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# **LUCIFER**

## **LMS User Manual**

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**LMS Version 1.62**

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## Chapter 1. Introduction

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### 1.1 Scope

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

### 1.2 Changes

**Attention: Masks prepared with LMS version 1.4 or lower cannot be used for observing after February 2010. Ims 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 comply with the sign convention of the LBT instrument rotator. As a consequence, a new telescope pointing mode had to be introduced for MOS observations.
2. Measured values for the LUCIFER pixel scales are now used instead of the design values.
3. Only one gerber file is generated which can be read by the LBT cutting machine as well as by the machine of the supplier 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 spectrum should interfere with this rectangle.
3. The correction for thermal contraction of the mask in LUCIFER (0.0025% shrinking during cool-down from ambient to -200 C) has been removed from the code. Instead, the thermal contraction is taken into account by adapting the telescope plate scale. Thus, the distinction between LUCIFER images and external images or catalogs is obsolete.

Changes made between LMS 1.51 and 1.52:

1. In the SkyCat window, the sign of the mask rotation angle listed together with the telescope pointing was wrong. This has been corrected, the rotation angle displayed 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.

Changes made between LMS 1.52 and 1.53:

1. The mask center position no longer changes when a mask that has been shifted relative to the image center is reloaded. The mask can now be shifted all over a large FITS image without restrictions.

2. Using the Auto-Slit option with a rotated mask no longer changes the sign of the mask rotation angle.
3. A check for at least three reference star has been implemented. A warning appears when the mask is saved with less than three reference stars.
4. A description of how to generate a SkyCat compatible catalog has been added to the manual.

Changes made between LMS 1.53 and 1.60:

1. The `Auto-Slit` functionality has been implemented in Tcl/Tk. The C++ code (binary `AP`) is obsolete. This eliminates the problems with compiling the C++ code on operating systems other than LINUX.
2. The part of this manual dealing with local catalogs and source lists has been rewritten.
3. The display of the array back projection on the focal plane has been modified. Only the contour of the accessible array area is plotted. I.e., the full width of the array (over which the spectra can extend) is indicated, but the height is limited to the field height.

Changes made between LMS 1.60 and 1.61:

1. The field size has been reduced so that the reference slits and the ID-number are outside the accessible field. This avoids interference of source spectra with the reference apertures and the ID cuttings.
2. The `Label`-button in the config menu now always displays the correct state.
3. The N/30 camera has been included in the camera selection menu.
4. Camera focal lengths have been replaced by magnifications (magnifications are directly measured and are used in LMS).

Changes made between 1.61 and 1.62:

1. Following a request from LBTO, the prefix of the LMS output files has been changed from `mos1/2` into `luci1/2`.

This should avoid confusion with the MODS mask cutting files.

**Attention: To load `lms` files generated with older LMS versions, in their filenames “`mos`” has to be replaced by “`luci`”!**

### 1.3 Abbreviations

FOV	field of view
ISF	instrument summary file
LMS	LUCIFER mask simulator
WCS	World Coordinate System (Ra and Dec)

### 1.4 Reference Documents

The following documents are referenced in this document:

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

[4] Astronomical Catalog Library, User Manual, GEN-SPE-ESO-19400-0949

All these documents are available on the ESO web-pages.

## **1.5 Acknowledgments**

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



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## Chapter 2. Overview and Requirements

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### 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 is a plug-in to the ESO SkyCat tool, a browser for astronomical images and catalogs. SkyCat either displays a FITS image or source positions loaded from a catalog. LMS overlays the contour of the LUCIFER field of view (or the mask area) together with the contour of the accessible detector area back projected on the telescope focal plane. Within the LUCIFER field of view, 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 field.

LMS 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 part of standard Linux installations. 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 (see below), then run the script.

#### 2.2.2 Other Operating Systems

LMS also runs under Mac OS. The corresponding SkyCat executable is not part of the LMS package and has to be downloaded from the ESO web pages.

