



# EUROPEAN SOUTHERN OBSERVATORY

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## Very Large Telescope Paranal Science Operations FIMS Manual

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# 1 About this manual

## 1.1 Scope

This manual describes the FORS Instrument Mask Simulator (**FIMS**). It should be used together with the FORS2 User's Manual (ESO document VLT-MAN-ESO-13100-1543) and the FORS2 Template Manual (ESO document VLT-MAN-ESO-13100-2309); both are available via the FORS web page:

<http://www.eso.org/instruments/fors/>.

In case of specific questions concerning your service mode observations and proposal preparation please contact the User Support Department at ESO through email:

[usd-help@eso.org](mailto:usd-help@eso.org)

For questions concerning your visitor mode run please contact the FORS Science Operations Team at Paranal:

[fors2@eso.org](mailto:fors2@eso.org)

## 1.2 Recent Changes

The changes listed in the P84 version of the manual are the following:

- Major revision due to 'FORS merger'; only FORS2 available, (R)ed and (B)lue CCD options available and polarimetry on FORS2
- FORS1 E2V mosaic images are now handled by fsmosaic
- column names for the input catalogues have been revised following reports of erratic behaviour

In P85 the changes are the following:

- FIMS version 3 released;
- Section 4.5 added, with description of HIT-MS mask creation;
- Table 14 added, with Example Session of HIT-MS mask acquisition;
- Revisions in many places to reflect changes introduced by FIMS 3.

## 1.3 Acknowledgments

The first edition of this FIMS manual was delivered as part of the FORS User Manual by the FORS Consortium (Landessternwarte Heidelberg and University Observatories of Göttingen and Munich, Germany) in the scope of the FORS contract. It was then edited by Gero Rupprecht, Hermann Bönhardt, Thomas Szeifert and Emmanuel Jehin (ESO). The FIMS software releases up to September 2000 were prepared by the Wolfgang Hummel (University Observatory Munich, now at ESO) and since then by Ana Maria Aguayo, Pedro Baksai and Mario Kiekebusch (ESO Paranal).

## 2 Introduction and Requirements

### 2.1 The FIMS Concept

FIMS, the **FORS Instrumental Mask Simulator** is the FORS Observer Support Software. It is a graphical user interface to show the FORS sky field which allows the precise positioning of the 19 FORS MOS slits and the slits of MXU masks by moving an instrumental “mask” over a sky image. FIMS is a plug-in for the ESO Skycat Tool, a browser for astronomical images and catalogs. It can be installed and used at the user’s home institute. It is also available at ESO headquarters and at the Paranal Observatory. Figure 1 shows FIMS in the context of the ESO Skycat.

FIMS, the auxiliary software and installation instructions can be downloaded from the following WEB page:

<http://www.eso.org/observing/p2pp/OSS/FIMS/FIMS-tool.html>

### 2.2 Some technical details in advance

#### 2.2.1 The fsmosaic plug-in

**Functionality of fsmosaic:** With the instrument now using mosaic detectors, the CCDs are read from two ports — one port per CCD. The raw data product to be delivered to the users will be two files with the images read from the upper “master” and lower “slave” detector, respectively. The mask preparation with fims will require a combined mosaic image of the full field of view. The merging will be done with a plug-in function fsmosaic which is called by fims for any FORS2 mosaic images to be loaded into fims. fsmosaic will classify the input files automatically as either old FORS pre-images, or contributed images, or as images taken with the new MIT/E2V detectors. In case that a new mosaic image is loaded the function will automatically look up the actual working directory for the associated “master” or “slave” images, it will merge the two files based on shift and rotation given in the fits headers and display it into the Skycat/FIMS window. It will also recognize files which were already merged earlier with fsmosaic and display the file directly to the Skycat window. The fsmosaic function has to be in the \$PATH of the working environment, which can be verified with UNIX command “`which fsmosaic`”.

**Keep the working directory clean:** fsmosaic will get confused if raw data, reduced data and intermediate reduction steps are kept on the same directory. Please copy the images which are thought to be used for the mask preparation to a clean directory (such as `.fims/PREP`).

**Keep the input data formats:** fsmosaic will work in coordinates of the detector plane and the vignetted parts of the MIT/E2V detectors or the over-scan regions must not be removed before the files are being merged. For more information concerning the safe use of pre-imaging data, see section 2.4.

**Using fsmosaic as a stand alone function:** Despite being designed as a plug-in to fims it is also possible to use fsmosaic as a stand alone tool to merge the two files of the MIT/E2V detectors for further investigations or as a quick-look tool to display the full field of view. The fsmosaic function can be used in the following way with the input file being either the “master” or the “slave” image taken with the detectors:

```
fsmosaic [-hV] [-v] input [output]
```

Optionally an output filename can be given if the resulting merged image is to be kept on disk. By default the result will be written to file `fsmosaic.fits`. The verbose mode flag `-v`, the help flag `-h` and the printout of the fsmosaic version flag `-V` are optional.

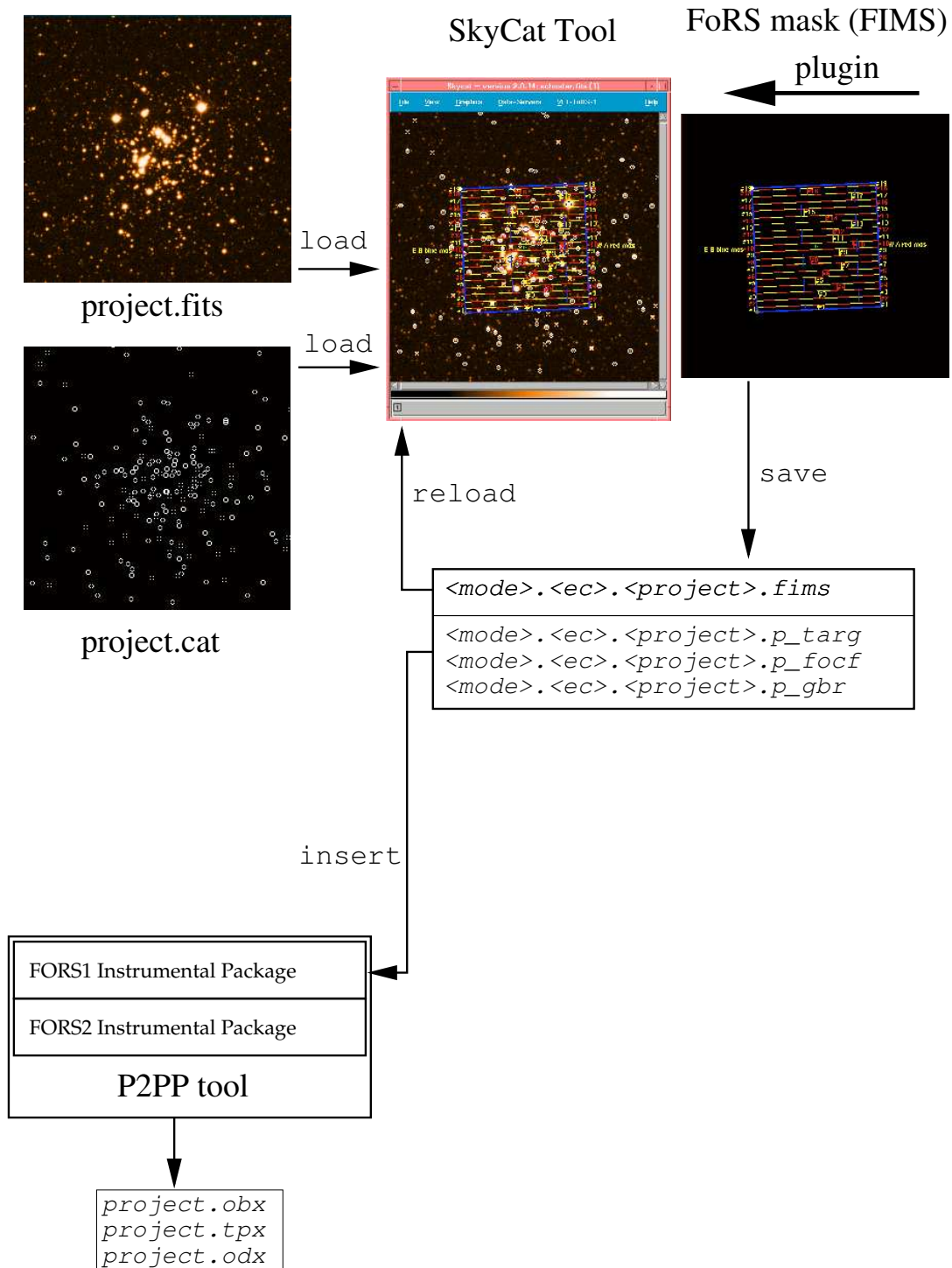


Figure 1: Interaction between Skycat, FIMS and P2PP — input and output files

### 2.2.2 Environment variables

Two important environment variables can be set to select the fims version and to select the Skycat versions in your working environment. In general the variables should be automatically set after the installation of the tar ball which includes all phase 2 related support software. The variables can be redefined with the `setenv` (tcsh) or `export` (bash) commands of your UNIX operation system:

The Skycat version can be set with command:

```
setenv SKYCAT_VER 2.7.3
```

The FIMS version can be selected in the following way – this should be only needed if more than one fims version is installed:

```
setenv FIMSROOT $HOME/fims/
```

### 2.2.3 Start-up of FIMS

Once installed FIMS is started with the command:

- `fims.sh R` for FORS2 with the MIT mosaic
- `fims.sh B` for FORS2 with the E2V mosaic

### 2.2.4 Interaction between Skycat, FIMS and P2PP — input and output files

In practice, Skycat handles the FITS images and optionally a user-defined target catalog, while FIMS handles the definition of the FORS focal plane instrumental mask (MOS, MXU, HIT-MS, OCC and PMOS) and its positioning. FIMS will write the subsequent focal plane setup commands into output files - it will also set the FORS collimator to be used for the observations.

FIMS outputs a number of files that are necessary to successfully define an Observation Block (OB); a target set-up file (suffix `.p_targ`), a focal-field set-up file (suffix `.p_focf`) and, in the case of MXU, a mask manufacturing file (also known as a “gerber file”, with suffix `.p_gbr`).

These files are inserted in the observation blocks using P2PP or are used to control the manufacturing of the MXU masks, i.e. they have a direct impact on the execution of the observations with FORS. One additional `.fims` file is used to save the complete mask design to be reloaded by the users in case that masks are to be modified after some time or on the fly in visitor mode observing runs.

Further instrument components like filters or grisms are not saved from the actual FIMS session to the `.p_targ`, `.p_focf` and `.p_gbr` files, but are only used to visualize focal plane restrictions for the user defined wavelength ranges. This allows that FIMS mask-set can be combined with different filter and grism setups (ignoring any constraints on wavelengths and similar).

### 2.2.5 Instrument Summary File

The Instrument Summary Files (ISFs) reflect the status of the instrumental database and are pre-defined for the respective observing period. The ISFs are part of the FIMS distribution package. They contain the dimensions of the field of view, the properties and physical locations of the longslits and the available optical components for each CCD mosaic. Recent changes in the instrument configuration will be only updated in the most recent software release and therefore the recommended versions of FIMS should be used exclusively.

## 2.3 FIMS Modes

### 2.3.1 Supported Modes:

For practical reasons the released FIMS version contains two trains: one for the (R)ed-sensitive MIT CCD mosaic and one for the (B)lue-sensitive E2V CCD mosaic. The two FIMS trains are specific for the respective detector mosaic, i.e. they reflect the options for the observations using the corresponding detector mosaic as well as the small differences in the focal plane geometry of the instruments.

The FIMS modes as listed in table 1 are supported with the actual release. Details on the available instrument components can be found in the FORS2 User’s Manual.

Mode	Observation type
IMG	imaging with occulting bar masks
MOS	multi-object spectroscopy using 19 movable slitlets
PMOS	multi-object spectro-polarimetry
MXU	multi-object spectroscopy with laser-cut masks
HIT-MS	high time resolution spectroscopy of target and comparison star

Table 1: FIMS modes

### 2.3.2 FIMS or fast mode target acquisition alternatives

The use of FIMS is mandatory for MOS, MXU, HIT-MS and imaging with occulting bars. It is also mandatory for polarimetric multi-object spectroscopy (PMOS), but not for single target spectro-polarimetry. IMG, LSS, IPOL and PMOS can be done with fast acquisition templates. The “traditional” blind offset method (locating a bright object on the slit and applying a known offset from that telescope position to the scientific target) can be used for faint targets with the fast mode templates as well. It is recommended to use the fast modes whenever possible.

## 2.4 Input frames and catalogs

### 2.4.1 Astrometric requirements

For preparing observations with FIMS, a FITS file with appropriate world coordinate keywords (World Coordinate System WCS) in the FITS header is required. Alternatively input catalogs can be used in frameless modes. Accurate target coordinates are required. The target positions must be very well known relative to the coordinates of “reference stars”. A maximum astrometric error of 1/6 of the slit-width can be tolerated: Every single target coordinate (w.r.t the reference stars) must be known to better than  $0''.2$  if a  $1''.2$  slit width is used. Compromises in the astrometry will cause slit losses.

### 2.4.2 Pre-images with FORS1 or FORS2

Pre-images taken with both FORS instruments can be typically used for the mask preparations.

There are a few important aspects to be considered during the data reduction of pre-images taken with FORS:

**Shift and add only:** The mask preparation for FORS MOS, PMOS, HIT-MS and MXU modes will require that the original scale and field distortion is the same for the reduced data as it was for the raw data. This is required since the FIMS tool will correct for the scale distortion in case of FORS pre-images at the time when the masks are saved. Advanced techniques to combine jitter images such as drizzle will require some distortion corrections before the techniques will be applied. It is strongly

recommended only to use clean shift and add techniques (eg. IRAF imcombine) to reduce images which are to be used for FIMS mask preparation.

