKEEPING_DIR` and the relevant FITS file checksums. Any modification to the directory contents and/or the file checksums will cause the corresponding actor when executed to run the pipeline recipe again, thereby rereducing the input data.

The forced rereduction of data at each execution may of course be desirable. To force a rereduction of all data for all `RecipeExecuter` actors in the workflow (i.e. to disable Lazy mode for the whole workflow), set the `EraseDirs` parameter under the “Global Parameters” area of the workflow canvas to `true`. This will then

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remove all previous results as well. To force a rereduction of data for any single `RecipeExecutor` actor in the workflow (which will be inside the relevant composite actor), right-click the `RecipeExecutor` actor, select `Configure Actor`, and uncheck the Lazy mode parameter tick-box in the “Edit parameters” window that is displayed. If the Lazy mode is switched off for an actor, all subsequent actors that use products from that one will also reprocess the data, as they see new products.

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10 Optimising Your Results Through Workflow Interaction

In this section, we use the information from section 5 along with the KMOS demo data supplied with `Reflex2` . 6 to illustrate how to optimise the scientific products in terms of quality and S/N. This is work in progress and the contents of this section will grow as we gain experience and add functionality. Optimising the results is achieved by interaction with the workflow actors via interactive windows displayed at key data reduction points in the data flow, which enable iteration of certain recipes in order to obtain better results.

We recommend that the user has already carried out the reductions for all demo DataSets as described in Section 5, although this is not a pre-requisite to following this section. By doing this, the user will be taking advantage of the workflow Lazy Mode, with minimal waiting time between various pipeline recipe executions.

Please follow these steps in order to optimise the reductions for the KMOS demo data:

1. Carry out the first four steps described in the Quick Start Section 5.
2. In the KMOS workflow, the interactive actor `Wavelength Calibration` (`WAVE_CAL`) is identifiable by an orange rectangle encompassing the actor name. The interactive mode is enabled by default. Should you wish to change that use `Open Actor` to get access to the the components of the interactive actors, then double-click on the composite actors, setting the “EnableInteractivity” parameter to `false`, and clicking `Commit` to save the changes to the workflow.
3. **Wavelength Calibration:** Figure 10.1 shows the interactive window that will pop-up at the end of the execution of the `kmo_wave_cal` pipeline routine. The image panels at the top of the window show the reconstructed arc frames for each of the three detectors at one of the six rotator position angles. To view the reconstructed arc frames at another rotator angle (either 0, 60, 120, 180, 240, or 300 degrees), simply click on the ovals in the *Angle selection* box. For each of the 18 reconstructed arc frames, the relative average offset of the reconstructed arc lines are plotted in units of pixels for each of the Argon and Neon arc lines (bottom two plots). One-half of the length of the error bars associated with each data point gives the average FWHM (in pixels) for each arc line.

On the right-hand edge of the interactive window the user may modify a number of parameters to improve the wavelength calibration. The parameters and their description is given in table 10.1. If parameters have been changed, then clicking on the `Re-run Recipe` will re-execute the `kmo_wave_cal` pipeline routine.