#### 2.2.3 Directories and Paths

We have kept the default FIMS directory structure for program and file locations. In case you want to organize your setup differently, just modify the paths in the `lms.sh` script. Starting in line 49 of the script, the directory structure is listed:

```
LMSROOT=${LMSROOT:-$HOME/lms_vxxx}
ISF_DIR=$LMSROOT/lib/mos
INS_ROOT=$HOME
INS_USER=.lms
PREP_DIR=$INS_ROOT/$INS_USER/PREP
LOG_DIR=$INS_ROOT/$INS_USER/LOG
SET_DIR=$INS_ROOT/$INS_USER/SET
```

The first line defines the path to the LMS directory, the fourth line defines the name of the data directory. This list assumes that the program tree is `/home/<user>/lms_vxxx` (with the `lms.sh` start script stored in the `bin` sub-directory, and the programs, libraries, and instrument files stored in the `lib` sub-directory), and that the data tree is `/home/<user>/.lms`, containing fits files in the `PREP`, the log-files in the `LOG`, and the output files (`.grb`, `.lms`, `.epsf`) in the `SET` sub-directory. `<user>` refers to the user's home directory. These paths can be modified by editing the corresponding lines with a simple text editor. Please make sure that the path to the `lms` directory is correct. The output directories are created by the start script in case they don't exist.

## 2.2.4 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 11`
- `./lms.sh 12`

where the first two commands start SkyCat with the LUCIFER1 menu, while the third one starts SkyCat with the LUCIFER2 menu (LUCIFER2 sub-menus are not yet implemented). Besides 11 and 12, 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 the hidden default directories (`.lms/LOG`, `.lms/PREP`, `.lms/SET`) in the user's home directory, defines environment variables, configures the plug-ins for SkyCat, and starts SkyCat.

LMS is accessible via the `LUCIFER` menu in SkyCat. Mainly this menu is described here.

## 2.2.5 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.

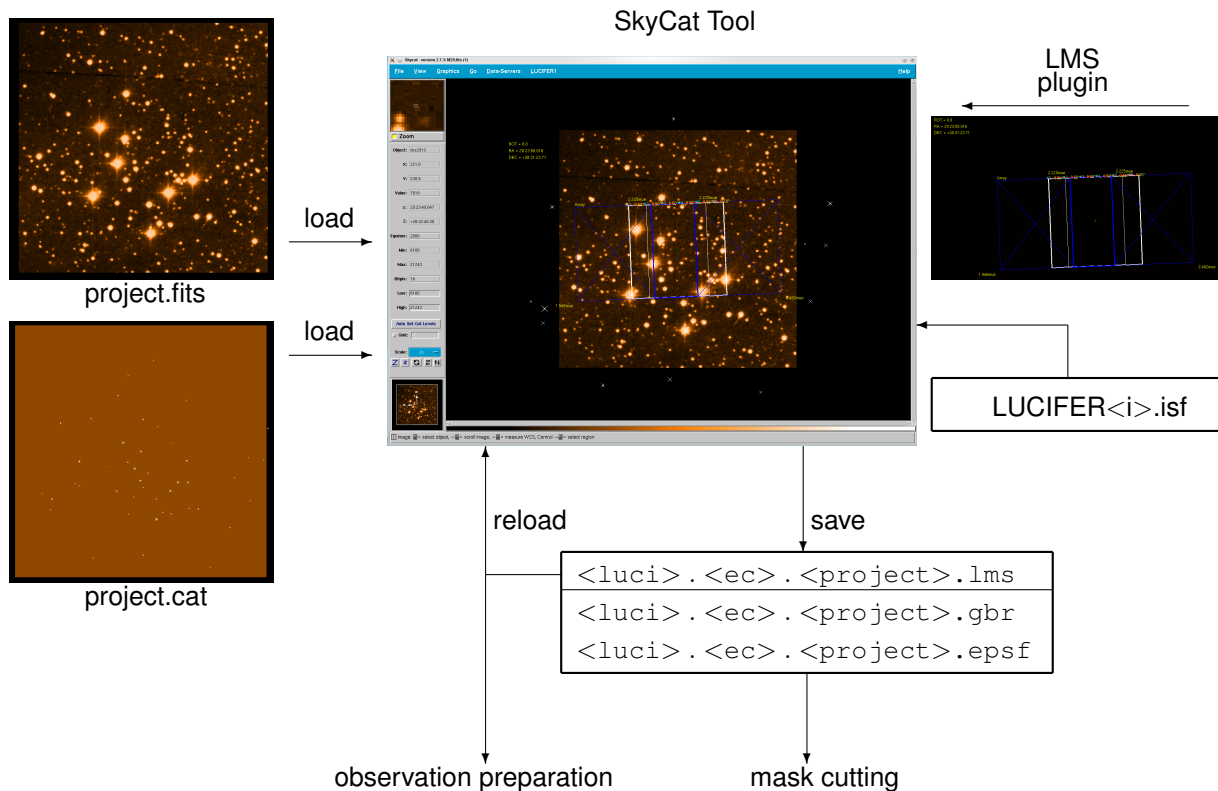


Figure 2.1: Interaction between SkyCat and LMS - input and output files.