**MIT/E2V mosaic - don't cut the edges:** In case of pre-imaging data taken with the MIT or E2V mosaic detectors it will be required to keep the original file format of the pre-images. Vignetted parts of the images, pre- and over-scan regions must not be cut before using the files with FIMS. The plug-in function `fsmosaic` delivered with the `fims` software can be used to merge the two files safely:

```
fsmosaic INPUT_FILE OUTPUT_FILE
```

The merged output files could be now combined with standard software such as `imcombine` (eg. for IRAF `imcombine`: a median of the jittered files with the `offset` parameter set to `wcs` should give satisfactory results for the mask preparations). First `fsmosaic` and then `imcombine`!

**Pipeline support:** The quality control group is delivering pre-reduced science frames to applicants which have requested pre-imaging runs with the MIT mosaic. The reduced and merged files can be combined with the standard data reduction tools.

### 2.4.3 Built-in Astrometric Corrections for FORS1 or FORS2 pre-images

The astrometric transformations are done automatically. The methods are summarized here as a reference for a better understanding of the procedure.

During the mask preparation the pixel coordinates are converted linearly into world coordinates reading the transformation parameters from the fits header of the pre-imaging files. This is done for FORS images and contributed images from other telescopes or catalogs.

In the case of FORS images the radial distortion coefficients (none linearity of the image scale) are read from the fits headers if available. Hard coded default values are used if the keyword is not found in the fits header of the pre-imaging file. The corrected coordinates are written into the `fims` output files (`.p_focf`, `.p_gbr`, `.p_targ`) which will be used during the target acquisition and mask preparation procedure. The `.fims` file which is used to save the mask configuration and to reload the masks contains the uncorrected distorted coordinates to simplify the reload procedure.

During the target acquisition procedure the inverse conversion of the coordinates is used. This is done with the coefficients valid for the instrument and CCD with which the observations are taken. The observation software predicts the position of the reference stars (and reference slits in MXU mode) on the CCD. It will then search and center the reference stars and slits around the predicted positions. Translation, rotation and image scale offsets are then calculated from the observed and predicted positions of the reference stars using an analytical method (it is not a fit). The rotation and translation offsets are applied to the telescope control system to center the mask on the sky. Image scale offsets can not be corrected, but are only displayed on the user interface to warn the support astronomer about a possible astrometric problem.

The resulting internal accuracy is typically below 50mas, but this doesn't include instrument flexures, which have to be corrected with an image taken through the slit mask.

### 2.4.4 Requirements for Contributed Input Images - World Coordinate Systems

Images obtained by FORS1 can be used as pre-images to prepare observations for FORS2. Images from other telescopes require careful and accurate astrometric calibrations (and WCS fits headers). Frames obtained by FORS1/2 itself or by HST-WFPC2 (`wmosaic` of `iraf`) will provide world coordinates, implemented as FITS header keywords.

If there is no frame available, or if the frame is not in FITS format, it is possible to use the Image Server facilities of Skycat in order to download a sky image from one of the available on-line archives. Note that also here the requirement for positional accuracy applies, as stated in section 2.4.1.

The usual astronomical orientation for sky maps is *North at the Top, East at the Left*, meaning RA is decreasing with increasing pixel number: image fits header keywords CD1\_1<0 and CD2\_2>0 (or equivalently CDELTA1<0 and CDELTA2>0).

If the input frame does not support world coordinates, the FITS header can be edited by using either a FITS header editor or Emacs<sup>1</sup>. Verify this step very carefully. A faulty or inaccurate setting of the frame's world coordinates will be carried over in all further steps. In particular the frame scales CD matrix are very sensitive, while an offset between the WCS and the optical positions read in the frame of less than 10'' can be corrected by the alignment procedure.

To verify the correct setting of WCS keywords load your modified frame into Skycat (select **File** **Open...**) and watch the  $\alpha$  and  $\delta$  values in the panel, when moving with the mouse over the sky field. For further verification you can use the AstroCat facilities to download e.g. all appropriate targets from catalogs like the Guide Star Catalog 2 or the USNO catalog (**Data-Servers** **Catalogs** **GSC-2 at ESO** **Set from Image** **Search**) and compare the optical positions in the frame with the catalog positions.

The WCS FITS header keywords describe a linear map-projection scale, hence non-linear effects caused e.g. by the telescope or instrumental optics generally are not accounted for. The WCS FITS header keywords of FORS1 and FORS2 images contain the local scale in the center of the focal field (= center of the CCD = the optical axis). The non-linear scale contributions due to the optical distortion of FORS are axially symmetric with respect to the optical axis. The optical image distortion of FORS2 is known to FIMS and will be corrected when a set-up is saved. Image distortion of preparation frames of other origin (e.g. from HST-WFPC2 or DSS) is not known to FIMS and hence cannot be corrected.

FIMS supports frames with at minimum size of 1'  $\times$  1'. This means that images obtained by FORS1 using the high resolution collimator and mosaic frames obtained with the WFPC2 of the HST can be used as underlying sky images for FIMS. If the image size is close to the lower size limit, several restrictions apply:

- Coordinate translations, in particular the positions of the mask elements outside the frame are no longer calculated via the built-in WCS package, but are extrapolated linearly from the WCS scale derived from the small-size FITS frame header. This means less accurate dimensions of the instrumental mask.
- The MOS slit blades can only be positioned inside the frame in MOS mode
- The center of the non-occulted strip (the center of the very wide slit) must be inside the frame

#### 2.4.5 Input catalogs and frameless mode

A frameless mode is also offered. No FITS frame is required, but a WCS area is defined for the FORS mask. This mode can be used when there is a target list available with high astrometric quality. The reference stars have to be selected from stars with the coordinates known in the same astrometric coordinate system.

Proceed as follows:

- **File** **Clear** to clear the display and to purge the WCS
- **Data-Servers** **GSC-2 at ESO** or load another target catalog (with reliable astrometry satisfying the requirements of section 2.4.1)
- specify the virtual field (RA,DEC, rmin, rmax) and **Search**

---

<sup>1</sup>in Emacs: do not add further lines (<carriage return>) in the FITS header descriptor!

- scroll with `B1` the color bar to highlight the virtual field.
- `FORS` `Enter Mode` and proceed further as in frame-mode

Please note that the plot symbols in skycat need to be set explicitly for the user provided input catalogs.

### 3 Mask preparation - common functionalities

In this section we describe the common basics of the mask preparation, common to all observing modes. Figure 2 shows a MOS mask prepared and displayed with FIMS/2.x together with the sub-menus of the main pull down menu added to Skycat. The main menu and sub-menus have slightly different labels and/or entries in versions 3.x; some of them are shown in Fig. 3 for the MOS mode.

A typical FIMS session would consist of the following steps

1. to load a FITS frame
2. to select an instrument mode
3. to configure the slits, grisms, display options, . . .
4. to prepare the mask (position, slit configuration)
5. to select reference targets
6. to save the setup; this creates the files for P2PP

#### 3.1 Basic movements and functionalities

The central green circle has the function of handling the mask as a whole. In the following, the 2 mouse buttons (left, middle) are designated `B1` and `B2`. Their functions when clicking on the central green circle are:

- `B1` : mark current mask position
- `B2` : rotate the instrument (and hence the whole mask) counter-clock-wise on the screen. The default step-size is  $5^\circ$ . The step-size can be controlled from the `Rotation Step` button in the `FORS Config/Layout` menu.
- `Shift B2` : rotate the Instrument (and hence the whole mask) clock-wise.
- `B1` and move: Changes telescope pointing position (and hence moves the mask as a whole)

The function of mouse button `B3` is still for measuring distances, as in the original Skycat.

**Note:** When large zooming is used, the green handling circle might be no longer visible on the canvas. In this case there are three possibilities:

- zoom out the canvas using `z`
- drag the white rectangle in the upper right pan-window to scroll the canvas to the appropriate position
- use the scroll bars of the canvas (only if Skycat has been started with the `-with-scroll` command line option, which is set by default).

#### 3.2 Reference stars and target acquisition

The selection of appropriate reference stars within fims will be the most important task to ensure that the science targets will be on the slit:

For all fims based observing modes reference stars have to be selected and centered on the input frame which was used for the mask preparation. These reference stars will be automatically identified on the acquisition image taken within the target acquisition sequence. From the positions measured on

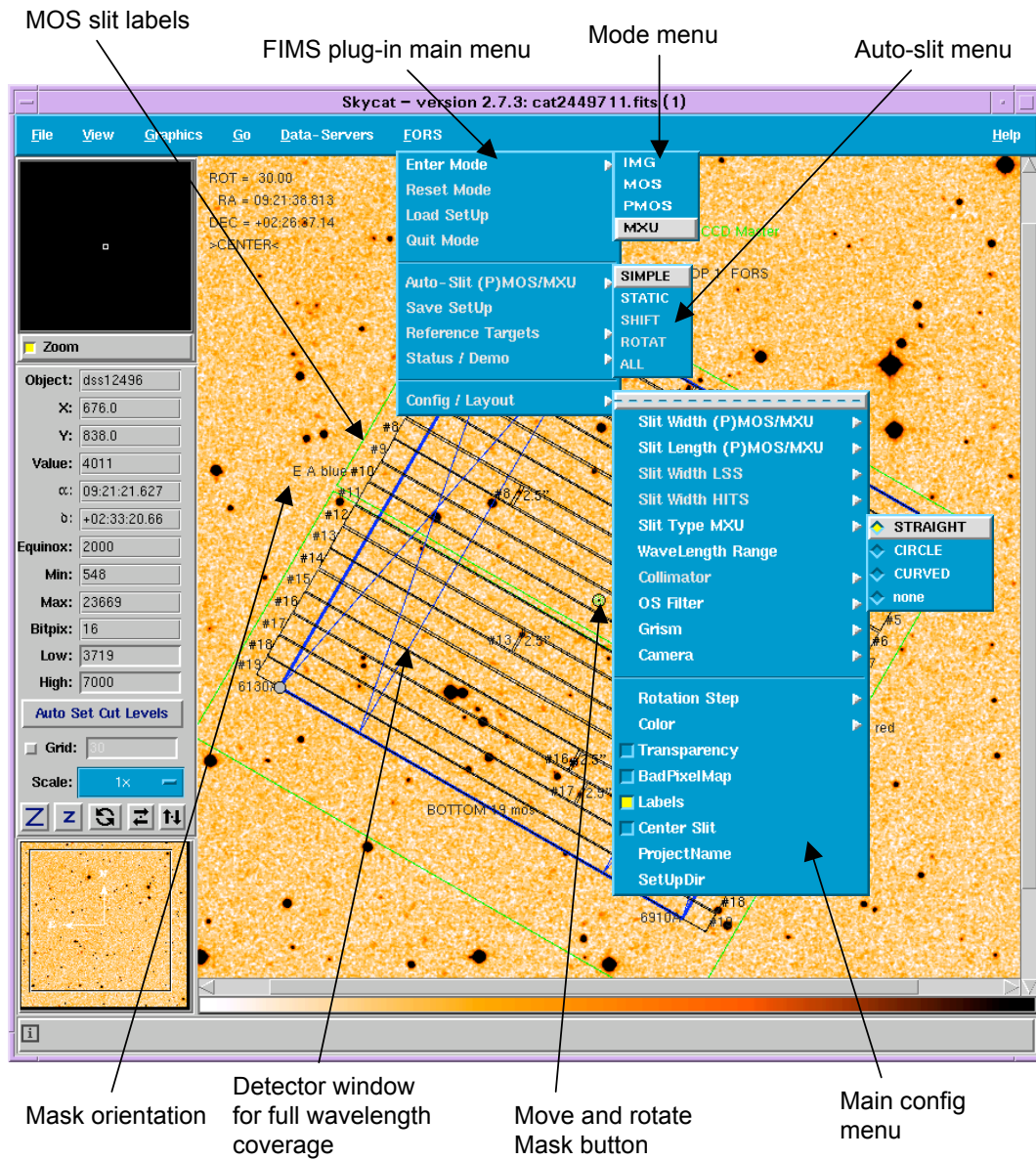


Figure 2: Screen snapshot of the FORS instrumental mask simulator (FIMS) and ESO Skycat, valid for versions 2.x of the software.

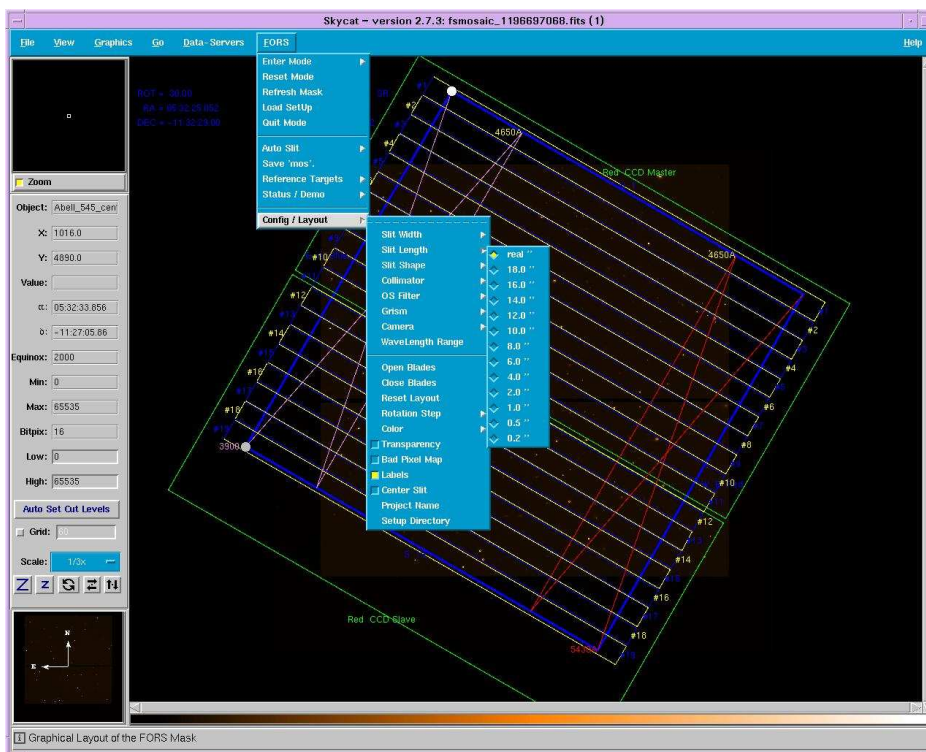


Figure 3: Same as Fig. 2 for the P85 FIMS version.

the acquisition images the translation and rotation offsets will be calculated automatically and the derived offsets will be send to the telescope control system. In the majority of cases this will be done automatically, but in some cases we will have to identify one of the reference stars interactively. We therefore request that the reference stars are identified on all user provided finding charts.