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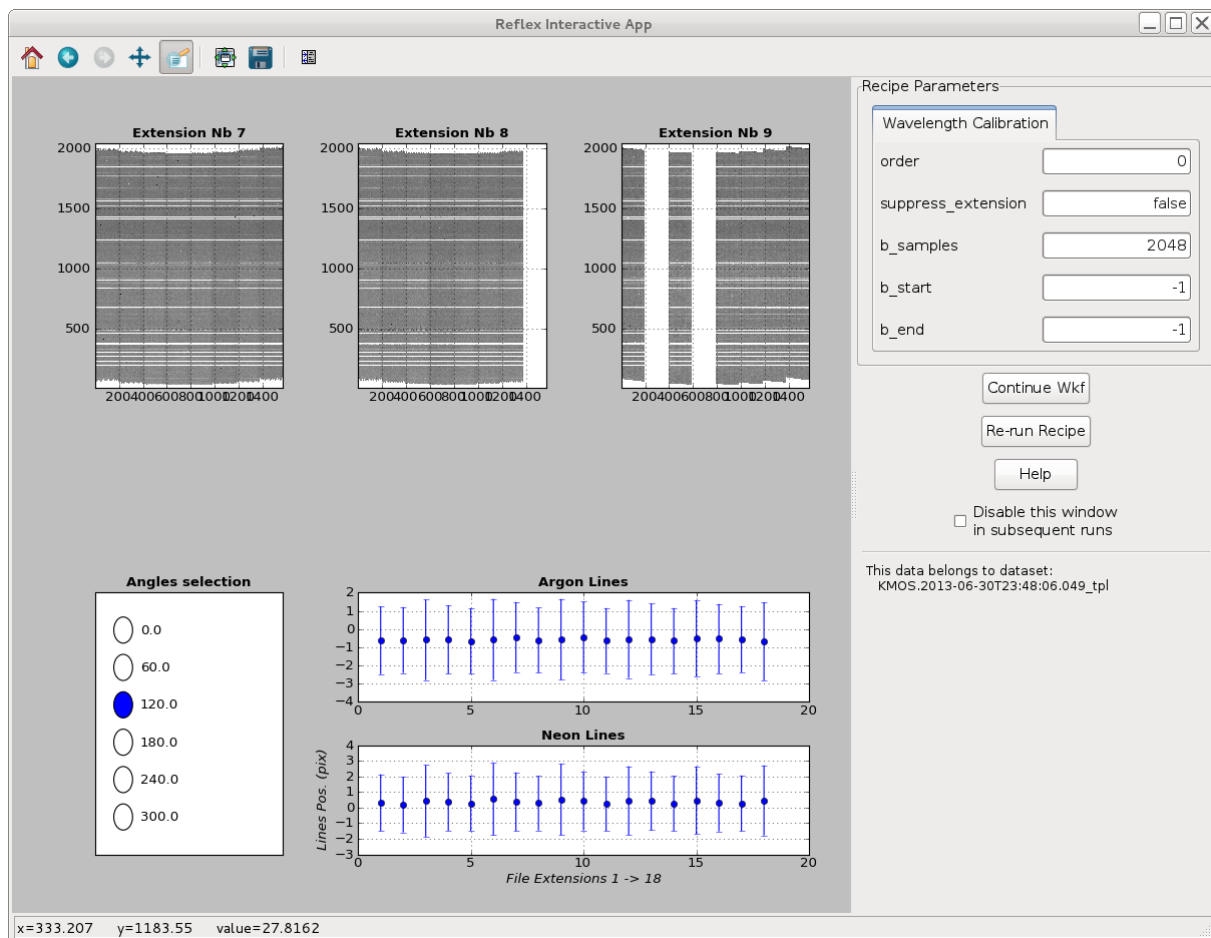


Figure 10.1: The interactive window for the Wavelength Calibration actor as displayed for the KMOS tutorial data set..

Table 10.1: Parameters that a user can manipulate within the WAVE_CAL interactive window

Parameter ¹	Value (default)	Explanation
-order	0	The polynomial order to use for the fit of the wavelength solution. The appropriate order is chosen automatically depending on the waveband. Otherwise an order of 6 is recommended, except for IZ-band, there order 4 should be used
-dev_flip	FALSE	Set this parameter to TRUE if the wavelengths are ascending on the detector from top to bottom
-dev_disp	-1	The expected dispersion of the wavelength in microns/pixel. If the default is not changed it will automatically be selected upon header keywords
-suppress_extension	FALSE	Suppress arbitrary filename extension. (if TRUE (apply) or FALSE (do not apply))
-b_samples	2048	The number of samples in wavelength for the reconstructed cube
-b_start	-1	The lowest wavelength [μm] to take into account when reconstructing (default of -1 sets the proper value for the actual band automatically)
-b_end	-1	The highest wavelength [μm] to take into account when reconstructing (default of -1 sets the proper value for the actual band automatically)

¹ All parameters, available to the *kmo_wave_cal* pipeline routine, have been included for use in the WAVE_CAL interactive window.

