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Chapter 1. Introduction

1.1 Scope

This manual explains the usage of the LUCIFER Mask Simulator (LMS). It should be used together with
the LUCIFER user manual and the ESO SkyCat manual.

1.2 Changes

Attention: Mask prepared with LMS version 1.4 or lower cannot be used for observing after Febru-
ary 2010. lms files generated with version 1.4 or lower should not be loaded into LMS version
1.50 or higher.

The major changes of LMS 1.50 as compared to LMS 1.4 are:

1. The sign of the mask rotation angle has been changed to the sign convention used for the LBT
instrument rotator. As a consequence, a new MOS pointing mode had to be introduced.

2. Measured values for the LUCIFER pixel scales are now used instead of the design values.

3. Only one gerber file is generated for mask cutting at the LBT and a company in Munich.

4. Slit center positions can be modified in the slit menu (positions are given in mm focal plane relative
to the mask center).

Changes made between LMS 1.50 and 1.51:

1. The variable lochost has been removed to avoid problems with different operating systems. The
only effect being that the name of the computer on which the mask was generated is no longer
listed in the lms-file.

2. A red rectangle is drawn close to reference aperture 6. This rectangle indicates the area occupied
by the mask ID number. No slit should be positioned in an area where its spectrum can interfere
with the red rectangle.

3. The correction for thermal contraction of the mask in LUCIFER (0.0025% shrinking during
cooldown from ambient to -200 C) has been removed. This should result in better slit positions. In
case you observe systematic offsets between slit and source positions, please let us know. Any
new information could help us to improve the position accuracy.

Changes made between LMS 1.51 and 1.52:

1. In the SkyCat window, the angle listed together with the telescope pointing was wrong. This has
been corrected, the rotation angle displayed on the screen is now consistent with the angle listed
in the lms-file (TEL.ROT.OFFANGLE).

2. The equations determining the positions of the blue lines limiting the area of unclipped spectra in
the field of view have been corrected.

1.3 Abreviations

FOV field of view
ISF instrument summary file
LMS LUCIFER mask simulator
WCS world coordinate system
1.4 Applicable Documents

FORS1+2 FIMS Manual, VLT-MAN-ESO-13100-2308
The ESO SkyCat Tool, Programmer's Manual, VLT-MAN-ESO-19400-1552
Real Time Display, User Manual, VLT-MAN-ESO-17240-0866

1.5 Acknowledgements

We thank ESO for the permission to use and modify the FIMS source code for our application.
Chapter 2. Overview and Requirements

2.1 The LMS Concept

LMS, the LUCIFER Mask Simulator, is a LUCIFER observer support software. It is based on FIMS, ESO's FORS Instrument Mask Simulator. LMS displays an image of the LBT focal plane together with the LUCIFER field of view (FOV) borders and the detector contour projected back on the focal plane. Within the LUCIFER FOV, MOS-slits can be positioned and reference stars can be selected. In addition, guide stars can be selected in the guider patrol field which partially overlaps with the LUCIFER FOV.

LMS is a plug-in to the ESO SkyCat tool, a browser for astronomical images and catalogs. It is written in Tcl/Tk and has been tested under OpenSuse Linux 10.3 to 11.2 using SkyCat 2.7.3 and Skycat 3.0. The SkyCat/LMS package can be installed and used at the user's home institute.

2.2 Some technical details

2.2.1 Linux Installation

Besides the LMS-package, an itcl interpreter is required, which is normally part of the Linux installation. The LMS-package can be downloaded from the MPE LUCIFER web page. The download file is named lms_vxxx.tar.gz, where xxx represents the version number. After unzipping the package, change to the lms_vxxx/bin directory. This directory contains the start script lms.sh and the SkyCat and AP (automatic positioning software) binaries. In case lms_vxxx is located in the user's home directory, execute the shell script to start LMS (type ./lms.sh). Otherwise, open the script and modify the path LMSROOT in line 49 to point to the LMS directory, then run the script.

2.2.2 Other Operating Systems

LMS also runs under Mac OS. In this case, the corresponding SkyCat executable has to be downloaded from the ESO web pages, and recompilation of the C programs for automatic slit positioning (named AP*.c) is required.

2.2.3 Start-up of LMS

LMS is started from the $LMSROOT/bin directory by calling the script lms.sh with or without a parameter defining the instrument:

- ./lms.sh
- ./lms.sh l1
- ./lms.sh l2

where the first two commands start SkyCat with the LUCIFER1 menu, while the third one starts SkyCat with the LUCIFER2 menu (LUCIFER2 submenus are not yet implemented). Besides l1 and l2, the following arguments are also valid: L1, L2, Lucifer1/2, and LUCIFER1/2.

lms.sh sets the paths to directories used by LMS, when run for the first time creates hidden default directories (.lms/LOG, .lms/PREP, .lms/SET) in the user's home directory, defines environment variables, configures the plugins for SKYCAT, and starts SKYCAT.

LMS is accessible via the LUCIFER menu in SkyCat. Mainly this menu is described here. For the usage of SkyCat itself, please refer to the corresponding manual which can be downloaded from the ESO web pages.
2.2.4 Input and output files

SkyCat handles FITS images and source catalogs, while LMS handles the LUCIFER instrument configuration, the positioning of the MOS slits, and the selection of reference and guide stars. The relation between the program modules and the input- and output-files is sketched in Fig. 2.1.