The absolute reference positions of MOS-slits in the focal plane of the instruments are given by reference images typically taken during daytime with the telescope at the zenith. In MOS mode the MOS slit 10 can be (optionally) placed very quickly into the focal plane during the acquisition image without taking an additional exposure. With a red or infrared broad band filter (or without filters) the MOS10 option can therefore improve the acquisition with limited observation overheads. A through slit image, taken after the target acquisition sequence, is mandatory. This is required to verify that the acquisition was successful and for the final optimization of the target positions on the slit. The throughslit image will be taken after the acquisition, when the mask is put into the focal plane, immediately prior to the spectroscopic observations.

In the case of the MXU and HIT-MS modes a reference slit image is taken during daytime by the observatory staff. This image will be used to measure the actual position and rotation angle of the mask in the focal plane of the telescope. The invar masks are sometimes slightly rotated when they are mounted into frames after manufacturing. For MXU only, the target acquisition software will automatically measure the positions of the six pre-defined reference slits on the bottom edge of the upper “master” CCD. These reference slits ensure we have a “baseline” that is long enough to correct for this rotation. A general rule for the selection of reference stars: For all multi-object observations (MOS, MXU, HIT-MS, PMOS) it will be required to correct rotation offsets between the pre-image and the actual telescope position with a high degree of accuracy. Therefore, we suggest that the user defines at least 5 reference stars. These should be widely spread over the field in which the science slits have been set. For imaging applications (IMG) and slitless spectroscopy the pointing of the telescope and therefore the selection of reference stars should be uncritical. The procedure how to select reference stars is explained in section 6.8.

After the upgrade to the mosaic detectors all reference stars must be selected on the upper “master” CCD. Fims forces the users to do it right, by hiding all other parts of the input images.

For any application it is mandatory to select unsaturated point sources as reference stars.<sup>2</sup> There should be no brighter star then the reference star within about 10 arcsecs and the reference stars should be about 10 arcsecs away from the edge of the field of view and about 10 arcsecs away from MOS slit 10 if this slit is used to define a new reference slit position during the target acquisition sequence.

### 3.3 Spectroscopy Setting: Configuring Slits, Grism, Filter and Wavelength Range

FIMS will visualize the focal field boundaries within which slits can be placed for a given wavelength range and filter grism combination. Some configuration steps will be required to enable the functionality. Slits can be set beyond this boundary anyway, but some parts of the specified spectral range will be lost:

For spectroscopic modes the default grism/order separation filter combination is `none/none`; the selection of grisms and filters is done from the `Config/Layout` menu.

The `Help` `Grism info` shows the proposed wavelength ranges for each grism-filter combination, as read from the Instrument Summary File ISF. This wavelength range reflects mostly the grism efficiency, but wavelength cut-off due to the order separating filter is taken into account. This wavelength range is larger than the CCD for the high dispersion grisms, hence only a fraction of the default wavelength range is covered by the CCD.

---

<sup>2</sup>The operation team has already seen spiral arms around reference “stars” and blooming bright stars which was fatal for the acquisition in all cases which were reported so far. The observatory staff will have to reject all these “stars” interactively to fix the problem.

A smaller wavelength range can be chosen via the    menu. The sky area limit, for which the user-defined wavelength range fits within the CCD is marked by two additional blue lines. Spectra of targets with MOS slit positions beyond the (left, right) blue line, will be cut at the blue or red end of wavelength range. The two *forbidden* target selection regions at both sides of the CCD are indicated by a large blue cross or - in other words - spectra of slits positioned in the blue-crossed area will be cut by the edge of the CCD.

### 3.3.1 About the screen output

Each time a new grism, a new filter or a new wavelength range is selected the grism info output is updated in the log window. A sample output looks like

Wave Limits:

INS\_DISP: 5.0 [mm/nm]

FOCSCALE: 1.901679 [arcsec/mm]

PIX: 0.030 [mm/pix] binned

CCDscale\_standard: 0.250124 [arcsec/pix]

CCDscale\_highres: 0.1250626 [arcsec/pix]

FORS CCD Frame

=====

» 435.0 < 200.0 < 590.0 < 730.0 < 870.0

» 435.0 < 435.0 < 590.0 < 730.0 < 870.0 GRIS300V+10 GG435+81

» DISP 110.0 A/mmCD 3.3 A/pix 13.2 26.4 A/'' 6.9 13.9 A/mmfc

» BLU 1550.0 A = 466.7 pixel = 116.7 '' = 1.945 ' = 61.380 mm(fp)

» RED 1400.0 A = 424.2 pixel = 106.1 '' = 1.769 ' = 55.800 mm(fp)

» USD 2950.0 A = 893.9 pixel = 223.6 '' = 3.727 ' = 117.179 mm(fp)

» SPE 4350.0 A = 1300.0 pixel = 325.2 '' = 5.419 ' = 170.986 mm(fp)

» Field Stop total range = 4516.1 A (SR) = 5354.4 A (HR)

» CCD total range = 6788.2 A (SR) = 6782.6 A (HR)

=====

The first block of lines gives the instrument characteristics at the focal plane. Then follow two lines giving the wavelengths in nm. From left to right:

1. The lower  $\lambda$  boundary as given by the grism-filter combination. This is the shortest wavelength that makes sense for the given grism/filter combination.
2. The user-specified lower  $\lambda$  boundary, defined by the  button.
3. The central  $\lambda$  as given by the grism/filter combination and which appears at the center of the CCD.
4. The upper user-defined  $\lambda$  boundary, defined by the  button.
5. The upper  $\lambda$  boundary as given by the grism-filter combination. This is the longest wavelength that makes sense for the given grism/filter combination.

FIMS recognizes that the user-defined lower  $\lambda$  value (value 2, line 9) is not inside the interval given by the instrument (value 1) and corrects it to the lowest permitted value (from 200.0nm to 435.0nm) in the second row. The second line also shows the grism name and the filter name. (note that this information is only for information and is not passed onto P2PP)

The line labelled DISP the grism dispersion in different units, where mmfc means mm in the focal plane and mmCD means mm on the CCD. The next two lines give the blue (BLU) and the red (RED) part of the user-defined (and FIMS corrected) wavelength range, again in different units. In our example the blue part of the spectrum is about 155nm long covering a range of 467 pixels or corresponding to 61mm in the focal plane.

For the absolute wavelength position on the CCD: Note that the central  $\lambda$  (590nm) appears on the CCD where the through-slit image would appear. The sixth line gives the total user-defined (USD) wavelength range, blue and red part together. The seventh line gives the total wavelength range as permitted by the grism/filter combination. This is the wavelength range not contaminated by the second order of the grism. In our example the total available uncontaminated range is 435nm. The CCD can cover 679nm (last line).

### 3.4 Finding guide stars for the VLT

FIMS or Skycat can be optionally used to verify if there are appropriate guide stars in the field of view of the unit telescope. The search is confined to an annular sky region around the telescope pointing coordinates, where the guide probe can be positioned without vignetting the relevant FORS field of view. The standard limiting radii of the search are

$$4.0' < R < 7.4' \tag{1}$$

when using the standard resolution collimator, and

$$2.3' < R < 7.4' \tag{2}$$

when using the high-resolution collimator. A further (seeing dependent) constraint for guide star selection is the brightness range of  $10.0 < m_v < 13.0$  for the median seeing of  $\sim 0.8$  arcsecs. If the telescope control system cannot find a suitable guide star within this region the pointing cannot be achieved, hence the observations cannot be carried out. To avoid this situation the number of available guide stars for the user defined pointing and active optics corrections can be retrieved using the on-line GSC-2 catalog. Press the following buttons   . Specify the mask central position (but do not use the button  when the mask has been moved away from the initial central position). Specify the inner and outer search radius (in arcmin) as well as the magnitude range of  $10.0 < m_v < 13.0$ . Press the  button to get all guide stars. If the number of guide stars is less than 3, another pointing (a small offset of about 20") may result in an improvement in the quality of the delivered data.

## 4 Mask preparation - mode specific functionalities

### 4.1 MOS mode

The MOS mask consists of the 19 movable slit blade pairs, the green central circle (to move and rotate the whole mask) and the focal field projected on the CCD (blue square).

#### 4.1.1 Positioning MOS slits

After having selected the collimator, slit width, grism, optionally a filter, and the wavelength range, the positioning of the slits is done just by pressing the left mouse button **B1** on the desired target position. When a slit is positioned it is automatically marked and the current position (RA, and DEC) is stored. Marked slits are labeled by their slit number in case the label option is on (**FORS** **Config/Layout** **Labels**). To position slits on well defined objects one can have them centered automatically using the **FORS** **Config/Layout** **Center Slit** option described below and in section 6.10.3.

The white and gray circle as well as the orientation labels can be clicked to move and rotate the mask. When the whole mask is rotated or shifted (by pressing **B1** or **B2** on the green circle) all slits will be unmarked and de-selected again. Marked slits can be de-selected via the **B2** button. The unmarked slit will be moved beyond the focal field into a park position.

**Center Slit option:** The center slit option selectable from the configuration menu will significantly improve the slit positions for point sources and other relatively compact targets. A Skycat feature with the centroid algorithm: a single click on the target and the centroid might fail. Click somewhere with the left mouse button **B1**, hold the button while moving the mouse, wait until you see the target in the center of the pick object window and release the mouse button now, ...

**Slits behind the green circle:** The left mouse button while used on the location of the green circle is defined to move the mask. It is only possible to put a slit behind the green circle with the “Center Slit” functionality as described above - click somewhere, keep the left mouse button pressed while moving the mouse behind the green circle, wait until you see the target in the “pick object” window and release the mouse button.

#### 4.1.2 Saving the setup

When selecting the “save” menu item (**FORS** **Save mos.3**), all marked slits together with the slit width and the slit position will be saved in the acquisition file or set-up file. Unmarked slits will be generally out of the focal field in a park position in order to close the focal field and to reduce light scattering in the instrument.

#### 4.1.3 Modifying slits

The slit width is initially selected in the **FORS** **Config/Layout** **Slit Width** menu item and is by default the same for all slitlets. The mask position, the mask orientation, and the 19 MOS slit positions is retained when changing the slit width. The width of MOS slits can also be changed individually, just by pressing **B1** on the slit width label of the desired slit (e.g. 1.0”). The minimum allowed slit width is 0.2 arcsec.

Each MOS slit can be de-selected (un-set) either by pressing with **B1** on the slit number label at the rim of the focal field (e.g. #4) or by pressing with **B2** on the slit number label of the slit itself. Pressing **B1** inside the slit will move the slit to the cursor position. Use the zoom buttons **z** and **Z** or use the white frame in the pan window when positioning the slit blades in detail. The **FORS** **Config/Layout** **Transparency** flag is to highlight selected MOS slits only.

#### 4.1.4 Slitless spectroscopy

Slitless spectroscopy (imaging with a grism) is handled either as a special sub-mode of MOS ( open option in the slit width menu) or through the imaging mode with occulting bars (see section 4.3). For this purpose all MOS slit blades are out of the focal field by default but may be individually set as in IMG to occult selected light sources in the sky field.

## 4.2 PMOS mode

### 4.2.1 PMOS mode

As in imaging polarimetry (IPOL) the odd numbered MOS slits are closed, while only the even numbered slits can be moved via mouse button  B1. The mask preparation steps as well as the target acquisition on the sky is done with the same sequences and procedures as for MOS mode. Basic mouse bindings, associated with the green circle, are retained, see section 3.1. The collimator check button in the layout menu is disabled in order to avoid PMOS in high resolution collimator mode.

**No PMOS mode with the high resolution collimator:** Spectropolarimetry using MOS slitlets and the high resolution collimator is not supported with FORS since the mode would require MOS slitlets of 11 arcsec length to be used with the given Wollaston prism.

## 4.3 IMG mode: imaging with occulting bars

For the imaging mode it is possible to use the MOS slit blades to occult bright sources in the field in order to avoid CCD saturation with charge overflow. In the standard resolution mode all slit blades are out of the image as an initial position. For the high resolution mode slit blades 1 to 5 and 15 to 19 are fully in the focal plane as a field stop to reduce scattering light in the instrument. Slit blade pairs 6 to 14 are shifted into the focal plane up to the edge of the CCD frame indicated by the blue rectangle.

The bindings for the green handling circle are as described for the MOS mode (section 4.1).

The positioning of the individual slit blades is done via mouse button  B1 and  B2. Unlike in the MOS mode only one slit blade is positioned to the mouse pointer. Pressing  B1 ( B2) at a position between the two slit blades will move the **Left (Right)** slit blade to the mouse pointer position.