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4. **Telluric Standard Star Calibration:** Figure 10.2 shows the interactive window that will pop-up at the end of the execution of the *kmo_std_star* pipeline routine. The image panel at the top-right of the window shows the median collapsed data cube (pipeline product: *STD_IMAGE*) For a single IFU. The total number of IFU's dedicated to observing a telluric standard star are listed to the left of this image and clicking on the circle will display the standard star from another IFU. For the tutorial data set only IFU #3 and IFU #12 observed standard stars.

At the bottom of the interactive window the extracted standard star spectrum (for the selected IFU) is displayed (pipeline product: *STAR_SPEC*) in flux units of ADU and wavelength units of microns.

On the right-hand edge of the interactive window the user may modify a number of parameters to improve the telluric standard star calibration. The parameters and their description is given in table 10.2. If parameters have been changed, then clicking on the **Re-run Recipe** will re-exectute the *kmo_std_star* pipeline routine.

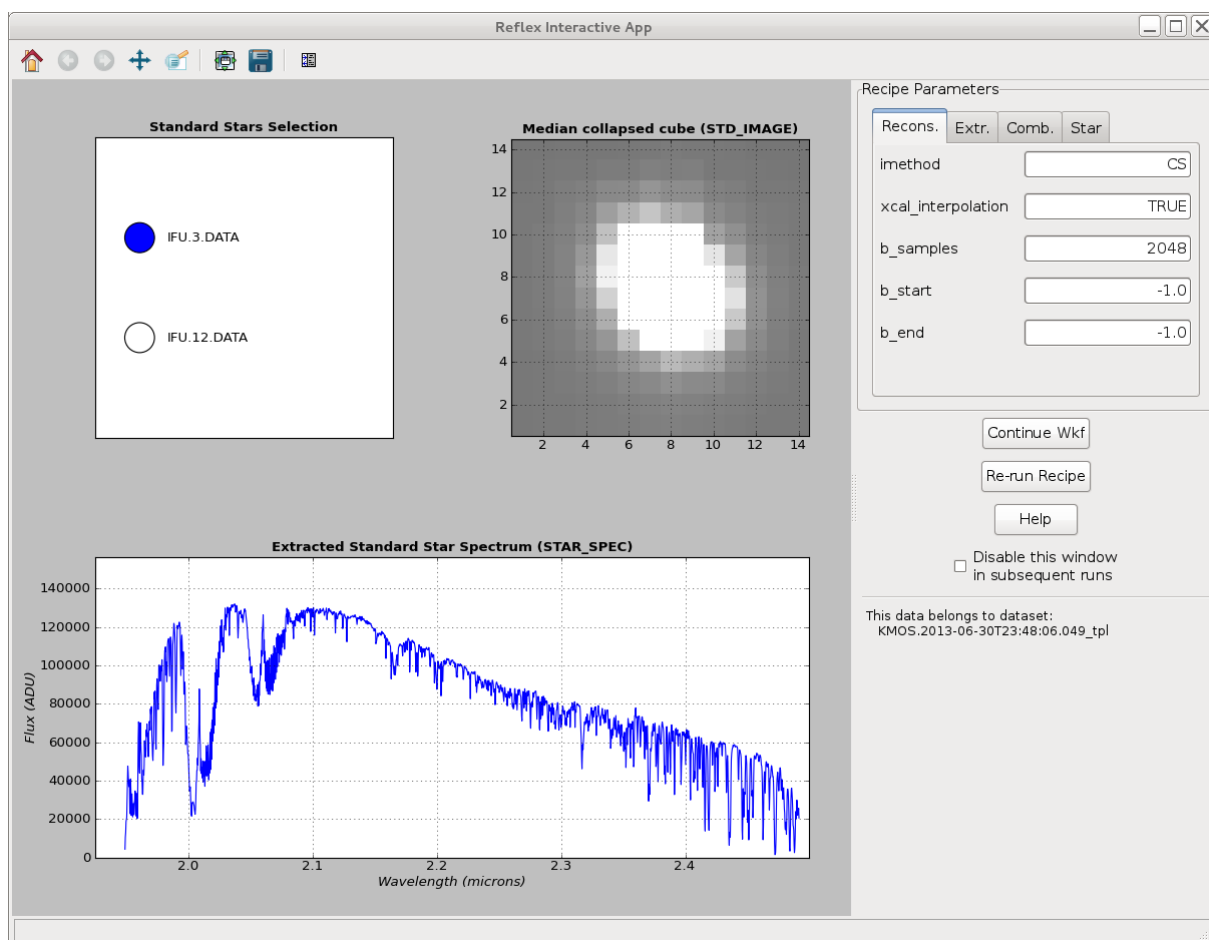


Figure 10.2: The interactive window for the Telluric Standard Star Calibration actor as displayed for the KMOS tutorial data set..

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Table 10.2: Parameters that a user can manipulate within the STD_STAR interactive window

Reconstruction		
Parameter ¹	Value (default)	Explanation
-imethod	CS	The interpolation method used for reconstructing the standard star data cube. A Cubic-spline (CS) interpolation is used as the default. Note that no error spectra will be generated for this interpolation method. The full list of interpolation methods include: CS : Cubic-spline NN : Nearest Neighbour lwNN : linear-weighted Nearest Neighbour swNN : square-weighted Nearest Neighbour MS : modified Shepard's method
-xcal_interpolation	TRUE	If TRUE interpolate the pixel position in the slitlet (xcal) using the two closest rotator angles in the calibration file. Otherwise take the values of the closest rotator angle.
-b_samples	2048	The number of samples in wavelength for the reconstructed cube