LMS requires at least two input files:

- A FITS image and / 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_vxxx/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 wavelengths and bandwidths, 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. Reload this file to recover the LMS 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 long-slit 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 frame-less 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 and the pixel scale of the fits image (or the source positions in a catalog) have to be known to about  $7 \cdot 10^{-4}$ .

### 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 processing images for mask preparation:

- 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. Distortions have been measured by imaging a sieve mask on the detector. Images have to be distortion corrected before combining them to a mosaic.

**Remark 1:** Presently (no adaptive optics available, seeing limited operation) 1 arcsec wide slits should be used to minimize slit losses by seeing. In case a single LUCIFER pre-image (no mosaic) is used, the mask is centered on the image, and the slits are positioned inside the white rectangle indicating low defocus (see Fig. 3.2), no distortion correction is required.

**Remark 2:** 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 from other telescopes require careful and accurate astrometric calibrations (and WCS FITS headers). 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 on-line 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 CDELTA1 < 0 and CDELTA2 > 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 CDELTA1, CDELTA2 are very sensitive, while an offset between the WCS and the optical positions in the frame of less than 10 arcsec can be corrected by the alignment procedure.

To verify the correct setting of WCS keywords load your modified frame into SkyCat (select   ) 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 (      ) 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).

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 Frame-less Modes

A frame-less 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.

To load a catalog from the web, proceed as follows:

- to clear the display and to purge the WCS
- or load another target catalog (with reliable astrometry satisfying the requirements of section 2.4.1)
- in the catalog query window, specify the virtual field (RA,DEC, rmin=0, rmax) and press

- adjust the image brightness by scrolling with **B1** (left mouse button) the color bar below the main SkyCat window in case the virtual field or the source positions are not visible,
- press **LUCIFER** **Init Mask** and proceed further as in frame-mode

To save this catalog in the PREP directory, select the menu item **File** **Save as ...** from the catalog query window. Choose a file name and the extension `cat`. To reload the catalog, use **Data-Servers** **Local Catalogs** **Load from file ...**.

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## Chapter 3. Mask Preparation

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This section first gives an overview of the mask preparation and then describes the basic operations in some detail.

### 3.1 Overview

A typical LMS session should consist of the following steps:

1. change to the `bin` sub-directory in the LMS root directory
2. start SkyCat/LMS by typing `./lms.sh`
3. load a FITS frame and / or a catalog
4. initialize and position the mask
5. configure the instrument, set the slit parameters
6. select reference stars
7. select guide stars
8. position the slits on the mask
9. save the setup

#### 3.1.1 Loading a FITS File or a Catalog

Before the mask can be initialized, a virtual field has to be defined by either loading a FITS image or a catalog into SkyCat. It is also possible to load a catalog on top of a FITS image. To load a FITS image, use `Open` in the SkyCat `File` menu. In case no FITS image is available, select `Image Servers` from the SkyCat `Data-Servers` menu, and choose one of the image sources. Similarly, catalogs can be downloaded from the `Data-Servers` / `Catalogs` menu. Local catalogs can be accessed via `Data-Servers` / `Local Catalogs` / `Load from file ...`.

#### 3.1.2 Initializing and Positioning the Mask

Once a virtual field is defined, the mask can be initialized by pressing `Init Mask` in the `LUCIFER` menu. This action enables the LUCIFER menu items, loads the instrument parameters from the ISF file, and draws a mask in standard configuration (N/1.8 camera, K-band filter, grating number 3). At this stage, the screen should look like in figure 3.1: On top of a fits image (or the source positions from a catalog) the usable field is drawn as a white rectangle. This usable field is slightly smaller than the actual 4' x 4' field which includes the six square reference apertures of 0.5'' width (marked #1 to #6) close to its upper edge as well as the area occupied by the ID-number cut into the mask (red rectangle close to aperture #6). Inside the white rectangle two vertical white lines limit the central region (2.5 arcmin wide) of acceptable defocus (due to the deviation of the cylindrical mask from the focal sphere).