Pressing  B1 or  B2 on the slit blade itself will recede the corresponding slit blade out of the field to the current mouse pointer position. Pressing  B1 on the slit number marker on the left or right edge of the mask, or  B2 on the slit number on the blade itself, will fully retract the blade. For the HR collimator retraction of a slitlet to park position may require its interactive repositioning to the HR field stop mask limit if deemed necessary for the observations.

When saving the IMG target set-up file, all blades ending near the border of the focal field will be automatically set to the park position, meaning either set to fully open or fully closed. An example is given in Table 11.

## 4.4 MXU mode

### 4.4.1 Basic information

The mask exchange unit of FORS2 is only offered with the SR collimator. This mode is distinctly different from all other modes from an operational point of view. Slit masks have to be manufactured and masks have to be inserted like optical components into the instrument before the OB can be executed.

### 4.4.2 Creating slits

Besides the basic key bindings for mask positioning (see section 3.1) and the usual menu buttons for grism and filter selection the following bindings are provided:

- press **B1** to create a MXU-slit
- press **B1** on the slit number label at the edge of the focal field to purge the slit.
- press **B1** on the slit width label to configure the the single slits.
- press **B2** on the slit number label next to the slit to purge the slit.

At the moment three MXU slit types are supported STRAIGHT (=rectangular slit, optionally rotated with respect to the dispersion direction), CIRCLE (= just a circle) and CURVED (= a third order Bezier polynomial).

To use the MXU mode to obtain the highest multiplex gain (largest number of spectra) one can use a interference filters or other filters to reduce the length of the spectra. One can therefore position more than one MXU slit side by side along the dispersion direction. In this case FIMS plots a short stripe at the position of the expected spectrum. It is recommended to define side by side MXU slits along decreasing dispersion direction.<sup>3</sup>

**Center Slit option:** The center slit option selectable from the configuration menu will significantly improve the slit positions for point sources and other relatively compact targets. A Skycat feature with the centroid algorithm: a single click on the target and the controid might fail. Click somewhere with the left mouse button **B1**, hold the button while moving the mouse, wait until you see the target in the center of the pick object window and release the mouse button now, ...

**Slits behind the green circle:** The left mouse button while used on the location of the green circle is defined to move the mask. It is only possible to put a slit behind the green circle with the “Center Slit” functionality as described above - click somewhere, keep the left mouse button pressed while moving the mouse behind the green circle, wait until you see the target in the “pick object” window and release the mouse button.

### 4.4.3 MXU reference slits

FIMS will define six small square reference slits on the bottom of the upper “master CCD”. The slits are used to calculate residual rotation and translation offsets of the mask in respect to the expected position in the focal plane of the telescope. These slits can not be modified by the users and users should not put target slits at the same position. FIMS will display the positions of the reference slits as indicated in the following figure:



<sup>3</sup>With the help of a deep image taken with the same filter it will be in theory possible to set slits on top of almost all targets for which it will be possible to take spectra in a reasonable time (but with the sky suppressed by a factor of  $6.8 * 60 / \text{slitwidth}$  – compared to slitless spectroscopy)

**Reference slits must be within the field of the pre-image:** It is necessary for the reference slits to fall within the boundary of the input pre-image (no matter if vignetted or not) due to the method in which skycat converts pixel to world coordinates. FIMS will remove the slits which are out of the field to allow to save the mask. The reference slit will be removed from the list also for the next masks unless the reset/mode function in menu FORS2 is called interactively. Please reset the mode after this sort of events - fims will issue a warning message. The masks with one or two removed reference slits can still be used for the science observations.

#### 4.4.4 Files and numbers

Each slit mask has a mask identification number (**MASK\_ID**) which is a 6 digit number between 900000 and 999999 (the first 100 being reserved for “technical” masks), and a mask name **MASK\_NA** which is **MASK\_** by default. This number will be cut in the same way as the slits into the invar mask sheet at a position outside the focal field.

When saving a MXU set-up FIMS creates a file with the ‘gbr’ extension. This file contains the slit set-ups, the default mask id and the mask size in the extended Gerber format (GerberX format or RS274X format). This file will have to be included in the OBs for the MXU via P2PP. At Paranal this file will be used by the Paranal mask preparation software to produce the mask with the Mask Manufacturing Unit (MMU). Finally, the mask will be inserted into FORS2 before the observations are scheduled.

**Mask name, Mask id, Mask NAID:** When saving a setup for the MXU the keyword **INS.MASK.NAID** will be created and included to the setup files.

The value is **Mddccccccc+dddddd** or **M< INS.MASK.NA >+< INS.MASK.ID >** where **ddd** is the FIMS internal counter as a three digit number. Its the same number that appears in the name of the well known **\*.p\_focf** file. The **ccccccc** is a 8 char long string. Its the user-defined project name which also appears in the name of the **\*.p\_focf** file. By default the first 8 chars of the fits file name is taken. The **dddddd** is a six digit random number between 900101 and 999999. When a mask is manufactured the six digit **INS.MASK.ID** is the only identification.

**Postscript file of the slit mask:** when saving a setup for the MXU, a postscript file is saved to **.fims/LOG** for printing an image of the mask with slit positions.

#### 4.4.5 MXU constraints

**Maximum MXU slit size:** Sizes of all individual slit apertures are restricted to 40 arcsec for mechanical reasons, since the long metal pieces can get stuck in the punching machine. It is however not excluded to produce larger multi-slits or unusual slit geometries by punching several individual MXU slits next to each other - with some space in between. However, such large multi-slits may cause mask plate bending and are thus to be discussed with the observatory staff.

**More than one curved slit:** It is possible to specify more than one curved slit in one setup. If a second curved slit is created the previously created cannot be edited any longer. It is not possible to modify previously defined curved slits (one has to delete the previous slit and define a new one).

**Slow shape modification:** Curved slits change their shape on-line (but not real-time) while moving a cyan Bezier polynomial grid point. The on-line low resolution shape of the curve is determined in Tcl/Tk and is hence very slow. It is recommended to use a large slit width and hence a large Bezier circle to avoid ‘loosing the anchor’ when modifying the slit shape. When the desired slit shape is achieved, the fake large slit width can be set back to the originally intended slit width.

## 4.5 HIT-MS mode

### 4.5.1 Basic information

The HIT-MS mode is based on the MXU mode, with the difference that the dispersion direction is orthogonal to that of the standard mode. Therefore only the cross-disperser grisms XGRIS\_600B and XGRIS\_300I are used. The wavelength range of the grisms is slightly different from that of the standard 600B and 300I. This is primarily caused by the asymmetric mount of the FORS2 MIT CCD mosaic which is off-centered by 33". Both MIT or E2V mosaics can be used. The user can define two 5" long slits (allowing 41 pairs of spectra per CCD readout), or a single 10" long slit. Any slit width can be defined, in the range 0".3–30". The position angle of the rotator is determined so that the target and comparison slits fall onto adjacent x-pixels on the CCD. The y-pixel positions of the two slits are determined by the offset between the target and the comparison star. This offset also determines the relative spectral coverage of the two spectra. Offsets in the range 5"–300" are possible, but it is recommended to choose a comparison with a separation of < 60" to ensure a reasonable flux calibration. The two slits are defined inside a fixed area toward the left side of the field of view, and should be placed on the main scientific target and on a comparison star (for slit loss determination). The reference targets for mask alignment must be defined in the area of the master chip. An Example Session of HIT-MS is given in Table 14.

### 4.5.2 Creating slits

Besides the basic key bindings for mask positioning (see section 3.1) and the usual menu buttons for grism and filter selection the following bindings are provided:

- press **B1** to create a HIT-MS slit;
- press **B1** on the slit number label at the edge of the focal field to purge the slit;
- press **B1** on the slit width label to configure the the single slits;
- press **B2** on the slit number label next to the slit to purge the slit.

Only the e slit type STRAIGHT is supported (=rectangular slit, optionally rotated with respect to the dispersion direction).

**Center Slit option:** The center slit option selectable from the configuration menu will significantly improve the slit positions for point sources and other relatively compact targets. A Skycat feature with the centroid algorithm: a single click on the target and the centroid might fail. Click somewhere with the left mouse button **B1**, hold the button while moving the mouse, wait until you see the target in the center of the pick object window and release the mouse button now, . . .

### 4.5.3 HIT-MS reference slits

The reference slits can be created anywhere within the master chip area, and outside the fixed area where the science slits are to be created. In this case the six small square reference slits on the bottom of the upper "master CCD" are not created, because they would create additional spectra that would interfere with the science ones.

**Reference slits must be within the master-chip field of the pre-image:** It is necessary for the reference slits to fall within the boundary of the input pre-image (no matter if vignetted or not) due to the method in which skycat converts pixel to world coordinates. FIMS will remove the slits which are out of the field to allow to save the mask. The reference slit will be removed from the list also for the next masks unless the reset/mode function in menu FORS2 is called interactively. Please reset the mode after this sort of events - fims will issue a warning message. The masks with one or two removed reference slits can still be used for the science observations.

#### 4.5.4 Files and numbers

Each slit mask has a mask identification number (**MASK\_ID**) which is a 6 digit number between 900000 and 999999 (the first 100 being reserved for “technical” masks), and a mask name **MASK\_NA** which is **MASK\_** by default. This number will be cut in the same way as the slits into the invar mask sheet at a position outside the focal field.

When saving a HIT-MS set-up FIMS creates four files with extensions **p\_targ**, **p\_gbr**, **p\_focf**, and **fims**. The file format is the same as the MXU output, apart from the **p\_targ** file which is the same format as the MOS output (ie. in one long string rather than a PAF). The ‘gbr’ file contains the slit set-ups, the default mask id and the mask size in the extended Gerber format (GerberX format or RS274X format). This file will have to be included in the OBs for the MXU via P2PP. At Paranal this file will be used by the Paranal mask preparation software to produce the mask with the Mask Manufacturing Unit (MMU). Finally, the mask will be inserted into FORS2 before the observations are scheduled.

##### **Mask name, Mask id, Mask NAID:**

When saving a setup for the HIT-MS the keyword **INS.MASK.NAID** will be created and included to the setup files.

The value is **Mdddccccccc+dddddd** or **M< INS.MASK.NA >+< INS.MASK.ID >** where **ddd** is the FIMS internal counter as a three digit number. Its the same number that appears in the name of the well known **\*.p\_focf** file. The **ccccccc** is a 8 char long string. Its the user-defined project name which also appears in the name of the **\*.p\_focf** file. By default the first 8 chars of the fits file name is taken. The **dddddd** is a six digit random number between 900101 and 999999. When a mask is manufactured the six digit **INS.MASK.ID** is the only identification.

## 5 Target Lists

It is not necessary to have a target list when working with FIMS. However, it is highly recommended in order to avoid target misidentification. Automatic positioning in (P)MOS and MXU mode will require a user defined target list. FIMS interacts with a target list during the following tasks:

- **Save:** (P)MOS/MXU slit positions are compared with the target list. If there is a match, the target is deleted from the loaded version of the catalog (but not from the target list on the harddisk) and the target name is copied to the target identifier of the current slit. If there is no target list loaded or no target is found in the target list, FIMS assigns NN as default target name for the current slit.
- **Automatic Positioning** puts (P)MOS/MXU slits to positions of the target list. The optical position of the frame is ignored. This task does not change the current target list.
- **frameless mode:** Usually the WCS used by FIMS is generated by the FITS header keywords of the underlying frame. When a target list is plotted without underlying frame a WCS is generated which can be used as a ‘play-ground’ for FIMS instead (frameless observation preparation). This task does not change the current target list.

The optical positions on the frame (pixel) and the WCS are sufficient to determine the correct positions of the slitlets. Even if there is a shift in the WCS with respect to the underlying frame the prepared MOS slitlet positions will be very accurate (mean positioning accuracy  $\simeq 0.07$  pixel), since the reference targets used for the alignment and the science targets in the slits are determined in the same (possibly shifted) WCS.

For situations where MOS/MXU set-ups have to be prepared with e.g. 100 science targets in one single FORS image it might be useful to find automatically the best mask positions in order to optimize the slit positions and to reduce the number of MOS exposures. For this purpose astronomical catalogs are required.

See also section 6.6 for further explanations and requirements for the use of target lists.

### 5.1 How to generate target lists

Target lists can be created in four ways:

1. A local catalog can be created with `EnterObject` where the positions are determined by the center/gauss method from the underlying image. It is recommended also to include the reference targets in the same catalog to make sure that science targets and reference targets use the same coordinate system.
2. Catalogs are also available from the web (see `Data-Servers`). When plotted over the FORS frame, they might be shifted with respect to the optical position, a consequence of the VLT pointing accuracy. It is generally possible to use automatic MOS slit positioning using external catalogs. However, it might be necessary to edit the table header keywords (see section 6.6 for the requirements). Again it is important that the reference targets must be taken from the external catalog as well and not from the optical position in the frame.
3. Load the preparation image into ESO-MIDAS and use the inventory package to create a target list. The target list can be converted to the Skycat format. (See the `midas2skycat.sh` script in the delivery package)
4. The output format of the widely used Source EXtractor software is already compatible with the Skycat catalog format.

## 5.2 Example target list

The target list is an ASCII file, where individual columns are separated with Tabs. If you do not have a target list, you can use the Skycat AstroCat facilities to download a target list from one of the available online catalogs. You can save this online catalog as a **local catalog**; e.g. press **File** **Save as...** in the GSC-2 at ESO window. Load this file again as a local catalog (**Data-Servers** **Local Catalogs** **Load from file...**) and edit it with the **Edit** button in the local catalog window.