LMS requires two input files:

- A FITS image or a source catalog to be loaded into SkyCat (by default located in .lms/PREP but the path can be modified; images and catalogs can also be downloaded via the Data-Servers menu), and
- the instrument summary file (ISF, located in lms_v1/lib/mos).

The ISF is an ASCII file containing all relevant instrument and telescope parameters, like camera and collimator focal lengths, grating parameters, filter central wavelength and bandwidth, detector pixel size and pixel numbers, and telescope plate scale. Individual files exist for LUCIFER 1 and 2.

LMS produces three output files which are written to .lms/SET:

1. The *.lms file contains the instrument parameters and the telescope pointing set during the session, as well as the slit parameters and the positions of reference and guide stars; this file permits the recovery of a session.
2. The Gerber file (*.gbr) contains the information required for mask cutting. The mask configuration stored in the Gerber file can be displayed by a freeware viewer like gerbv.
3. The *.epsf file contains a postscript image of the mask for direct viewing in case a Gerber file viewer is not available (the mask ID is not shown in this image).
2.3 LMS Modes

LMS supports two modes: MOS mode and technical mask mode. In MOS mode, new masks can be generated, and the three output files just mentioned are stored. In technical mask mode, an existing longslit mask is loaded, and only the *.lms file is saved. For more details see chapter 3 on mask preparation and chapter 6 on technical masks.

2.4 Input frames and catalogs

2.4.1 Astrometric Requirements

For preparing observations with LMS, a FITS file with appropriate world coordinate keywords (World Coordinate System WCS) in the header is required. Alternative inputs are catalogs in frameless mode. Accurate target coordinates are required. The target positions relative to the coordinates of reference stars must be known very well, because the reference stars are used for mask alignment. A maximum astrometric error of 1/6 of the slit-width can be tolerated. Compromises in the astrometry will cause slit losses. For 0.5" wide slits, every single target coordinate must be known to better than 0.1" w.r.t the reference stars. This also implies that the telescope image scale, the LUCIFER pixel scale and the LUCIFER image distortions have to be known and have to be reproducible to about 7 \times 10^{-4}. A distortion correction has to be applied to LUCIFER images before they can be used as input for LMS.

2.4.2 Pre-Images with LUCIFER

Pre-images taken with both LUCIFER instruments can be used for mask preparation. However, the following aspects should be considered when preparing images for mask generation:

- Pre-images are taken with the N/3.75 camera, resulting in a 4' x 4' field. In case the mask is shifted and/or rotated for slit positioning, part of the mask will be outside the image area. Moreover, the useful part of the auto guider patrol field is outside the image area in any case. The latter can be overcome by extracting stars from a catalog (because the relative position accuracy is not critical in this case), but it is normally desirable to have the full field for source and reference star selection. Therefore, a small mosaic centered on the science field should be recorded, the single images should be distortion corrected, merged into one FITS image, and provided as input for LMS.

- LMS anticipates distortion corrected LUCIFER images scaled to the warm masks. Distortions and warm scale have been measured by imaging a sieve mask on the detector. A pinhole array with well known hole separations at room temperature is cut into this mask. Although the mask temperature is about 100 K in LUCIFER, taking the pinhole separations of the warm mask results in a calculated magnification which transforms detector positions into coordinates on the warm mask (as required for mask cutting).

Remark: LUCIFER provides FITS images which are NOT compliant with the astronomy imaging standard, but are flipped about the north-south axis, i.e. east is to the right of north. SkyCat and LMS handle this case correctly, therefore the mask image is also flipped as compared to standard images, and the slits are correctly positioned for both, LUCIFER and standard images.

2.4.3 Requirements for Contributed Input Images

Images obtained by LUCIFER1 can be used as pre-images to prepare observations for LUCIFER2 and vice versa. These images as well as images from other telescopes require careful and accurate astrometric calibrations (and WCS fits headers). Frames obtained by LUCIFER1/2 provide world coordinates in the FITS header. If no fits frame is available, it is possible to use the image server facilities of SkyCat to download a sky image from one of the available online archives. Note that also here the requirement for positional accuracy applies as stated in section 2.4.1.

The standard orientation for sky maps and images is north to the top, and east to the left, meaning RA is decreasing with increasing pixel number (image fits header keywords CDELT1 < 0 and CDELT2 > 0). If the input frame does not provide world coordinates, the FITS header can be edited by using either a
FITS header editor or emacs. 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 CDELT1, CDELT2 are very sensitive, while an offset between the WCS and the optical positions 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 or the USNO catalog (Data-Servers Catalogs Guide Star Catalog 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 are not accounted for. The WCS FITS header keywords of LUCIFER1 and LUCIFER2 images contain the local scale in the center of the focal field (= center of the array = the optical axis).

**Caveat:** The linear local image scale in combination with the limited numerical precision can cause slit position errors if a large image is used, and the mask is shifted several arcmin from the image center.

LMS supports frames with a minimum size of 1’ x 1’. If the image size is close to the lower size limit, 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 FITS frame header. The MOS slit positions are less accurate in this case.