-b_start	-1	The lowest wavelength [μm] to take into account when reconstructing (default of -1 sets the proper value for the actual band automatically)
-b_end	-1	The highest wavelength [μm] to take into account when reconstructing (Default of -1 sets the proper value for the actual band automatically)
Extraction		
-fmethod	gauss	The type of function that should be fitted spatially to the collapsed image. This fit is used to create a mask to extract the spectrum of the object. The full list of fitting methods include: gauss moffat
-neighborhoodRange	1.001	Defines the range to search for neighbors during reconstruction.
-flux	FALSE	Apply conservation of flux (TRUE/FALSE).
Combination		
-cmethod	ksigma	The method of frame combination to be used. ksigma is an iterative sigma clipping. For each position all pixels in the spectrum are examined. If they deviate significantly, they will be rejected according to the conditions: $\text{val} > \text{mean} + \text{stdev} * \text{cpos_rej}$ and $\text{val} < \text{mean} - \text{stdev} * \text{cneg_rej}$ The full list of combination methods include: ksimga : kappa-sigma clipping median : at each pixel position the median is calculated average : at each pixel position the average is calculated sum : at each pixel position the sum is calculated min-max : The specified number of minimum and maximum pixel values will be rejected. -cmax and -cmin apply to this method
-cpos_rej & -cneg_rej	3.0 & 3.0	The positive and negative rejection thresholds for bad pixels.
-citer	3	The number of iterations for kappa-sigma-clipping (applies only when -cmethod = ksigma).
-cmax & -cmin	1 & 1	The number of maximum and minimum pixel values to clip with min/max-clipping (applies only when -cmethod = min_max).
Star		
-startype	FALSE	If this parameter is specified, the stored star types of the observed objects in the FITS headers are overridden. This value applies to all objects examined in the input frames. Examples could be A3I , G3IV or K0I . The first letter defines the star type, the second letter the spectral class and the last letters the luminosity class.
-magnitude	FALSE	If this parameter is specified, the stored magnitudes in the FITS headers are overridden. For HK two magnitudes for each H and K have to be specified (separated by a comma). All other gratings use a single magnitude.