An example for a user defined target list is given below:

ID<\tab>	RA<\tab>	DEC<\tab>	MAG<\tab>	PRI
--<\tab>	--<\tab>	---<\tab>	---<\tab>	---
NGC0815_001<\tab>	7:00:28.3<\tab>	+05:01:18<\tab>	27.0<\tab>	0
NGC0815_002<\tab>	7:00:27.3<\tab>	+05:01:17<\tab>	20.0<\tab>	1
NGC0815_003<\tab>	7:00:33.3<\tab>	+05:01:19<\tab>	19.2<\tab>	0
NGC0815_004<\tab>	7:00:13.3<\tab>	+05:01:17<\tab>	20.7<\tab>	0
NGC0815_005<\tab>	7:00:20.3<\tab>	+05:01:16<\tab>	25.0<\tab>	0
NGC0815_006<\tab>	7:00:25.3<\tab>	+05:01:17.2<\tab>	22.3<\tab>	1

where <\tab> means pressing the Tab key.

The first three columns are necessary, while the latter two **mag** and **pri** are optional. The priority column **pri** can be used for further selective constraints in the automatic positioning task in MOS mode. If the target list does not contain a column with **mag** or **pri** use the **FORS** button of the menu bar in the catalog window to add columns to the local catalog. When creating a local catalog from a target list, where the coordinates are only given in CCD pixel positions, you can use the **Edit** **Enter new object** **Pick object...** commands to create your target list step by step. During a FIMS session the user-defined target list will contain the targets which are not yet stored in a target acquisition file (TAF). Each time the mask position is saved, the matched objects will be purged from the target list. It is therefore highly recommended to use a **local copy of the target list** during the preparation of observations with FIMS.

## 5.3 Saving target acquisition files

Saving a TAF in MOS or PMOS mode invokes a search of all selected slit positions in the local catalog. In PMOS mode odd numbered slits cannot be selected and are omitted for the search. If one of the slit positions (the RA, DEC position inside the slit, where the user has clicked, not necessarily the center of the slit) is found in the user-defined target list, the corresponding object will be purged from the target list. The local catalog contains at any moment all objects not yet selected for an observation block. At the end of a FIMS session after several mask configurations all targets are stored in TAFs and an empty target list remains. It is therefore highly recommended to use a copy of the target list for a FIMS session.

## 5.4 More about fims preparation with target lists

**Reference stars:** In frameless mode the coordinates of the reference stars have to be typed into the reference star panel which will show up when the **Reference Star - Add** function is started.

**Set Plot Symbols:** After loading the input catalogs it will be required to set the plot symbols. This task is started from the options menu of the catalog panel. First select the catalog columns from the “not used” field, then select a column (like “\$id”) to be displayed and the size of the symbols (like 10 or 18.-\$mag if the size should be scaled with the magnitude). Finally press “Add Symbol” and “Apply”.



## 6 FORS Menu Reference

This section gives a comprehensive description of all pull down menu items in the FIMS “FORS” menu and its sub-menus.

FORS	
Enter Mode ▷	section 6.1
Reset Mode	section 6.2
Refresh Mask	section 6.3
Load SetUp	section 6.4
Quit Mode	section 6.5
Auto-Slit ▷	section 6.6
Save <mode> . <number>	section 6.7
Reference Targets ▷	section 6.8
Status/Demo ▷	section 6.9
Config/Layout ▷	section 6.10

### 6.1 Enter Mode

Selecting one of the items in this menu (IMG = Direct Imaging, MOS = Multi Object Spectroscopy, PMOS = Polarimetric Multi Object Spectroscopy, MXU = Mask Exchange Unit, HIT-MS = HIgh Time resolution-Multi Shift) plots the focal field (blue square) and the current instrumental mask over the sky image. The mask is initialized and oriented according to the FORS2 reference system definition. The rotator angle ( $= (-1) \times$  position angle on the sky) is zero. The orientation means MOS slit blade pair 1 is on the North<sub>sky</sub> side, MOS slit blade pair 19 is a the South<sub>sky</sub> side, MOS drive unit A is on the West<sub>sky</sub> side and MOS drive unit B is on the East<sub>sky</sub> side. The correct orientation of the mask with respect to the underlying sky image can be verified using the **FORS** **Config/Layout** **Labels** button.

### 6.2 Reset Mode

This menu item initializes the instrumental mask again, by shifting the mask to the initial world coordinates with the initial orientation (position angle = zero). Usually the initial position will be the telescope pointing of the underlying frame. The telescope pointing will be extracted from the FITS header (keywords CRVAL1, CRVAL2). If one is working with extracted images the telescope pointing may be outside the frame. In this case the mask will be put to the frame center.

### 6.3 Refresh Mask

This option is to be used to simply render the graphics again, in case the display becomes confused. It does not perform any real action on the configuration.

### 6.4 Load SetUp

This menu item configures the mask according to a set-up file. Set-up files are created with the **Save** button. Load files with the `.fims` extension (e.g. `mos.15.myprojec.fims`).

mode	default target set-up filename	INS keyword type
IMG	img2<ec>.<PN>.fims	INS.MOS<i>.POS, INS.MOS<i>.WID
MOS	mos2<ec>.<PN>.fims	INS.TARG<i>.ALPHA, INS.TARG<i>.DELTA
PMOS	pmos2<ec>.<PN>.fims	INS.TARG<i>.ALPHA, INS.TARG<i>.DELTA
MXU	mxu2<ec>.<PN>.fims	INS.TARG<i>.ALPHA, INS.TARG<i>.DELTA
HIT-MS	hitms2<ec>.<PN>.fims	INS.TARG<i>.ALPHA, INS.TARG<i>.DELTA

Table 2: Default target set-up file names and keywords.ec = exposure counter; PN = project name

**Note:** The saved set-up files for IMG use different keywords for the slit blades with respect to MOS and PMOS. Therefore setup files of different modes are not exchangeable, therefore do not load e.g. the file `img1.13.NGC_0815.fims` when the current mode is `mos`.

MOS and PMOS slit positions are defined by WCS; IMG slit blade positions are defined by mm in the focal plane. One exception is slitless spectroscopy (`FORS` `Config/Layout` `Slit Width` `open`) where the MOS slit blades are out of the focal field by default. They can however be used as in IMG to occult bright foreground sources and their spectra. Default target set-up file names and used keywords are summarized in table 2.

## 6.5 Quit Mode

This menu item deletes the mask of the current mode and de-activates all FIMS features.

## 6.6 Auto-Slit

The automatic positioning of (P)MOS, MXU and HIT-MS slits on catalog positions requires target lists. For large user-defined target lists the slit blades can be positioned automatically under several constraints. In any case the slits will be positioned to the catalog targets which might not fully coincide with the optical positions in the FITS frame. When (P)MOS/MXU/HIT-MS slits are positioned by the Auto-Slit routine the reference target positions must be specified from the same catalog and not from the underlying image: The reference targets used for pointing the telescope must originate from the same source as the science targets. Either both from the underlying image or both from the same catalog.

<code>Auto-Slit</code>	
<code>SIMPLE</code>	section 6.6.2
<code>STATIC</code>	section 6.6.3
<code>SHIFT</code>	section 6.6.4
<code>ROTATE</code>	section 6.6.5
<code>ALL</code>	not used

The full list of auto-slits above is available for (P)MOS, while only SIMPLE and STATIC are available for MXU, and SIMPLE for HIT-MS.

### 6.6.1 Requirements

Automatic (P)MOS/MXU/HIT-MS slit positioning on target catalogs works for several on-line catalogs like GSC, SIMBAD, NTT archive, USNO, as well as on user-defined target lists. In addition to the requirements for astrometric accuracy (section 2.4.1) and target catalogs to be used with Skycat

(section 5) the catalog must also meet the following requirements to be used for automatic positioning with FIMS:

- The table header keyword for right ascension must be **RA** or **ra**.
- The table header keyword for declination must be **DEC** or **dec**.
- The table header keyword for the target name must contain one of the following strings to be recognized by FIMS: **ID**, **target**, **name**, **object**, or **Id**. The target name may contain blank characters as e.g. object names in SIMBAD.
- the optional keyword for brightness must be **MAG** or **Mag**
- the optional keyword for the priority flag must be **PRI** or **Pri**

### 6.6.2 SIMPLE

(MXU mode only) Create a slit on all targets of the user provided catalog if the target is within the field of the mask. There is no verification if the spectra will overlap. The user has to interactively remove the slits for which the spectra will overlap. This option was primarily created to allow to create masks for which the length of the spectra is reduced by the use of an interference filter.

### 6.6.3 STATIC

Take the current mask coordinates (RA and DEC) and position angle (PA), search for targets in the user defined local catalog and push slits to appropriate target positions. If there is more than one target per slit blade pair available then the object closest to the slit blade center line is used. If the target list provides the **prio**-column then targets with **prio=1** are preferred even if a **prio=0** target would be closer to the slit blade center. The two blue lines indicate the CCD area for which the instrumental wavelength range fully matches the CCD. Automatic positioning takes only targets within this area into account since spectra of objects beyond this area will be cut due to the CCD edge. The instrumental wavelength range is defined by the combination of grism/order separation filter. If only a fraction of the available wavelength range is of scientific interest, the fractional wavelength range can be specified via the **FORS** **Config/Layout** **WaveLength Range** button. Since this user-defined wavelength range is smaller than the instrumental wavelength range, the CCD area for which the smaller user-defined wavelength range matches the CCD, is larger. The **STATIC** method does not move or rotate the instrumental mask. The mask with the new slit-positions will be redrawn. This method is appropriate when the underlying sky frame has the same size as the **FORS** mask, like images obtained with **FORS** itself in **IMG** mode. All other Auto-Slit methods vary the mask position as an outer loop but call the basic **STATIC** method for each given mask position. For (P)MOS positioning the target closest to the MOS stripe central line is chosen. In MXU mode **STATIC** is the only available mode for **AutoPos**, since MXU provides a much larger range of slit positions than the **MOS**. For crowded fields, the **AutoPos** set-up for MXU is dependent on the target sorting order of the catalog. Hence besides the initial mask position, the mask position angle, the **priority** and the magnitude flag of each individual target also the sorting order of the catalog (**Options** **Set sort columns** in the catalog window) can be varied to optimize the MXU set-up.

### 6.6.4 SHIFT

Trial and error analysis. This method does not keep the user-defined mask position, but the position angle is retained. Find best-fit mask position by using each target of the catalog as a telescope pointing. For each position the **STATIC** method is called. The mask is shifted to the best-fit position. This method is useful if either the underlying sky FITS frame is much larger than the

FORS field and/or if the distribution of targets in the field is no longer random (e.g. concentrated as a ring around a stellar cluster).

### 6.6.5 ROTATE

Take the current mask position (RA and DEC) and position angle (PA). Vary position angle in the interval  $PA - 30^\circ \dots PA + 30^\circ$  with a step size of  $\Delta PA = 1^\circ$ . For each position angle the **STATIC** method is called. If one of the tested position angles result in a larger match quality, the mask will be redrawn with the new PA.

## 6.7 Save

This saves the current mask settings and creates a number of files in the  $\$INSROOT/.fims/SET$  directory (or in a directory specified by    ), consisting of the form:

`<mode>.<counter>.<projectname>.<ext>` where

`<mode>` is one of mos2, img2, pmos2, mxu2, hitms2 (for the notations see Table 2)

`<counter>` is incremented with each save operation in order to avoid overwriting previous set-ups of the same project name

`<projectname>` is an 8 character user defined name. See section 6.10.3.

`<ext>` is one of fims, p\_targ, p\_focf, p\_gbr where

- **fims** is the file which FIMS uses to re-load a set-up
- **p\_targ** contains the value for the INS.TARG keyword, i.e. this is the target set-up file. Used to preset the telescope.
- **p\_focf** contains the value for the INS.FOCF keyword, i.e. this is the focal plane set-up file.
- **gbr** contains the slit information in MXU mode in Gerber format.

Please keep all output files produced by FIMS; they could be useful later if a problem occurs while constructing the OB.

During the save procedure, in a first step the reference targets are verified and the user is asked again if the set-up should be saved. Follow the recommendation and don't save set-ups that will fail at Paranal. In MXU/HIT-MS mode at least one, but for better alignment accuracy better 5-7 reference slits must be specified before saving the mask.

The following sub-items exist in this menu:

- **(P)MOS/MXU** If the AstroCat interface is active, the slit blade positions are compared with the entries of the user defined local catalog. The search area is two times the MOS slit width<sup>4</sup>. Since Skycat version 2.5.3 provides the usage of more than one user defined so called local catalogs, you have to select one of the active local catalogs, from which the slit positions will be deleted. **Note:** The save command only considers top-level catalogs, loaded by the  menu bar button in the **Skycat toplevel window**. Catalogs loaded from the  menu bar button in a **catalog window** will not be considered.

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<sup>4</sup>All targets with coordinates matching one of the slit positions are deleted from the loaded version of the user-defined target list. If the currently local target list is saved with the  button in the catalog pop-up window with the same name, the initially loaded full target list gets saved for security reasons to `<targetlist>.BAK`. Therefore it is recommended to load a copy of your full target list to Skycat.

## 6.8 Reference Targets

MOS, PMOS, HIT-MS and MXU target acquisitions have to be aligned using reference stars. For (P)MOS, HIT-MS and MXU mode, select up to 10 bright reference targets, ideally close to the slit positions.

Reference targets can be specified at any time during a FIMS session, but no longer during the save sequence. Press **FORS** **Reference Targets** **add** to add reference targets. Purge reference targets by a comma separated list (e.g. 7,3) in the **purge** menu. The **reset** button finally erases all entries in the reference target list.

Selected reference targets will be highlighted via a cyan circle. The parameters of the chosen reference targets will be shown in the PickObject window. If less than 10 reference objects are required, **Enter** an empty string in the entry form and ignore the error message.