### 2.4.4 Input Catalogs and Frameless Modes

A frameless mode is also offered. No FITS frame is required, but a WCS area is defined for the LUCIFER mask. This mode can be used if a target list with high astrometric quality is available. 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 Catalogs Guide Star Catalog** 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**
- scroll with **B1** (left mouse button) the color bar to highlight the virtual field
- **LUCIFER Init Mask** and proceed further as in frame-mode

Please note that the plot symbols in SkyCat need to be set explicitly for user provided input catalogs.
Chapter 3. Mask Preparation

In this section we describe the basics of mask preparation. Figure 3.1 shows the LUCIFER menu opened on top of a fits image with a mask. Figure 3.2 shows the inner part of the field with the outline of the mask (field of view), several slits, and 3 guide stars.

A typical LMS session would consists of the following steps:

1. load a FITS frame
2. initialize the mask
3. configure the instrument, set the slit parameters
4. select reference stars
5. select guide stars
6. position the slits on the mask
7. save the setup

Figure 3.1: Screen shot of SkyCat and the LMS menus on top of a mask. The detector outline determines the lengths of the spectra.
**Caveat:** In case no reference stars have been selected, a warning is issued before the mask configuration is stored. This warning should be taken serious. Without reference stars, the telescope pointing cannot be checked. Guide stars are mandatory for telescope tracking. More than one guide star may be required if the star moves outside the guider patrol field when switching between on-source and off-source position.

![Figure 3.2: Screen shot of a mask. The field of view limits the slit positions. Spectra produced by slits outside the two parallel blue lines are clipped by the detector. Outside the two vertical inner white lines the defocus may influence the image quality. Mini coordinate system: the lines point in positive x and y direction and are 10 mm long.](image)

### 3.1 Basic Movements and Functionalities

The central green circle on the mask image (Fig. 3.2) has the function of handling the mask as a whole. In the following, the 2 mouse buttons (left, middle) are designated \texttt{B1} and \texttt{B2}. Their functions when clicking on the central green circle are:

- \texttt{B1}: mark current mask position

- \texttt{B2}: rotate LUCIFER1/2 (and hence the mask) counter-clockwise on the screen. The default step-size is 5°. The step-size can be controlled from the \texttt{Rotation Step} button in the \texttt{LUCIFER1/2 Config/Layout} menu.

- \texttt{Shift + B2}: rotate LUCIFER1/2 (and hence the mask) clockwise.

- \texttt{B1} and move: Changes telescope pointing position (and hence moves the mask)
The function of mouse right button B3 is still for measuring distances, as in the default SkyCat setup.

**Caveat:** Rotating or shifting the mask deletes all slits! Therefore, first position the mask correctly, then select the reference and guide stars and finally position the slits.

**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 lower left 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, as is done by lms.sh).

### 3.2 Reference Stars and Target Acquisition

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

**Reference stars have to be selected from the data set which is used for slit positioning.** Before taking a MOS-spectrum, these reference stars are identified on the image taken during the target acquisition sequence. From their measured positions, the translation and rotation offsets are calculated and these values are used for telescope pointing correction and instrument rotator angle correction. At the LBT, finding the corrections and communicating them to the telescope is in the responsibility of the observer.

The absolute positions of MOS-slits (and thus the correct mask ID) are verified by mask images typically taken during daytime with the telescope at the zenith. These images will also be used to measure the position and rotation angle of the mask in the focal plane from the positions of the six reference slits along the top edge of the array. Again, it is the responsibility of the observer to check the correct alignment and positioning of the mask.

A general rule for the selection of reference stars: For MOS-observations it will be required to correct rotation and position offsets between the pre-image and the actual telescope pointing with high accuracy. Therefore, we recommend 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. The procedure how to select reference stars is explained in section 5.6.

It is mandatory to select unsaturated point sources as reference stars which are bright enough to achieve a high signal-to-noise ratio within an integration time of typically 1 minute. There should be no brighter star than the reference star within about 10 arcsecs and the reference stars should be at least about 10 arcsecs away from the edge of the field of view.

### 3.3 Instrument settings

After initializing the mask, LMS visualizes the focal field boundaries as a white square. Two white lines in north-south direction inside this square confine the 2.5 arcmin wide central area of small defocus (caused by the deviation of the cylindrical mask from the focal sphere). The back image of the detector contour on the focal plane is presented by a blue square. The two blue lines inside the square confine the field within which slits can be placed without spectral clipping for a given camera/grating/filter combination. Slits can be set beyond this boundary, but some parts of the specified spectral range will be lost.

The default camera / filter / grating combination is: N/1.8 camera / Ks band filter / GRATING3; the selection of these elements is done from the Config/Layout menu (for details see section 5.9). Selection of a band filter will automatically select the optimum grating and disable the radio buttons for gratings not available with this filter.
The Help Grating Info info shows allowed filter/grating combinations together with the spectral orders, the band filter center wavelengths, and the 50% limits, as read from the Instrument Summary File (ISF). Please note that for some combinations, the spectrum does not fit on the array. In this case the two blue border lines limiting the unclipped area are connected to the corresponding array edges by red diagonals, indicating that no unclipped spectrum can be recorded. (To avoid confusion, the diagonal lines are displayed only if Labels is activated in the LUCIFER1/2 Config/Layout menu). A smaller wavelength range can be chosen via the Config/Layout WaveLength Range menu. This choice has no physical effect, but re-draws the border lines of the unclipped area. LMS recognizes if the user-defined wavelengths limits are outside the filter band, and replaces these values by the default band limits.