¹ All parameters, available to the *kmo_std_star* pipeline routine, have been included for use in the STD_STAR interactive window.

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5. **Science Reduction:** Figure 10.3 shows the interactive window that will pop-up at the end of the execution of the *kmo_sci_red* pipeline routine.

The selection panel at the top of the window shows the list of individual reconstructed science images (pipeline products: *SCI_RECONSTRUCTED*) in the processed data set. Each file can be selected by clicking on the oval with the left mouse button.

The central selection panel summarizes the status of each individual IFU for the selected frame. IFU's for which an extracted spectrum can be viewed are shown as *Active* and are plotted in green. The other IFU statuses, in *Collision*, *NotInPAF*, *Locked*, and *NotInPAF&Locked* are shown in cyan, blue, black, and red, respectively. These IFU's cannot be selected. To select an *Active* IFU the user should use the centre mouse button. The selected IFU is then shown with a bar beneath its numbered box.

At the bottom of the interactive window the extracted science frame spectrum (for the selected IFU) is displayed in flux units of ADU and wavelength units of microns. The flux is shown as a blue line, while the associated error is given in red. Currently, the extracted spectrum is derived in the python script of the interactive window. Each 14×14 pixel plane of the science data cube is averaged and plotted as a function of wavelength.

On the right-hand edge of the interactive window the user may modify a number of parameters to improve the science frame reduction. The parameters and their description is given in table 10.3. If parameters have been changed, then clicking on the Re-run Recipe will re-execute the *kmo_sci_red* pipeline routine.

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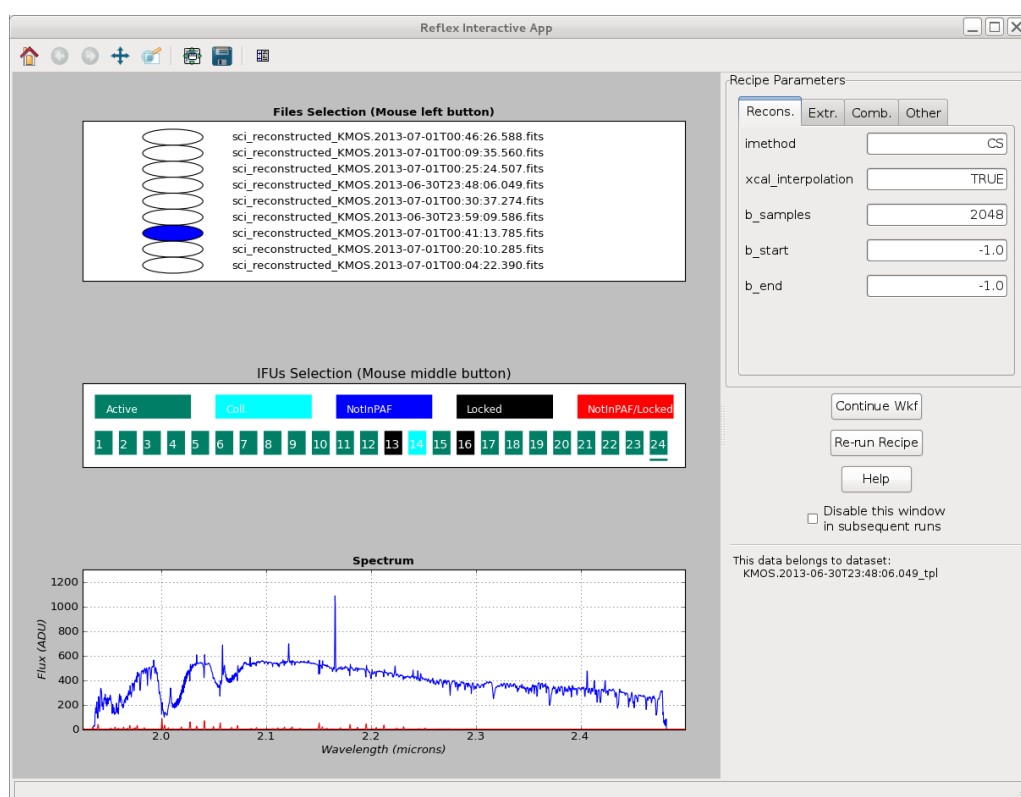


Figure 10.3: The interactive window for the Science Reduction actor as displayed for the KMOS tutorial data set..