The sub menus are

- **plot** to plot the reference targets on the screen
- **show** to list the reference targets and their positions
- **add** to add further reference targets. The forbidden area for reference target selection is obscured by a cyan strip.
- **purge** to purge individual reference targets from the list; e.g. enter 1,4 to purge targets #1 and #4
- **verify** to check that all reference targets can be handled by FORS
- **reset** to delete the complete list of reference targets
- **MOS10** to switch the MOS10ALI flag. When MOS10ALI is ON the MOS slit 10 will be in the focal field in the MOS acquisition image for high precision alignments. Reference targets under this slit cannot be used to align the telescope position hence this sky region should be omitted when selecting reference targets.

## 6.9 Status/Demo

**Status** creates a new toplevel window showing the current status of the FIMS session. The contents of the three fields

- Instrument
- Session
- FORS MXU

are self-explaining.

**Demo** A brief demonstration of the capabilities and functions of FIMS.

## 6.10 Config / Layout

This cascaded menu contains instrumental configuration options and options for the graphical layout of the mask. Depending on the selected instrument mode, certain parameters can be selected from the FIMS configuration menu. Only some configuration parameters like the collimator and the slit geometry are written in the FIMS output files. Other parameters selected within FIMS (e.g. wavelength range, grisms and filters) are only used within the FIMS session to display the location of the spectra and other user supporting features. Accordingly the same masks can be used with different filters and grisms which are selected later in p2pp.

### 6.10.1 Instrumental configuration options

- **Slit Width**
  - **spectroscopy with slit** initializes the MOS/MXU/HIT-MS mask with a new common slit width for all slits. The slit width can be between 0'3 and 60'0.
  - **spectroscopy without slit** (P)MOS slit widths of 10'0, 22'0, 30'0, 45'0, 60'0 are intended for slitless spectroscopy. Finally the **open** option takes all MOS slit blades out of the focal field by default. Like in IMG mode MOS slit blades can again be individually positioned to obscure the spectra of bright foreground sources. Use the **transparency** layout option to better visualize the slit arms in the field of view.
- **Slit Length** initializes the MOS/MXU/HIT-MS mask with a new common slit length for all slits. For MOS the actual slit length is physically fixed in the instrument. The slit blades are 22'' wide, but the decker on top of the blades effectively reduces the length of the even MOS slits down to 20''. The FIMS option to diminish the MOS slit lengths is only virtual to visualize a preferred background region in the slit for the targets (e.g. if a sky background region of an offset of at least 5'' is required, select **10 arcsec** (= 20'' - 2 × 5'') background/offset area on each side of the target spectrum). Some of the MOS slit blades do not build a slit with a completely constant width over the full slit length, but show some deviations at the slit edge. Using a visually reduced MOS slit length avoids target positioning at the critical MOS slit edges. This option can also be used to define small reserved strips which could - during the observations with this mask - be used for jitter offsets along the MOS slits. The **real** option returns to the full slit length of the MOS unit. For MXU this option determines the real slit length, and for HIT-MS this can only be 5'' or 10''.
- **Slit Shape** This is only enabled for MXU. Choose one of the 3 currently supported slit types STRAIGHT, CIRCLE or CURVED. Note: modifying curved slits in the FIMS display needs some patience and the display update may be slowed down. Please do not rush. It is possible to create more than one curved slit, but it is not possible to modify the curved slit created. Some kind of strategy for the creation of curved slits is advisable. The maximum number of MXU slits is 1000 (including the 6 reference slits). Working with curved slits (modifying etc.) can slow down the update of the FIMS display. Be patient and do not rush (if you do so, you are told by the computer that it needs more time).
- **WaveLength Range** Specify the Wavelength Range in nm for one of the spectroscopic modes (MOS, PMOS, MXU, HIT-MS) and reset the mask with the new wavelength region boundaries. Note that the wavelength range is not a physical instrumental configuration option, but is only used as a graphical aid (see Auto-Slit button and MOS mode). The real spectrum length is usually limited by the CCD borders. The default wavelength range as given in the pop-up window shows the available wavelength range either limited by the order sorting filter or by the grism efficiency = 50% for the central slit. FIMS uses half this range as the default, but this range can be modified to check at which wavelength the cutoff by the CCD occurs. It is not possible to choose wavelength limits beyond the ones given in this pop-up window.

When using the low dispersion grism GRIS\_150I in connection with MOS, the zero order spectrum can be projected onto the left hand side of the CCD when the MOS slit is positioned to the right (more than  $\simeq 44''$  from the optical axis). The zero order can easily become saturated on the CCD and will bleed into neighboring MOS spectra, hence simulating spectral lines in the neighboring MOS spectra. To avoid the zero order on the CCD use an upper wavelength limit of  $\lambda_{\max} = 1160\text{nm}$  in the wavelength range window to indicate the correct MOS position limit for which the zero order of the spectrum no longer falls within the CCD.

- **Collimator** use either the standard resolution collimator `COLL_SR+6` or the high resolution collimator `COLL_HR+7`. This option is enabled only for (P)MOS, and IMG. In high resolution collimator mode only the central part of the focal field is projected on the CCD. The CCD-matching area is indicated by the thick blue square. Since the collimator change is the most time consuming instrument set-up, the collimator will be set already during the **preset**, meaning during the telescope pointing and mirror adjustments. Therefore for some acquisition templates the collimator must be specified by FIMS and is included in the `.p_targ` set-up file which consists of the TCS keywords.
- **OS Filter** Select one of the (order separating) filters or **none**. In MXU appropriate interference filters can also be selected. The filter is dynamically chosen among the ones defined in the ISF file.
- **Grism** Select one of the available grisms, which are dynamically loaded from the ISF file. The filter and grism selection has been introduced because of a link-back problem. The MOS, HIT-MS and MXU acquisition templates are only to specify the MOS slit blades and MXU/HIT-MS mask ID, respectively, and are therefore independent of the grism and order separation filter used later in the observation template. However, an optimized MOS/MXU/HIT-MS preparation with FIMS needs to know the wavelength range, which is specified in the subsequent observation template. Therefore, it is advisable to select the filter, grism and optionally the user-defined fractional wavelength range for the CCD window.
- **Camera** Select either the "MIT (Red)" (Default) or the "E2V (Blue)" detector. This should be done before the mask is designed, as it will cause the mask to be reset. It sets important parameters like the gap and relative orientation of the two chips.

### 6.10.2 Graphical layout options

- **Reset Layout** xxx ask Pedro xxx
- **Rotation Step** of the mask. Default is 5 degrees mask rotation (position angle) per click with **B2** (clock-wise) or **shift B2** (anti clock wise) on the green central circle of the mask.
- **Color** Change the colour of the mask. The colour of the green handling circle and the blue square CCD area is not influenced. Default: Yellow/Blue.

### 6.10.3 Special options

- **Labels** configuration option of the active mask. The orientation of the mask is shown. In MOS, PMOS, and IMG mode the slits are numbered at the edge of the mask, whilst in MXU/HIT-MS they are placed next to the slit. Positioned (specified) slits are also labeled directly at the slit position. Unspecified slits are not labeled.
- **Center Slit** This option re-centers the slitlet when positioned by the cursor. When this option is used a *PickObject* pop-up window appears. Each time a slitlet is moved by a simple cursor click, the slitlet is re-centered from the current cursor position to the resulting position of the center gauss method. If center-gauss fails (indicated by the red message in the *PickObject* window), the cursor position is used (as if this option is **off**). This option is suitable when using MOS/MXU/HIT-MS in connection with point source targets, while for extended (and spatially asymmetric) targets like galaxies the direct cursor position might be a better solution to position the MOS/MXU/HIT-MS slits.

**Center Slit option:** The center slit option selectable from the configuration menu will significantly improve the slit positions for point sources and other relatively compact targets. A

Skycat feature with the centroid algorithm: a single click on the target and the centroid might fail. Click somewhere with the left mouse button [B1], hold the button while moving the mouse, wait until you see the target in the center of the pick object window and release the mouse button now, ...

**Slits behind the green circle:** The left mouse button while used on the location of the green circle is defined to move the mask. It is only possible to put a slit behind the green circle with the "Center Slit" functionality as described above - click somewhere, keep the left mouse button pressed while moving the mouse behind the green circle, wait until you see the target in the "pick object" window and release the mouse button.

- **ProjectName** is used when storing the output files with the **Save** option. `<projectname>` is an 8 character long user defined name. The default project name consists of the 8 first characters of the FITS file name. If no image is loaded, as is the case for observation preparation in frameless mode, the default project name is `no_image`. The project name is a FIMS internal way to distinguish between different set-up files. This FIMS internal project name is not the project ID released by the OPC.
- **Transparency** Toggle the reticle showing the slit positions.
- **Bad Pixel Map** Show the map in white color.
- **Setup Directory** The default directory for saving the `.fims`, `.p_targ`, `.p_focf` and `.p_gbr` files is the `$INTRoot/.fims/SET` which is defined in the `fims.sh` startup file. This entered value will become the saving directory for the whole session. This directory is not automatically created if it does not exist.

All other functions are kept as convenient as possible. All positioning actions can be done by pointing with one of the two mouse buttons ( [B1], [B2] ) to one of the graphical elements. The function of mouse button [B3] is still for measuring distances, as in the original Skycat. The Skycat function of [B2] (canvas scrolling) is overloaded but not overwritten with the rotate-mask function.

## 7 FIMS Cook Book and Example Sessions

In this section the use of FIMS is demonstrated by a button list with some explanations. Not all examples may be offered in the form in which they are demonstrated here. In general a FIMS session consists of 6 main parts:

1. **Select Mode:** Select from choice of
  - IMG, MOS, MXU, PMOS, HIT-MS
2. **Configure Instrument:** We propose the following sequence:
  - (a) select Camera (Red or Blue)
  - (b) select collimator (for IMG only)
  - (c) select slit width (for spectroscopic modes MOS, MXU, HIT-MS, PMOS)
  - (d) select slit length (optional for MOS, MXU, HIT-MS, PMOS)
  - (e) select grism
  - (f) select order separation filter
  - (g) specify wavelength range
3. **Position Telescope:** Move and rotate the mask with the central green circle
4. **Position Slits:** The MOS slits can be positioned by
  - cursor (a FITS image is required, default)
  - a center-gauss method (a FITS image is required)
  - an automatic positioning method (a target list is required)
5. **Select Reference Stars and Slits:** For the alignment of the masks with the field of view
  - select up to 10 reference stars to be used for the field acquisition. (While the absolute minimum is 1 reference star, we recommend a minimum of 5 for best results)
  - select alignment method (for MOS: with/out slit 10, for MXU: reference slits)
6. **Save Setting:** The settings are complete and can be saved to a target set-up file.
7. **Create Finder Chart:** The finder chart should show the overlay of the mask on the pre-image and attached to Service Mode OBs

The target set-up file just created should be verified by loading the `.fims` set-up file again. The mask should adjust according to the entries in the target set-up file. A full description of the Finding Chart plug-in can be found at [. These instructions should be followed for all OBs submitted as part of the PhaseII package.](#)

The following tables are a summary of button sequences executed for several tasks. The FITS image used in the following example sessions is a 10 second test exposure taken by FORS1. This frame is available via the FIMS web page (<http://www.eso.org/observing/p2pp/OSS/FIMS/FIMS-tool.html>).

Button	Explanation
<p> <input type="button" value="File"/> <input type="button" value="Open..."/> click on 'FORS1.fits'  Scale: <input type="text" value="1/4x"/>  <input type="text" value="Low:450"/> <input type="text" value="High:800"/>  <input type="button" value="Data-Servers"/> <input type="button" value="Catalogs"/> <input type="button" value="GSC-2 at ESO"/> </p> <p>In the <b>Catalog Window</b>: <input type="button" value="Set from Image"/></p> <p> CW: <input type="text" value="MinRadius:0"/> <input type="text" value="MaxRadius:5"/>  CW: <input type="text" value="Brightest:"/> <input type="text" value="Faintest:"/>  CW: <input type="text" value="Equinox:J2000"/> <input type="text" value="MaxObjects:1000"/>  CW: <input type="button" value="Search"/>  CW: <input type="button" value="File"/> <input type="button" value="Save as..."/> </p> <p> CW: <input type="button" value="File"/> <input type="button" value="Close"/>  <input type="button" value="Graphics"/> <input type="button" value="Clear"/>  <input type="button" value="Data-Servers"/> <input type="button" value="Local Catalogs"/>  <input type="button" value="Load from file..."/> </p>	<ul style="list-style-type: none"> <li>• select and load a FITS image</li> <li>• choose a suitable image scale</li> <li>• select cuts in the main panel</li> <li>• Create a target list from the online ESO archive. The following steps are optional for observation preparation</li> <li>• Take initial search starting point from the FITS image</li> <li>• specify the circle to search in the archive</li> <li>• using empty fields to take all targets available</li> <li>• default</li> <li>• 22 objects are found and plotted</li> <li>• copy this catalog to disk. Here we use the name <i>A.pt1</i></li> <li>• close the <b>Guide Star</b> catalog</li> <li>• clear catalog drawings on the screen</li> <li>• load <i>A.pt1</i> now as local working catalog</li> </ul>