The WaveLength Range menu also permits selection of the center wavelength (the wavelength at the slit image). This setting has a physical effect in that it tilts the grating to move the selected wavelength to the slit image.

### 3.4 Finding Guide Stars for the LBT

LMS can be used to verify if there are appropriate guide stars in the patrol field of the autoguider. When the Guide Stars add button is pressed, LMS shows a red contour limiting the guide probe patrol field. The guide stars have to be located inside this contour. Guide stars should not be selected from the region overlapping with the LUCIFER field (white square), because positioning of the guide probe inside the LUCIFER field causes vignetting. During LUCIFER commissioning it was found that the contour of the patrol field as provided by LBT and drawn in LMS is not correct. The boarder will be re-defined as soon as correct data are available. The useful guide star brightness range is 11 to 15 mag. In case no guide star is found, guiding is not possible and the observation cannot be carried out.

Guide stars can be retrieved using online catalogs and can be superimposed on the fits image. Press the button Data-Servers and Catalogs to access on-line catalogs. The relative position offset between guide stars on one side, and reference stars and science objects on the other side can be up to 10″. Therefore, guide star positions can be taken from other sources than science objects and reference stars.

### 3.5 Creating Slits

Beside the basic key bindings for mask positioning (see section 3.1) and the LUCIFER menu items, LMS provides the following bindings:

- press B1 to create a MOS-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 single slits (width, length, tilt, center position in x and y)
- press B2 on the slit number label next to the slit to purge the slit

Presently two MOS slit types are supported STRAIGHT (=rectangular slit, optionally tilted with respect to the dispersion direction) and CIRCLE (= just a circle).

**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. Centering may not be possible if the object extends beyond the Pick Object window. In this case, reduce the zoom factor of this window until the source is fully inside the window.
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.

Modifying slit parameters: Two lines containing the slit center position (in mm focal plane coordinates, measured from the optical axis) have been added to the slit menu. They are meant for minor adjustments of the slit position. A small coordinate system next to the slit appears when the [Enter] button in the slit editing menu is pressed for the first time (even if no changes have been made). The lengths of the two axes correspond to 10 mm in the telescope focal plane. The axes point in positive x (parallel to the dispersion direction) and y direction. This system should help to estimate the required changes in the slit center position. The coordinate system disappears if the zoom factor is changed or the editing menu of another slit is opened. Presently, no plausibility check is implemented for the modified slit position. While slits can be created only inside the white square limiting the FOV, they can be placed outside the FOV by changing their positions in the slit menu. Be careful to stay within the white square!

3.5.1 MOS Reference Slits

LMS defines six small square reference slits close to the upper edge of the mask which cannot be modified by users. These slits are used to detect residual rotation and translation offsets of the mask with respect to the expected position in the focal plane of the telescope. LMS displays the positions of the reference slits as indicated in Fig. 3.3 (for LUCIFER FITS images, the slit order is reversed, i.e., slit number 1 is the rightmost). Close to slit 6 the mask ID number is cut into the mask sheet. To avoid overlap of science spectra with those produced by the slits of the ID number, no slit should be positioned between the red rectangle containing the six reference slits and the white FOV edge parallel to this rectangle.

![Figure 3.3: Screen shot of the mask upper edge showing the six reference apertures generated by LMS and the red rectangle next to reference slit # 6 containing the mask ID number.](image)

3.5.2 Files and Numbers

File names: As already mentioned in the previous chapter, LMS generates three files for a science mask, *.lms, *.gbr, *.epsf. These files have the same names. E.g., the lms file has the format mos<d>.<ddd>.<project>.lms. In this string, the first d is 1 for LUCIFER 1 and 2 for LUCIFER 2, ddd is a 3-digit counter which is incremented by 1 each time an lms file is saved (leading zeros are omitted), project is an up to 8 characters long string which can be set in the ProjectName window in the Config / Layout menu. If no project is specified, the file name reduces to mos<d>.<ddd>..lms.

Mask name, Mask id, Mask NAID: Each slit mask has a unique identification number, MASK_ID, and a mask name MASK.NA. The id-number is cut into the mask sheet in the position indicated in Fig. 3.3. When saving a mask setup, the keyword INS.MASK.NAID is created and included in the lms file. The format of its value is Mdddcccccccc+dddddd which is equivalent to M< INS.MASK.NA >+< INS.MASK.ID >. Starting from left, the substring ddd contains the three digit number of the LMS internal counter, cccccc is the up to 8 char long string containing the user-defined project name, both of which also appear in the file names. dddddd is a six digit random number between 900 001 and 999 999 representing the mask id (values between 900 000 and 900 100 are reserved for technical masks). When a mask has been cut, it can be identified by this INS.MASK.ID only.
3.5.3 MOS Constraints

**Maximum MOS slit size:** Sizes of all individual slit apertures are restricted to 20 arcsec for mechanical reasons. It is however not excluded to produce larger multi-slits or unusual slit geometries by punching several individual slits next to each other - with some space in between. However, such large multi-slits may cause mask sheet bending and are thus to be discussed with the observatory staff.
Chapter 4. Target Lists

It is not necessary to have a target list when working with LMS. However, it is highly recommended in order to avoid target misidentification. Automatic positioning will require a user defined target list.