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
Table 10.3: Parameters that a user can manipulate within the SCI_RED interactive window




Reconstruction		
Parameter ¹	Value (default)	Explanation
<code>-imethod</code>	CS	The interpolation method used for reconstructing the science data cube. A Cubic-spline (CS) interpolation is used as the default. Note that no error spectra will be generated for this interpolation method. The full list of interpolation methods include: CS : Cubic-spline NN : Nearest Neighbour lwNN : linear-weighted Nearest Neighbour swNN : square-weighted Nearest Neighbour MS : modified Shepard's method
<code>-xcal_interpolation</code>	TRUE	If TRUE interpolate the pixel position in the slitlet (xcal) using the two closest rotator angles in the calibration file. Otherwise take the values of the closest rotator angle.
<code>-b_samples</code>	2048	The number of samples in wavelength for the reconstructed cube
<code>-b_start</code>	-1	The lowest wavelength [μm] to take into account when reconstructing (the default of -1 sets the proper value for the actual band automatically).
<code>-b_end</code>	-1	The highest wavelength [μm] to take into account when reconstructing (the default of -1 sets the proper value for the actual band automatically).
Extraction		
<code>-fmethod</code>	gauss	The type of function that should be fitted spatially to the collapsed image. This fit is used to create a mask to extract the spectrum of the object. The full list of fitting methods include: gauss and moffat
<code>-neighborhoodRange</code>	1.001	Defines the range to search for neighbors during reconstruction.
<code>-flux</code>	FALSE	Apply conservation of flux (TRUE/FALSE).
Combination		
<code>-cmethod</code>	ksigma	The method of frame combination to be used. ksigma is an iterative sigma clipping. For each position all pixels in the spectrum are examined. If they deviate significantly, they will be rejected according to the conditions: $\text{val} > \text{mean} + \text{stdev} * \text{cpos_rej}$ and $\text{val} < \text{mean} - \text{stdev} * \text{cneg_rej}$ The full list of combination methods include: ksigma : kappa-sigma clipping median : at each pixel position the median is calculated average : at each pixel position the average is calculated sum : at each pixel position the sum is calculated min-max : The specified number of minimum and maximum pixel values will be rejected. <code>-cmax</code> and <code>-cmin</code> apply to this method
<code>-cpos_rej & -cneg_rej</code>	3.0 & 3.0	The positive and negative rejection thresholds for bad pixels.
<code>-citer</code>	3	The number of iterations for kappa-sigma-clipping (applies only when <code>-cmethod = ksigma</code>).
<code>-cmax & -cmin</code>	1 & 1	The number of maximum and minimum pixel values to clip with min/max-clipping (applies only when <code>-cmethod = min_max</code>).
Other		
<code>-smethod</code>	FALSE	The interpolation method used for shifting. The full list of shifting methods include: CS : cubic spline NN : nearest neighbour
<code>-background</code>	FALSE	Specify if a background subtraction should be applied.
<code>-pix_scale</code>	0.2	Change the pixel scale (in arcsec). The default value of 0.2 arcsec results in cubes of size 14×14 pixels, while a scale of 0.1 arcsec would results in cubes of 28×28 pixels, etc.
<code>-no_subtract</code>	FALSE	If set to TRUE , the found objects and references will not be sky subtracted. Additionally all IFUs will be reconstructed, even the ones containing skies. This option sets the parameter <code>no_combine</code> to TRUE automatically.
<code>-ifus</code>		The indices of the IFUs to combine. The number of entries has to match the number of input frames. For example, to combine IFUs number 1, 5, 12, and 21 this parameter should be set to: 1;5;12;21
<code>-method</code>	header	The shifting method to use. The full list of shifting methods include: header : the shifts are calculated according to the WCS information stored in the header of each IFU. none : the cubes are directly recombined, with no shifts applied. center : the shifts are calculated using a centering algorithm. user : the shifts are read from a user specified file. The path of the file must be provided using the <code>-filename</code> parameter.
<code>-filename</code>		When using the <code>-method user</code> (see above), specify the path name to the file with the shift vectors.