Table 3: Session 1: Loading an image and a catalog. CW = Catalog Window

Button	Explanation
<p> <input type="button" value="FORS"/> <input type="button" value="Enter Mode"/> <input type="button" value="MOS"/>  <input type="button" value="FORS"/> <input type="button" value="Config/Layout"/> <input type="button" value="Labels"/>  <input type="button" value="FORS"/> <input type="button" value="Status/Demo"/> <input type="button" value="Status"/>  <input type="button" value="FORS"/> <input type="button" value="Config/Layout"/> <input type="button" value="Grism"/>  <input type="text" value="GRIS_600z+23"/>  <input type="button" value="Help"/> <input type="button" value="Grism info"/>  <input type="button" value="FORS"/> <input type="button" value="Config/Layout"/> <input type="button" value="OS Filter"/>  <input type="text" value="OG_590+32"/>  <input type="button" value="Ok"/>  <input type="button" value="FORS"/> <input type="button" value="Config/Layout"/> <input type="button" value="Wavelength Range"/>  enter 700 and 850  <input type="button" value="Enter"/> <input type="button" value="Close"/>  <input type="button" value="FORS2"/> <input type="button" value="Config/Layout"/> <input type="button" value="Slit Width"/>  <input type="text" value="2.00 ''"/>  <input type="button" value="FORS2"/> <input type="button" value="Config/Layout"/> <input type="button" value="Slit Length"/>  <input type="text" value="real ''"/> </p>	<ul style="list-style-type: none"> <li>• Enter MOS mode, draw MOS mask</li> <li>• Show the Labels, Regard the correct mask orientation</li> <li>• pop up the FIMS status panel</li> <li>• select grism</li> <li>• read the appropriate order sorting filter</li> <li>• select OS filter</li> <li>• close grism info</li> <li>• popup wavelength range window</li> <li>• enter wavelength range (in nm), required for all targets.</li> <li>• activate new wavelength range and redraws the target selection field; close the window</li> <li>• select a common slit width of 2 arcsec for all 19 slits</li> <li>• we don't require a lower limit of the sky background area around the target spectra</li> </ul>

Table 4: Session 2: MOS target acquisition: configure instrument

mouse buttons on green circle	Explanation
<p> <input type="button" value="B1"/> = move  <input type="button" value="B2"/> = rotate  <input type="button" value="Shift"/> <input type="button" value="B2"/> = -rotate </p>	<ul style="list-style-type: none"> <li>• move and rotate the mask by clicking in the green circle.</li> <li>• Try to match following values: RA=08:00:03.993, • DEC=-00:01:26.37 and ROT=-30.</li> </ul>

Table 5: Session 3: MOS target acquisition: move mask

buttons	Explanation
<p> <input type="button" value="FORS"/> <input type="button" value="Reference Targets"/> <input type="button" value="show"/> <input type="button" value="ok"/>  <input type="button" value="FORS"/> <input type="button" value="Reference Targets"/> <input type="button" value="add"/>  <input type="button" value="ON"/>   <input type="button" value="Ok"/> </p>	<ul style="list-style-type: none"> <li>• show the reference target list with coordinates.</li> <li>• add further reference targets to the list</li> <li>• Use the MOS 10 slit in the acquisition image for high accuracy alignment. The MOS 10 would occult reference targets, hence this sky region is forbidden.</li> <li>• first read then click</li> </ul>
	Repeat this sequence up to ten 10 times
<p> <input type="button" value="Pick object..."/>   <input type="button" value="B1"/>           <input type="button" value="Enter"/>  <input type="button" value="Close"/> </p>	<ul style="list-style-type: none"> <li>• in the EnterObject pop-up window to select reference target via PickObject method</li> <li>• click on bright point source in the main window. Watch the PickObject sub image before you release <input type="button" value="B1"/> and check fit result. If the center/gauss has failed (The red Can't do message appears in the FWHM label of the PickObject window) press either the <input type="button" value="Pick Object"/> button in the PickObject window or the <input type="button" value="Pick Object..."/> button in the EnterObject window to select the Reference Target anew.</li> <li>• in the EnterObject window</li> <li>• in the EnterObject window to continue</li> </ul>
<p> <input type="button" value="Enter"/>   <input type="button" value="OK"/>  <input type="button" value="Close"/>  <input type="button" value="Close"/> </p>	<ul style="list-style-type: none"> <li>• (empty entry field) in the EnterObject window to finish</li> <li>• in the Warning window (ignore it)</li> <li>• in the EnterObject window to finish</li> <li>• in the PickObject window</li> </ul>
<p> <input type="button" value="FORS"/> <input type="button" value="Reference Targets"/> <input type="button" value="verify"/>   <input type="button" value="OK"/> </p>	<ul style="list-style-type: none"> <li>• verify reference target positions. Follow the messages and press</li> <li>• in the verification message window.</li> </ul>

Table 6: Session 4: All modes: Select reference targets

Button	Explanation
<p> <input type="button" value="Z"/> <input type="button" value="z"/>  <input type="button" value="B1"/>  <input type="button" value="B2"/>    <input type="button" value="B1"/>    <input type="button" value="B1"/>    <input type="button" value="FORS"/> <input type="button" value="Config/Layout"/> <input type="button" value="Center Slit"/>    <input type="button" value="B1"/> on the object </p>	<ul style="list-style-type: none"> <li>• Zoom your preferred sky region and</li> <li>• click on the position you want the slit to be.</li> <li>• click on the slit number label 4 of the slit to de-select MOS #4.</li> <li>• click on the slit number label 5 at the rim of the focal field to de-select MOS 5.</li> <li>• click on the slit width label of MOS 7 to specify new slit width for MOS 7</li> <li>• switch the center-slit option <b>ON</b>. Wait a moment for the PickObject pop/up window.</li> <li>• (a) click on the target in the main window; (b) hold <input type="button" value="B1"/> and shift the cursor and watch the target in the zoom window of the PickObject window; (c) release <input type="button" value="B1"/> . The source will be fitted by a 2D Gaussian and the slit will move from the cursor position to the source center. If the fit failed use the <input type="button" value="z"/> in the PickObject window and try again. If fit failed the slit will move to the last <input type="button" value="B1"/> press position.</li> </ul>

Table 7: Session 5: MOS target acquisition: position MOS slit manually and Center/Gauss slit positioning

Button	Explanation
<p> <input type="button" value="Data-Servers"/> <input type="button" value="Catalogs"/> <input type="button" value="GSC-2 at ESO"/>  In the GSC2 Catalog window: <math>\alpha \delta</math>  min Radius=4.0, max Radius=7.4    Brightest=11.0, Faintest=14.0    <input type="button" value="Search"/> </p>	<ul style="list-style-type: none"> <li>• create a local set of guide stars</li> <li>• type the mask center (telescope pointing)</li> <li>• specify TCS guide star search field. <b>Use only these values</b></li> <li>• specify TCS guide star limiting magnitude. <b>Use only these values</b></li> <li>• If more than 3-5 guide stars are found it will be ok</li> </ul>

Table 8: Session 6: TCS guide star search

Button	Explanation
<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">FORS</div> <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-left: 10px;">Save mos.2</div> <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">OK</div>  <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">OK</div>  <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">OK</div> <i>AP.ptl</i>	<ul style="list-style-type: none"> <li>• start the target acquisition saving sequence</li> <li>• in the reference target verification window or 2,4 in case those targets are not accepted.</li> <li>• acknowledge verification message after optional delete of rejected reference targets.</li> <li>• Save the set-up file to the default directory.</li> <li>• if more than one local catalog is active, select one</li> <li>• Look in the status panel if the last saved filename is updated</li> </ul>
<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">FORS</div> <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-left: 10px;">Reset Mode</div> <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">FORS</div> <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-left: 10px;">Reference Targets</div> <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-left: 10px; margin-bottom: 5px;">reset</div> <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">FORS</div> <div style="border: 1px solid black; padding: 2px; display: inline-block; margin-left: 10px;">Load SetUp</div>	<ul style="list-style-type: none"> <li>• reset the mask</li> <li>• delete all reference targets</li> <li>• load the target set-up file again</li> </ul>

Table 9: Session 7: MOS target acquisition: save MOS set-up

Button	Explanation
<p> <input type="button" value="FORS"/> <input type="button" value="Reset Mode"/>  <input type="button" value="FORS"/> <input type="button" value="Reference Targets"/> <input type="button" value="reset"/>  <input type="button" value="FORS"/> <input type="button" value="Load SetUp"/>  <input type="button" value="Data-Servers"/> <input type="button" value="Catalogs"/> <input type="button" value="USNO at ESO"/> </p> <p>In the Catalog Window: <input type="button" value="Set from Image"/></p> <p>           CW: <input type="text" value="MinRadius:0"/> <input type="text" value="MaxRadius:5"/>            CW: <input type="text" value="Brightest:"/> <input type="text" value="Faintest:"/>            CW: <input type="text" value="Equinox:J2000"/> <input type="text" value="MaxObjects:1000"/>            CW: <input type="button" value="Search"/>            CW: <input type="button" value="File"/> <input type="button" value="Save as..."/> </p> <p>           CW: <input type="button" value="File"/> <input type="button" value="Close"/>  <input type="button" value="Graphics"/> <input type="button" value="Clear"/>  <input type="button" value="Data-Servers"/> <input type="button" value="Local Catalogs"/>  <input type="button" value="Load from file..."/> </p>	<ul style="list-style-type: none"> <li>• reset the mask</li> <li>• delete all reference targets</li> <li>• load the target set-up file again</li> <li>• Create a target list from the online ESO archive. The following steps are mandatory for AutoSlit positioning             <ul style="list-style-type: none"> <li>• Take initial search starting point from the FITS image</li> <li>• specify the circle to search in the archive</li> <li>• using empty fields to take all targets available</li> <li>• default</li> <li>• 192 objects are found and plotted</li> <li>• copy this catalog to disk. Here we use the name <code>USNO.pt1</code></li> <li>• close the <code>USNO</code> catalog</li> <li>• clear catalog drawings on the screen</li> <li>• load <code>USNO.pt1</code> now as local working catalog</li> </ul> </li> </ul>
<p> <input type="button" value="FORS"/> <input type="button" value="AutoPos"/> <input type="button" value="STATIC"/> </p> <p>USNO.pt1 <input type="button" value="Ok"/></p> <p> <input type="button" value="FORS"/> <input type="button" value="AutoPos"/> <input type="button" value="SHIFT"/> </p> <p>USNO.pt1 <input type="button" value="Ok"/></p> <p> <input type="button" value="FORS"/> <input type="button" value="AutoPos"/> <input type="button" value="ROTATE"/> </p> <p>USNO.pt1 <input type="button" value="Ok"/></p>	<ul style="list-style-type: none"> <li>• the mask position and the position angle will be retained</li> <li>• select the USNO catalog and acknowledge. 18 slits will be positioned, except MOS 5</li> <li>• the mask position angle will be retained, but not the mask position</li> <li>• select the USNO catalog and acknowledge. 18 slits will be positioned, except MOS 10</li> <li>• the mask position will be retained, but not the position angle</li> <li>• select the USNO catalog and acknowledge. 18 slits will be positioned, except MOS 5</li> </ul>

Table 10: Session 8: MOS AutoPos target acquisition

Button	Explanation
<p> <input type="button" value="File"/> <input type="button" value="Open..."/>  <input type="button" value="FORS"/> <input type="button" value="Enter Mode"/> <input type="button" value="IMG"/>  <input type="button" value="FORS"/> <input type="button" value="Status/Demos"/> <input type="button" value="Status Panel"/>    <input type="button" value="FORS"/> <input type="button" value="Config/Layout"/> <input type="button" value="Labels"/>  <input type="button" value="FORS"/> <input type="button" value="Config/Layout"/> <input type="button" value="collimator"/>  <input type="button" value="COLL_HR+7"/>  <input type="button" value="FORS"/> <input type="button" value="Reset Mode"/>  <input type="button" value="B1"/> on the green circle  <input type="button" value="B2"/> and <input type="button" value="Shift"/> <input type="button" value="B2"/> on the green circle  <input type="button" value="B1"/> <input type="button" value="B2"/>    <input type="button" value="B1"/>    <input type="button" value="B1"/>    <input type="button" value="FORS"/> <input type="button" value="Config/Layout"/> <input type="button" value="Transparency"/>  <i>Session 4</i> </p>	<ul style="list-style-type: none"> <li>• load your FITS image</li> <li>• enter imaging mode</li> <li>• open the FIMS status panel if it is not open from the previous session</li> <li>• show labels</li> <li>• select high resolution collimator</li>   <li>• move the mask by dragging the green circle</li> <li>• rotate the mask by clicking on the green circle</li> <li>• move optionally MOS slit blades inside the CCD field to obscure presumably saturated objects</li> <li>• on the slit number label at the rim of the focal field to deselect both blades</li> <li>• on the slit width label to edit free space between both blades</li> <li>• highlight the user-defined slit blades</li> <li>• Continue with Reference Target set-up before saving</li> </ul>

Table 11: Session 9: IMG occult acquisition

Button	Explanation
<pre> FORS Config/Layout ProjectName Enter Close FORS Config/Layout Set-upDir  Enter Close FORS Save img1 OK OK FORS Reset Mode FORS Load SetUp  FORS Save img1 OK Edit  FORS Reset Mode FORS Load SetUp FORS Quit Mode </pre>	<ul style="list-style-type: none"> <li>• select project name, this name will appear in the set-up file</li> <li>• for the project name</li> <li>• change from the default output directory (<code>.fims/SET = \$INSROOT/\$INS_USER/\$SET_DIR</code>) to a new output directory, e.g. <code>/home/tralala</code>. The newly specified directory is not created by FIMS. It will stay for the rest of the session if not re-defined again</li> <li>• enter directory name and close widget</li> <li>• start the target acquisition saving sequence.</li> <li>• for the reference targets</li> <li>• to save set-up files to the new Set-upDir</li> <li>• Reset Mode</li> <li>• load set-up from the new Set-upDir <code>/home/tralala</code> to verify the set-up file</li> <li>• start the target acquisition saving sequence.</li> <li>• for the reference targets</li> <li>• Edit the Set-upDir and the output file name again, (e.g. from <code>/home/tralala/img.5.NGC_330</code> to <code>.fims/SET/img2.17.PhiPer</code> again). The file extension <code>.fims</code> should be omitted. <b>Warning:</b> you can overwrite any file on the disk. Therefore, we recommend not to use this option.</li> <li>• Reset Mode</li> <li>• load set-up from the new Set-upDir <code>.fims/SET</code></li> <li>• exit IMG mode</li> </ul>