LMS interacts with a target list during the following tasks:

- **Save**: MOS 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, LMS assigns NN as default target name for the current slit.

- **Automatic Positioning** puts MOS 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 LMS 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 “playground” for LMS 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, 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 set-ups have to be prepared with e.g. 100 science targets in one single LUCIFER 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 exposures. For this purpose astronomical catalogs are required.

4.1 How to Generate Target Lists

Target lists can be created in four ways:

1. A local catalog can be created with the **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 LUCIFER frame, they might be shifted with respect to the optical position, a consequence of the telescope pointing accuracy. It is generally possible to use automatic MOS slit positioning with external catalogs. Again it is important that the reference targets are 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.

4. The output format of the widely used Source EXtractor software is already compatible with the SkyCat catalog format.

4.2 Example Target List

The target list is an ASCII file, where individual columns are separated by 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 Guide Star Catalog 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:

<table>
<thead>
<tr>
<th>id</th>
<th>alp</th>
<th>dec</th>
<th>mag</th>
<th>pri</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC0815 001</td>
<td>7:00:28.3</td>
<td>+05:01:18</td>
<td>27.0</td>
<td>0</td>
</tr>
<tr>
<td>NGC0815 002</td>
<td>7:00:27.3</td>
<td>+05:01:17</td>
<td>20.0</td>
<td>1</td>
</tr>
<tr>
<td>NGC0815 003</td>
<td>7:00:33.3</td>
<td>+05:01:19</td>
<td>19.2</td>
<td>0</td>
</tr>
<tr>
<td>NGC0815 004</td>
<td>7:00:13.3</td>
<td>+05:01:17</td>
<td>20.7</td>
<td>0</td>
</tr>
<tr>
<td>NGC0815 005</td>
<td>7:00:20.3</td>
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<td>0</td>
</tr>
<tr>
<td>NGC0815 006</td>
<td>7:00:25.3</td>
<td>+05:01:17.2</td>
<td>22.3</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.1: Example target list

where the Tab key is pressed after each but the last value in one line.

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. If the target list does not contain a column with mag or pri use the LUCIFER 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 array pixel positions, you can use the Edit Enter new object Pick object... commands to create your target list step by step.

During a LMS 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 LMS.

4.3 Saving Target Acquisition Files

Saving a TAF invokes a search of all selected slit positions in the local catalog. 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 LMS 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 LMS session.

4.4 More about LMS 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, the plot symbols have to be set. 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.
This section gives a comprehensive description of all pull down menu items in the LMS menu and its sub-menus.

### LUCIFER1/2

- **Init Mask**
  - section 5.1
- **Load Setup**
  - section 5.2
- **Quit Mode**
  - section 5.3
- **Auto-Slit**
  - section 5.4
- **Save Setup**
  - section 5.5
- **Reference Targets**
  - section 5.6
- **Guide Stars**
  - section 5.7
- **Status Panel**
  - section 5.8
- **Config/Layout**
  - section 5.9

### 5.1 Init Mask

The mask can only be initialized if a WCS is defined, i.e., if a FITS image or a catalog has been loaded. Pressing this button plots the focal field (white square) and the current instrumental mask over the sky image. The two white lines within the square limit the area of acceptable defocus due to the deviation of the cylindrical mask from the focal sphere. The closely spaced red lines near the top of the field indicate the area in which the six reference apertures (0.5'' x 0.5'') are positioned. The mask ID-number is also cut in this area. The blue square is a back projection of the detector outline onto the focal plane, its size changes with the camera selected. For the two blue lines inside the square refer to the [Labels option in the Config/Layout submenu](#).

The mask is initialized and oriented according to the underlying FITS image (the 6 reference slit are aligned along the northern edge of the mask, slit number 1 is next to the eastern edge). The rotator angle (= (-1) x position angle on the sky) is zero. The orientation of the FITS image is indicated in the small window on the lower left of the SkyCat GUI.

### 5.2 Load SetUp

This menu item configures the initialized mask by reading all relevant telescope, instrument, and mask parameters from an *.lms file which has been saved during a previous session. Be careful to load the setup for the FITS image or catalog in use. In case the wrong setup file is read, no error message is issued, but normally the mask image is no longer visible, because it is located outside the sky area displayed in the SkyCat window. The name of the FITS image associated with an *.lms file is listed in the comment lines at the top of the *.lms file.

### 5.3 Quit Mode

This menu item deletes the mask and de-activates all LMS features.
5.4 Auto-Slit

The automatic positioning of MOS slits on catalog positions requires target lists. For large user-defined target lists, the slits 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 MOS 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. Reference targets used for pointing the telescope must always originate from the same source as science targets. Either both from the underlying image or both from the same catalog.

5.4.1 Requirements

Automatic MOS 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 for target catalogs to be used with Skycat (section 5), the catalog must also meet the following requirements to be used for automatic positioning with LMS:

- 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 LMS: 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

5.4.2 Usage

The Auto-Slit program takes the current mask coordinates (RA and DEC) and position angle (PA), searches for targets in the user defined local catalog and sets slits to appropriate target positions. If there is more than one target per slit height available then the object closest to the frame center line is used. If the target list provides the pri-column then targets with pri=1 are preferred even if a pri=0 target would be closer to the frame center.