¹ Only the most important parameters, available to the *kmo_sci_red* pipeline routine, have been included for use in the SCI_RED interactive window.

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6. For each of the three interactive windows described above, the panel of buttons at the very top-left of the window may be used to manipulate the displayed plots. The buttons have the following functions:

-  - Reset all the plot ranges to their original values.
-  - Undo the last modification of the plot ranges (if possible).
-  - Redo the next modification of the plot ranges (if possible).
-  - Selecting this button allows the user to use the mouse to shift the plot ranges by left-clicking on the target plot canvas and then dragging the mouse around while keeping the left mouse button held down, and releasing when ready.
-  - Selecting this button allows the user to zoom in on each plot by left-clicking on the target plot canvas to mark the top-left corner of a rectangle and then dragging the mouse to the bottom-right corner of the rectangle and releasing. The plot ranges will then be modified to match the rectangle that was defined. The following constraints can be made by holding simultaneously a key while pressing the left mouse button:

Constrain pan/zoom to x axis	hold	<input type="text" value="X"/>
Constrain pan/zoom to y axis	hold	<input type="text" value="Y"/>
Preserve aspect ratio	hold	<input type="text" value="Ctrl"/>
-  - Clicking this button opens a “Configure subplots” window that allows the user to adjust the spacing and positioning of the individual plots.
-  - Clicking this button opens a “Save to file” window which allows the user to save a screenshot of the current interactive window.
-  - Clicking this button allows the user to change the display levels of the 2-dimensional merged image by clicking on pixels within the 2-dimensional image (similar to ds9).

Use these buttons to inspect the plots in the interactive window in more detail.

7. Once the user is satisfied with the results, then clicking on the button will continue with the rest of the workflow.
8. As noted in the Quick Start Section 5, the workflow will then proceed through its remaining processing steps and write out all pipeline products to the end products directory (specified by the parameter `END_PRODUCTS_DIR` under “Setup Directories” in the workflow canvas). The science data products from the tutorial data set are summarized in section 7 in table 7.2. The intermediate pipeline calibration products can be found in subdirectories of the `TMP_PRODUCT_DIR` and are summarized in section 7 and in table 7.1.

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11 Frequently Asked Questions

- **Where are my intermediate pipeline products?** Intermediate pipeline products are stored in the directory `<TMP_PRODUCTS_DIR>` (defined on the workflow canvas) and organised further in directories by pipeline recipe.
- **Can I use different sets of bias frames to calibrate my flat frames and science data?** Yes. In fact this is what is currently implemented in the workflow(s). Each file in a DataSet has a purpose attached to it ([4]). It is this purpose that is used by the workflow to send the correct set of bias frames to the recipes for flat frame combination and science frame reduction, which may or may not be the same set of bias frames in each case.
- **Can I run Reflex from the command line?** Yes, use the command:

```
reflex -n <workflow_path>/<workflow>.xml
```

The `-n` option will set all the different options to Kepler and the workflows that avoid any graphical display (including pipeline interactive windows). Note that this mode is not fully supported, and the user should be aware that the path to the workflow must be absolute and even if no GUI elements are shown, it still requires a connection to the window manager.