Table 12: Session 10: IMG save acquisition and change Set-upDir

Button	Explanation
<p> <input type="button" value="FORS"/> <input type="button" value="Enter Mode"/> <input type="button" value="MXU"/> </p> <p> <input type="button" value="Status/Demo"/> <input type="button" value="Status"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Labels"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Grism"/> <input type="text" value="GRIS_600z+23"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="OS Filter"/> <input type="text" value="GG435+81"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="MXU slit type"/> <input type="text" value="STRAIGHT"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Slit Width"/> <input type="text" value="1.4"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Slit Length"/> <input type="text" value="8"/> </p> <p> <input type="button" value="B1"/> </p> <p> <input type="button" value="B1"/> </p> <p> <input type="button" value="B1"/> ... <input type="button" value="Enter"/> <input type="button" value="Close"/> </p> <p> <input type="button" value="B1"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Center slit"/> </p> <p> <input type="button" value="B1"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="MXU slit type"/> <input type="text" value="CIRCLE"/> </p> <p> <input type="button" value="B1"/> ... </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="MXU slit type"/> <input type="text" value="CURVED"/> </p> <p> <input type="button" value="B1"/> </p> <p> <input type="button" value="B1"/> </p> <p> <input type="button" value="B1"/> </p> <p> <i>Session 4,</i> </p> <p> <input type="button" value="Save"/> </p> <p> <input type="button" value="OK"/> </p> <p> ... </p>	<ul style="list-style-type: none"> <li>• Enter Mask eXchange Unit mode of FORS2. We assume that there is already an underlying image</li> <li>• pop up status window</li> <li>• Switch labels on</li> <li>• select grism</li> <li>• select order separation filter</li> <li>• select aperture type: straight slit</li> <li>• select common slit width</li> <li>• select common slit length</li> <li>• on the green circle: move and rotate the mask as in all other modes</li> <li>• on a target to create a slit on the target</li> <li>• on the slit width label (1.4") to edit length, width and position angle of slit</li> <li>• on the slit number label ( 1) at the rim of the focal field to purge the slit again</li> <li>• switch on the center slit option and wait until the pick object window appears</li> <li>• (press and drag as usual) and release B1 to carry out the center/gauss. If the object is inside the current focal field, a new slit will be created and centered to match the target position.</li> <li>• select aperture type: circle</li> <li>• The same event bindings for the labels as for a straight slit</li> </ul> <ul style="list-style-type: none"> <li>• select aperture type: curved slit</li> <li>• on the slit width label (1.4") and enter 15" slit width</li> <li>• on one of the three cyan Bezier grid points to drag the cyan circle and modify the shape of the curved slit. Note <b>Slow cursor movement</b></li> <li>• on the slit width label (15") and reduce slit width to the desired slit width of e.g. 1.0"</li> <li>• specify reference targets</li> <li>• start the save sequence</li> <li>• for the number of reference slits</li> <li>• Continue as explained in the MOS target acquisition sequence</li> </ul>

Table 13: Session 14: MXU sky mask acquisition

Button	Explanation
<p> <input type="button" value="FORS"/> <input type="button" value="Enter Mode"/> <input type="button" value="HIT-MS"/> </p> <p> <input type="button" value="Status/Demo"/> <input type="button" value="Status"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Labels"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Grism"/> <input type="text" value="XGRIS_300I+91"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="OS Filter"/> <input type="text" value="OG590+32"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Slit Width"/> <input type="text" value="1.4"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Slit Length"/> <input type="text" value="5"/> </p> <p> <input type="button" value="B1"/> </p> <p> <input type="button" value="B1"/> </p> <p> <input type="button" value="B1"/> ... <input type="button" value="Enter"/> <input type="button" value="Close"/> </p> <p> <input type="button" value="B1"/> </p> <p> <input type="button" value="Config/Layout"/> <input type="button" value="Center slit"/> </p> <p> <input type="button" value="B1"/> </p> <p> <i>Session 4,</i> </p> <p> <input type="button" value="Save"/> </p> <p> <input type="button" value="OK"/> </p> <p> ... </p>	<ul style="list-style-type: none"> <li>• Enter HIgh Time resolution - Multi Shift mode of FORS2. We assume that there is already an underlying image</li> <li>• pop up status window</li> <li>• Switch labels on <ul style="list-style-type: none"> <li>• select grism XGRIS_600B+92 or XGRIS_300I+91</li> </ul> </li> <li>• select order separation filter OG590+32 if desired for grism XGRIS_300I+91</li> <li>• select common slit width</li> <li>• select slit length 5" for two slits, or 10" for one slit</li> <li>• on the green circle: move and rotate the mask as in all other modes</li> <li>• on a target to create a slit on the target</li> <li>• on the slit width label (1.4") to edit length, width and position angle of slit</li> <li>• on the slit number label (#1) at the rim of the focal field to purge the slit again</li> <li>• switch on the center slit option and wait until the pick object window appears</li> <li>• (press and drag as usual) and release B1 to carry out the center/gauss. If the object is inside the current focal field, a new slit will be created and centered to match the target position.</li> <li>• specify reference targets</li> <li>• start the save sequence</li> <li>• for the number of reference slits</li> <li>• Continue as explained in the MOS target acquisition sequence</li> </ul>

Table 14: Session 14b: HIT-MS sky mask acquisition

## A PSO Internal information

Beside the possibility to create a specific mask for the science purpose there is a possibility to use so-called technical masks, which are permanently stored at Paranal (but not necessarily continuously available in the instrument).

A set of technical masks are provided. They are listed in the Table A. There are technical masks like 900 001 and 900 002 for maintenance and technical masks for science like 900 003-900 010. Most of the technical masks consist only of one single slit for ECHS or HITS. This means FORS2 ECHS mode can be scheduled either with two MOS slits or with the technical MXU mask 900 009 containing a single 44 arcsec long slit (hence simulating the 2 MOS slits). All available FORS2 technical masks are coded as a FORS aperture definition file. They are copied from the default directory `$FIMSROOT/lib/fors` to the `$SET_DIR` directory each time FIMS is started. After having specified the grism and the filter a technical masks can be used to prepare observations. Just press the `Load SetUp` and edit the filter entry field in the file select menu from the default filename extension `.fims` to `.fad` and load the technical mask as any other user defined set-up.

When e.g. the `FIMSROOT/lib/fors/mxu2.004.standard.fad` aperture definition file is selected FIMS will recognize the `fad` file extension and will change to **MXU technical mask mode**. Each `Reset Mode` will switch back to the default **MXU normal mask mode**.

MASK ID	Tag	ADF	mode	contents
900 001	SCAL_4sl	mxu2.001.standard.fad	MOS	4 slits
900 002	SIEB_1_0	mxu2.002.standard.fad	technical mask	19x19 circles, not offered for science observations
900 003	HITC_0_5	mxu2.003.standard.fad	HITS	0.5" slit center
900 004	HITC_1_0	mxu2.004.standard.fad	HITS	1.0" slit center
900 005	HITC_5_0	mxu2.005.standard.fad	HITS	5.0" slit center
900 006	HITB_0_5	mxu2.006.standard.fad	HITS	0.5" slit bottom
900 007	HITB_1_0	mxu2.007.standard.fad	HITS	1.0" slit bottom
900 008	HITB_5_0	mxu2.008.standard.fad	HITS	5.0" slit bottom
900 012	HITI_5_0	mxu2.012.standard.fad	HITI	5" wide stripes
900 013	SIEB_0_5	mxu2.013.standard.fad	technical mask	0.5" circles, not offered for science observations
900 014	HIEC_1_0	mxu2.014.standard.fad	technical mask	1" trailing not offered for science observations
900 015	HITS_0_5		HITS fast	0.5" 85mm left
900 016	HITS_0_7		HITS fast	0.7" 85mm left
900 017	HITS_1_0		HITS fast	1.0" 85mm left
900 018	HITS_1_3		HITS fast	1.3" 85mm left
900 019	HITS_1_7		HITS fast	1.7" 85mm left
900 020	HITS_2_0		HITS fast	2.0" 85mm left
900 021	HITS_5_0		HITS fast	5.0" 85mm left

Table 15: MXU standard (technical) masks and aperture definition files (ADF)

In MXU **technical mask** mode as well as in modes with a fixed mask like LSS and HITS, the complete mask will be shifted in such a way that the corresponding slit will be centered on the target.

mouse buttons on green circle	Explanation
<pre> FORS2  Enter Mode  MXU  Status/Demos  Status Config/Layout  Labels Config/Layout  Grism  GRIS_600z+23 Config/Layout  OS Filter  GG435+81 Help  Mask Info  OK Load SetUp .fims/SET/*.fad mxu2.010.standard.fad B1  Session 4, Save OK ... </pre>	<ul style="list-style-type: none"> <li>• Enter Mask eXchange Unit mode of FORS2. We assume that there is already an underlying image</li> <li>• pop up status window</li> <li>• Switch labels on</li> <li>• select grism</li> <li>• select order separation filter</li> <li>• show available technical masks</li> <li>• pop up the file select widget</li> <li>• in the filename Filter Entry form</li> <li>• select the technical mask for ECHS</li> <li>• on the green circle: move and rotate the mask as in all other modes</li> <li>• specify reference targets</li> <li>• start the save sequence</li> <li>• for the number of reference slits</li> <li>• Continue as explained in the MOS target acquisition sequence</li> </ul>

Table 16: Session 15: MXU technical mask acquisition

Special MXU masks can be shifted, rotated as in all other modes with a fixed mask as e.g. LSS. In case the center-slit option is ON, the MXU technical mask slit can be centered on the object. Special mask set-ups can be saved as a sky (user-defined science) mask set-ups. When saving a set-up of a special mask no Gerber file is created.

Technical masks from the set listed in table 15 are not offered for science observations with FORS2.

## B List of Acronyms

CCD	Charge Coupled Device
DSS	Digital Sky Survey
ECHS	ECHelle Spectroscopy
ESO	European Southern Observatory
FIMS	FORS Instrumental Mask Simulator
FORS	FOcal Reducer low dispersion Spectrograph
HIT	HIgh Time resolution mode
HIT-MS	HIT multi shift mode
HR	High Resolution
HST	Hubble Space Telescope
IMG	IMaGing
IPOL	Imaging POLarimetry
ISF	Instrument Summary File
LSS	LongSlit Spectroscopy
MMU	Mask Manufacturing Unit
MOS	Multi Object Spectroscopy
MXU	Mask eXchange Unit
OB	Observation Block
OCC	OCCulting mode
P2PP	Phase 2 Proposal Preparation (tool)
PMOS	Polarimetric Multi Object Spectroscopy
PSO	Paranal Science Operations
SCT	SkyCat Tool
SR	Standard Resolution
TAF	Target Acquisition File
USNO	US Naval Observatory
WCS	World Coordinate System
WFPC2	Wide Field Planetary Camera2

## C World Coordinate System Information

The header of the FITS file used for preparing a FORS target mask with FIMS should contain the following keywords, for a linear scale:

The standard notation for FORS for WCS FITS header keywords is the CDi\_j notation.

```
CTYPE1 =      'RA---TAN'   / tangential projection type
CRVAL1 =      12.345678    / x- coord of reference pixel: RA in deg
CRPIX1 =      512.0        / x coord of reference pixel: PIXEL
CTYPE2 =      'DEC--TAN'   / tangential projection type
CRVAL2 =     -12.34567     / y- coord of reference pixel: DEC in deg
CRPIX2 =      525.5        / y coord of reference pixel: Pixel
CD1_1 =       3.185E-5     / partial derivative
CD1_2 =     -5.616E-5     / partial derivative
CD2_1 =       5.616E-5     / partial derivative
CD2_2 =       3.185E-5     / partial derivative
EQUINOX =     2000.0       / equinox
```

Besides this there is the CROTA/CDELTA-notation..

```
CTYPE1 =      'RA---TAN'   / tangential projection type
CRVAL1 =      12.345678    / x- coord of reference pixel: RA in deg
CRPIX1 =      512.0        / x coord of reference pixel: PIXEL
CTYPE2 =      'DEC--TAN'   / tangential projection type
CRVAL2 =     -12.34567     / y- coord of reference pixel: DEC in deg
CRPIX2 =      525.5        / y coord of reference pixel: Pixel
CDELTA1 =     -3.234E-5    / x- scale: degrees per pixel
CROTA1 =      10.0         / rot in degrees, from N to E
CDELTA2 =      3.234E-5    / y- scale: degrees per pixel
CROTA2 =      10.0         / rot in degrees, from N to E
EQUINOX =     2000.0       / equinox
```

Finally, there is also the PCiiijjj/CDELTA-notation in use, where PC keywords are the rotation matrix:

```
CTYPE1 =      'RA---TAN'   / tangential projection type
CRVAL1 =      12.345678    / x- coord of reference pixel: RA in deg
CRPIX1 =      512.0        / x coord of reference pixel: PIXEL
CTYPE2 =      'DEC--TAN'   / tangential projection type
CRVAL2 =     -12.34567     / y- coord of reference pixel: DEC in deg
CRPIX2 =      525.5        / y coord of reference pixel: Pixel

CDELTA1 =     -3.234E-5    / x- scale: degrees per pixel
CDELTA2 =      3.234E-5    / y- scale: degrees per pixel
PC001001 =    0.9848       / cos(CROTA)
PC001002 =    0.1736       / - sin(CROTA)
PC002001 =    0.9848       / sin(CROTA)
PC002002 =    0.1736       / cos(CROTA)
EQUINOX =     2000.0       / equinox
```

Transformation formulae between the different keyword notations are given in “A Users Guide for the Flexible Image Transport System (FITS)” (version 3.1, NASA), “Definition of the Flexible Image Transport System (FITS)” (NOST 100-1.2) and the “Data Interface Control Document” (GEN-SPE-ESO-19400-0794).