The two blue boarder lines inside the detector square indicate the array area for which the instrumental wavelength range fully fits on the array. Automatic positioning takes only targets within this area into account since spectra of objects beyond this area will be clipped by the array edge. The instrumental wavelength range is defined by the combination of filter, grating, and camera. If only a fraction of the available wavelength range is of scientific interest, this reduced wavelength range can be specified via the LUCIFER Config/Layout WaveLength Range button. Since this user-defined wavelength range is smaller than the instrumental wavelength range, the array area for which the user-defined wavelength range matches the array, is larger.

Auto-Slit does not move or rotate the instrumental mask. The mask with the new slit-positions is redrawn. This method is appropriate when the underlying sky frame has the same size as the LUCIFER mask, like images obtained with LUCIFER itself.

For crowded fields, the Auto-Slit set-up depends 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 MOS set-up.

5.5 Save

This saves the current mask settings and creates three files in the $INSROOT/.lms/SET directory (or in a directory specified by LUCIFER Config/Layout Set-upDir), using the syntax:
<mode>.<counter>.<projectname>.<ext> \textbf{where}

- \textit{<mode>} is always mos1 or mos2 in LMS
- \textit{<counter>} is incremented with each save operation in order to avoid overwriting previous set-ups of the same project name
- \textit{<projectname>} is an 8 character user defined name. See section 5.9.3
- \textit{<ext>} is one of lms, gbr, epsf where
  - lms is used by LMS to re-load a set-up, and for observation preparation, since it contains telescope pointing and slit positions,
  - gbr contains the slit information in Gerber format, and is used for mask cutting,
  - epsf contains a mask image, including the mask contour, centering slots, reference apertures, and science slits, but not the mask ID-number.

Please keep all output files produced by LMS; they could be useful later if a problem occurs during observation.

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 the LBT. At least two, but for better alignment accuracy 5-7 reference sources must be specified before saving the mask.

If the AstroCat interface is active, the slit positions are compared with the entries of the user defined local catalog. The search area is two times the MOS slit width4 (TBC). (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 Save as... 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.) Since SkyCat from version 2.5.3 on provides the usage of more than one user defined so called local catalog, you have to select one of the active local catalogs, from which the slit positions will be deleted.

\textbf{Note}: The save command only considers top-level catalogs, loaded by the Data-Servers menu bar button in the SkyCat toplevel window. Catalogs loaded from the Data-Servers menu bar button in a catalog window will not be considered.

### 5.6 Reference Targets

MOS target acquisitions have to be aligned using reference stars. Select up to 10 reference targets, ideally close to the slit positions. Reference targets can be specified at any time during an LMS session, but no longer during the save sequence. Press LUCIFER 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 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 Pick Object window. To exit the selection process press the button Close in the Enter Object window twice.

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 outside the red square (which is essentially the contour of the LUCIFER field of view).
- **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 LUCIFER
- **reset** to delete the complete list of reference targets

### 5.7 Guide Stars

At the LBT, the observer has to provide the guide stars for his observations. For this purpose, the menu item Guide Stars has been added. This menu has the same sub-menus as the Reference Targets menu, and they work in the same way. However, the guide stars selection procedure is quite different from the reference star selection procedure for the following reasons:

1. Since the guide stars are used for tracking only, the relative accuracy between slit and reference star positions on one side, and the guide star positions on the other side is not stringent (offsets of the order 10 arcsec are allowed). Once the guide star has been found, the reference objects can be aligned by telescope offset and instrument rotation. This implies that guide stars and science objects / reference stars can be extracted from different sources.

2. Guide stars are not recorded by LUCIFER, but by the AGW (auto guider and wavefront sensor unit). Therefore, although the guider can pick up stars in the LUCIFER field, the guide stars should be located north to the LUCIFER field to avoid severe vignetting.

3. The autoguider rotates with LUCIFER on the instrument rotator, and therefore the guide star field is fixed relative to the mask. Therefore, if no guide star is located north of the mask, rotate the mask until a guide star is above its “upper” edge to avoid vignetting by the probe.

4. Brightness range for guide stars: 11 to 15 mag.

5. For each pointing, one guide star is required. For small offsets, two pointings can share the same guide star as long as it stays within the guider patrol field.

*Note:* Presently, the guide star patrol field is not exactly known. Tests during LUCIFER commissioning indicated that it differs from the red contour drawn by LMS.

### 5.8 Status Panel

The button **Status Panel** creates a top level window showing the current status of the LMS session. The contents of the three fields:

- **Instrument Setup**
- **MOS Slits**
- **Session**

is self-explaining.

### 5.9 Config / Layout

This cascaded menu contains instrumental configuration options and options for the graphical layout of the mask. All instrument parameters are written in the lms file to keep track of the instrument configuration selected for a specific mask. However, the mask itself does not depend on the instrument configuration, and the observer is free to set other instrument parameters during observation.