- **How can I add new actors to an existing workflow?** You can drag and drop the actors in the menu on the left of the Reflex canvas. Under `Eso-reflex -> Workflow` you may find all the actors relevant for pipeline workflows, with the exception of the recipe executor. This actor must be manually instantiated using `Tools -> Instantiate Component`. Fill in the “Class name” field with `org.eso.RecipeExecutor` and in the pop-up window choose the required recipe from the pull-down menu. To connect the ports of the actor, click on the source port, holding down the left mouse button, and release the mouse button over the destination port. Please consult the Reflex User Manual ([4]) for more information.
- **How can I broadcast a result to different subsequent actors?** If the output port is a multi-port (filled in white), then you may have several relations from the port. However, if the port is a single port (filled in black), then you may use the black diamond from the toolbar. Make a relation from the output port to the diamond. Then make relations from the input ports to the diamond. Please note that you cannot click to start a relation from the diamond itself. Please consult the Reflex User Manual ([4]) for more information.
- **How can I run manually the recipes executed by Reflex?** If a user wants to re-run a recipe on the command line he/she has to go to the appropriate `reflex_book_keeping` directory, which is generally `reflex_book_keeping/<workflow>/<recipe_name>_<number>`. There, subdirectories exist with the time stamp of the recipe execution (e.g. `2013-01-25T12:33:53.926/`). If the user wants to re-execute the most recent processing he/she should go to the `latest` directory and then execute the script `cmdline.txt`. Alternatively, to ensure that the path to `esorex` is the correct one, the user can execute

```
ESOREX_CONFIG="INSTALL_DIR/etc/esorex.rc"
INSTALL_DIR/bin/esorex --recipe-config=<recipe>.rc <recipe> data.sof
```

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where `INSTALL_DIR` is the directory where Reflex and the pipelines were installed.

If a user wants to re-execute in the command line a recipe that used a given raw frame, the way to find the proper `data.sof` in the bookkeeping directory is via `grep <raw_file> */data.sof`. Afterwards the procedure is the same as before.

If a recipe is re-executed with the command explained before, the products will appear in the directory from which the recipe is called, and not in the `reflex_tmp_products` or `reflex_end_products` directory, and they will not be renamed. This doesn't happen if you use the `cmdline.txt` script.

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12 Troubleshooting



Figure 12.1: *TheDataOrganizer* interactive window reports an error “:No DataSets have been created, check the data set and the OCA rules.”.

1. I downloaded the data from the ESO archive, put them into a new directory, tried to run `Reflex` on them, but

(a) it crashes

This may happen if one of the files was downloaded only partially (check for a file with the extension `fits.Z.part`). You will have to download that file again in order to have an uncorrupted file (and remove the partial one).

(b) it fails with error message “:No DataSets have been created, check the data set and the OCA rules.”(see Figure 12.1.)

This error may be due to the fact that the data provided by the ESO archive are compressed (`<filename>.fits.Z`). Please remember to uncompress the data before executing `Reflex`.

(c) all DataSets are greyed out in the DataSets interactive window.

The ESO archive used with `CalSelector` does not always supply all static calibration files. As a consequence some/all DataSets are greyed out because they were missing such required data.

Missing static calibration should be found by `reflex` in
`<install_directory>/calib/<pipeline_version>/cal`.

2. The “Select DataSets” window displays my DataSets, but some/all of them are greyed out. What is going on?

If a DataSet in the “Select DataSets” window is greyed out, then it means that the DataSet that was constructed is missing some key calibration(s) (i.e. the DataSet is incomplete). To find out what calibration(s) are missing from a greyed out DataSet, click on the DataSet in question to highlight it in blue, and then click on the button `Inspect Highlighted`. The “Select Frames” window that appears will report the category of the calibration products that are missing (e.g. `MASTER_BIAS`). From this the user has then to determine the missing raw data (in this case bias frames). If static calibrations are missing the mechanism unfortunately does not work, but should be found by `reflex` in
`<install_directory>/calib/<pipeline_version>/cal`

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Acknowledgements

The `Reflex` team in alphabetical order consists of Pascal Ballester, Daniel Bramich, Vincenzo Forchì, Wolfram Freudling, César Enrique García, Maurice Klein Gebbinck, Andrea Modigliani, Sabine Moehler, Mark Neeser & Martino Romaniello.

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