#### 5.9.1 Instrument Configuration

This section defines the LUCIFER hardware options and the overall slit parameters. Slit parameters can be modified individually after slit creation.
- **Slit Type** choose one of the 2 currently supported slit types STRAIGHT or CIRCLE. Default is STRAIGHT. The maximum number of MOS slits is 200.

- **Slit Width** choose a slit width between 0.25″ and 15″, default is 0.5″. Changing this value affects all existing and newly created slits. After creation, the parameters of an individual slit can be adjusted by left clicking on the slit width next to the slit image (requires Labels on).

- **Slit Length** choose a slit length between 2.0″ and 20.0″, default is 4″. For modification and re-definition, the same as for Slit Width holds.

- **WaveLength Range** specify the wavelengths range and the center wavelength in nm and redraw the mask with the new wavelengths region boundaries. Default values are set when a filter is selected. Note that there is a fundamental difference between setting the center wavelength and setting the limits. The center wavelength is defined as the wavelength at the position of the slit image. Changing this value physically tilts the grating and thus shifts the observable spectral range across the array. Naturally, the grating tilt, and therefore the change in center wavelength is limited by the instrument design. The physical limit is ±5°, LMS calculates the tilt from the center wavelength and the instrument configuration, and gives a warning if the tilt is too large. On the other hand, the wavelengths range is not a physical instrumental configuration option, but is only used as a graphical aid (see Auto-Slit button). The real spectrum length is usually limited by the array borders or by the filter width. The default wavelength range as given in the pop-up window shows the band filter FWHM range. The wavelengths limits defined by the array size are displayed close to the lower corners of the array (irrespective of the band filter transmission). Entering wavelengths limits outside the filter band is ignored.

- **Camera** choose one of the 2 LUCIFER cameras, N/1.8 (0.25″/pixel, for spectroscopy), N/3.75 (0.12″/pixel, for seeing limited imaging). Default is the N/1.8 spectroscopy camera. In combination with grating 2 and 3 it can make sense to use the N/3.75 camera. Changing the camera affects the blue square (array back imaged on the focal field). For the N/3.75 camera, the field is nearly identical with the detector projection. For the N/1.8 camera, the field is smaller than the array. The camera focal lengths are defined in the isf file; together with the fixed collimator focal length, they define the magnification between focal field and detector array.

- **Band Filter** choose one of the LUCIFER band filters z, J, H, K, Ks, HK, where HK covers H- and K-band; default is K with grating 3, (see next menu item). Selecting a band filter also selects a default grating and disables the grating menu buttons not compatible with the selected filter (e.g., the HK filter can be used only with grating 2 and the z and J filters can be used only with grating 1).

- **Gratings** choose one of the 3 LUCIFER gratings. Grating 1 can be used with all filters except HK. It is operated in different orders (5 for z to 2 for K) and provides the highest resolution. Grating 2 has been design for wide band spectroscopy and is always used in first order. It is primarily combined with the HK filter, but can also be used with the H, K, and Ks filters. The resolution is less than half of the grating 1 resolution. Grating 3 is optimized for K band spectroscopy and has a similar resolution as grating 2, which can be doubled with the N/3.75 camera (without loosing spectral coverage in K).

### 5.9.2 Graphical Layout Options

These options have no influence on the instrument configuration and on the mask properties, they are aids for the mask preparation.

- **Rotation Step** select the rotation angle of the mask per mouse click. 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 color of the mask. The colors of the green handling circle and the blue square array area are not affected. Default: Yellow/Red.

• **Labels** configuration option of the active mask. The telescope pointing and the orientation of the mask are shown. Slits are numbered at the edge of the mask and next to the slit image. In addition, a label indicating the slit width is drawn next to slit. The wavelengths limits defined by the array size are shown close to the lower corners of the array projection (blue square). The central wavelength is shown on the upper edge of the array at the two blue lines limiting the spectral range without clipping by the array.

### 5.9.3 Special Options

These options provide means for slit positioning and for project administration.

• **Center Slit** This option centers the slit on a source. The method 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. \(<\text{projectname}>\) is an up to 8 character long user defined name. If no project name is defined, this part of the file name is omitted. The project name is a LMS internal way to distinguish between different set-up files.

• **Set-upDir** The default directory for saving the \textit{.lms}, \textit{.gbr}, and \textit{.epsf} files is \texttt{$\text{INTROOT/\}.lms/SET} which is defined in the \texttt{lms.sh} startup file. The 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.
Chapter 6. Technical Masks

In the previous chapters, the generation of multi-slit masks for science observations has been described. LMS also offers the option to set up observations with long slit masks, so-called technical masks, which are permanently stored at the LBT (but not necessarily continuously available in the instrument). Long slit masks cannot be modified, but the observer can use LMS to select reference and guide stars. Therefore, only the *.lms file is saved in this mode.

The existing technical masks are listed in Table 6. The first three masks are for maintenance only, the others are single slit masks for science. All available technical masks are coded as LUCIFER aperture definition files (ADF). They are copied from the default directory $LMSROOT/lib/mos to the $SET_DIR directory each time LMS is started. After having specified the band filter and the grating, a technical mask can be used to prepare observations. Just press the [Load SetUp] button and edit the filter entry field in the file select menu from the default filename extension .lms to .adf and load the technical mask as any other user defined set-up. When, e.g., the $LMSROOT/lib/mos/mos1.004.standard.adf aperture definition file is selected, LMS will recognize the adf file extension and will change to technical mask mode. To switch back to the default normal mask mode, press [Quit Mode] then [Init Mask].

Remark: The mask is initialized in normal mode. Therefore, the 6 reference apertures are plotted on the mask, these apertures don’t exist on technical masks.

<table>
<thead>
<tr>
<th>MASK ID</th>
<th>Tag</th>
<th>ADF</th>
<th>mode</th>
<th>contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>990063</td>
<td>PINHOLE</td>
<td>mos1.063.standard.adf</td>
<td>technical</td>
<td>pinhole array</td>
</tr>
<tr>
<td>990001</td>
<td>PINHOLE</td>
<td>mos1.001.standard.adf</td>
<td>technical</td>
<td>pinhole array</td>
</tr>
<tr>
<td>990031</td>
<td>BLIND</td>
<td>mos1.031.standard.adf</td>
<td>technical</td>
<td>blind mask</td>
</tr>
<tr>
<td>990034</td>
<td>SLIT,100</td>
<td>mos1.034.standard.adf</td>
<td>single slit</td>
<td>1.00 arcsec longslit</td>
</tr>
<tr>
<td>990029</td>
<td>SLIT,075</td>
<td>mos1.029.standard.adf</td>
<td>single slit</td>
<td>0.75 arcsec longslit</td>
</tr>
<tr>
<td>990032</td>
<td>SLIT,050</td>
<td>mos1.032.standard.adf</td>
<td>single slit</td>
<td>0.5 arcsec longslit</td>
</tr>
<tr>
<td>990065</td>
<td>SLIT,025</td>
<td>mos1.065.standard.adf</td>
<td>single slit</td>
<td>0.25 arcsec longslit</td>
</tr>
</tbody>
</table>

Table 6.1: List of LUCIFER technical masks
Appendix A. Guider Patrol Field

The autoguider is installed in front of LUCIFER. A moveable camera can pick up a star in the region around the LUCIFER field as indicated in Fig. A.1. The telescope does not provide SW for guide star selection, therefore, it has been implemented within LMS.

![Figure A.1: The LBT guide star patrol field.](image)

A, B, C, and D indicate the software limits for the guider patrol range. With respect to the field center, the coordinates of A, B, C, and D in mm are: A = (-184,26), B = (171,24), C = (136,147), and D = (-155,125). To avoid vignetting, guiding should be limited to a radial distance of 4.5' from the LUCIFER field center. In addition, a strip of 30" along the edges of the LUCIFER detector should be avoided. This strip can be reduced or even ignored for MOS observations, depending on the slit position (e.g. the strips on the E and W side are not relevant as long as slits are within the recommended region of 2.5' width in EW direction). The ARC AB is part of of circle of xx mm radius about M = (0,612.5).

The values for A, B, C, D have been supplied by LBT. Guider operation during LUCIFER commissioning indicated that the actual patrol field is smaller. An update for these values is required!
Appendix B. Scales

For mask cutting, two scales are important: the focal scale of the telescope, and the linear pixel scale on the detector (relating mm in the telescope field to pixels on the detector). The relevant scale for mask cutting is the focal scale providing the relation between the astrometric source positions and their linear locations in the focal field. However, when LUCIFER pre-images are used, the linear pixel scale is required to transform source positions on the detector back to focal field (and therefore mask) positions. Since slit positions are spread approximately over an area of 90 mm width, and the position accuracy should be better than 1/6 of the slit width, corresponding to \(25 \mu m\) or \(2.8 \cdot 10^{-4}\) for 0.25 arcsec slits.

This implies that both scales have to be known and stable to better than this accuracy. LMS uses the following design values for the scales:

<table>
<thead>
<tr>
<th>Scale Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope image scale</td>
<td>0.6000 mm/arcsec</td>
</tr>
<tr>
<td>N1.8 camera pixel scale</td>
<td>0.1500 mm/pixel</td>
</tr>
<tr>
<td>N3.75 camera pixel scale</td>
<td>0.0720 mm/pixel</td>
</tr>
</tbody>
</table>

From measurement with a sieve mask (array of pinholes with 2.5 mm pitch) in LUCIFER the following pixel scales have been deduced (without correction for the thermal contraction of the mask):

<table>
<thead>
<tr>
<th>Scale Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1.8 camera pixel scale</td>
<td>149.9 ±0.7 (\mu m/arcsec) 0.249833 arcsec/pixel</td>
</tr>
<tr>
<td>N3.75 camera pixel scale</td>
<td>71.98 ±0.08 (\mu m/arcsec) 0.119967 arcsec/pixel</td>
</tr>
</tbody>
</table>

The angular scale was derived assuming the telescope image scale of 0.6000 mm/arcsec. In addition, from astrometry with LUCIFER using the N3.75 camera, a scale of 0.120088 arcsec/pixel was derived. Combining this measured scale with the also measured linear scale for the N3.75 camera, the telescope image can be calculated to be 0.599394 arcsec/mm.

The new values are now used in LMS. However, these are only single measurements. The scales have to measured repeatedly over a longer period to confirm that they are constant to about \(2 \cdot 10^{-4}\) as required by the slit position accuracy.