In the upper left corner of the SkyCat main window, the rotation angle of the mask and the mask center coordinates are indicated. Immediately after mask initialization, the rotation angle is zero, and the mask center is identical with the image or the catalog center. By dragging the green dot at the mask center, the mask can be shifted across the field. By clicking the green dot with the center mouse button, the mask rotates counter-clockwise in steps defined the `Rotation Step` sub-menu of the LUCIFER

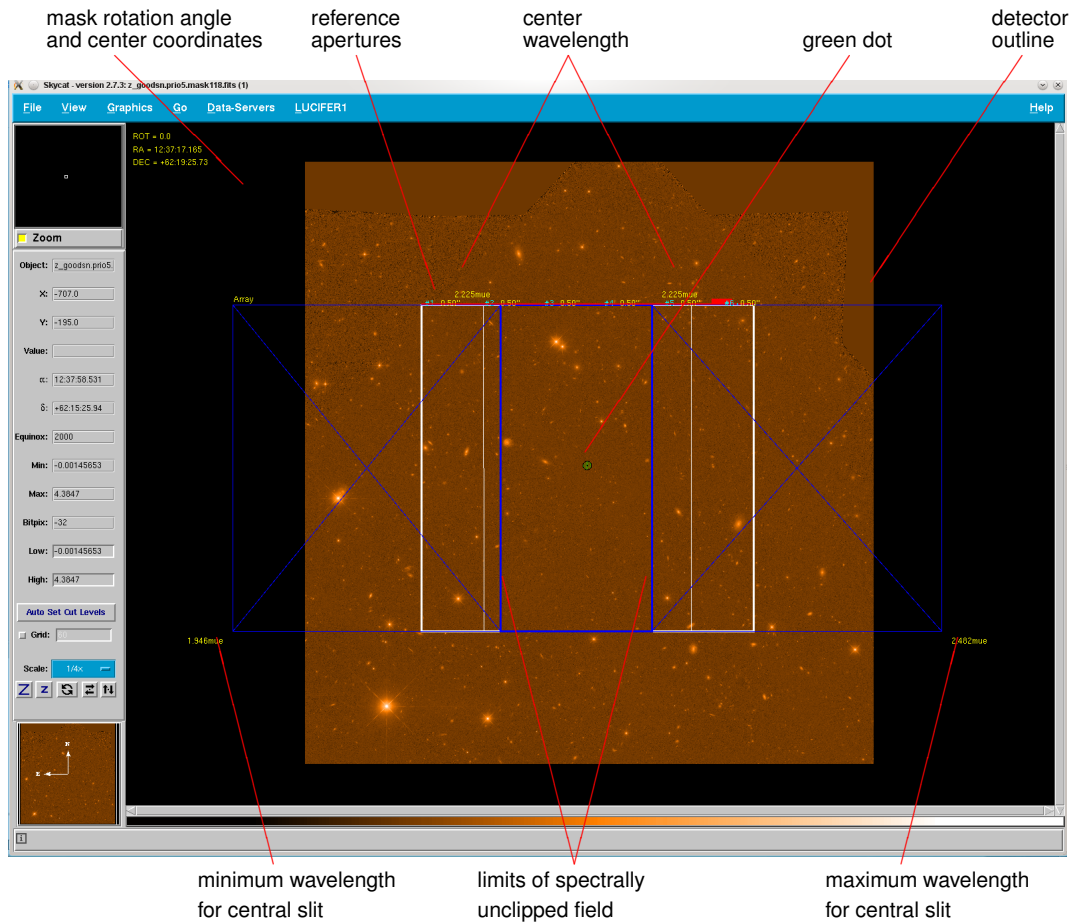


Figure 3.1: Screen shot of SkyCat with a FITS-image loaded and a mask initialized in the default configuration (K-band filter, GRATING 3, N1.8 camera). The mask is centered on the image.

**Config / Layout** menu. When the shift key is pressed while clicking the center mouse button, the mask rotates clockwise.

In this situation, left clicking anywhere inside the white rectangle creates a slit at the mouse pointer position with default parameters (4 arcsec long, 0.5 arcsec wide).

**Caveat:** Shift and rotate the mask before positioning any slits. Moving the mask will delete all slits!

### 3.1.3 Configuring the instrument

A blue rectangle indicates the spectroscopically usable detector area (spectra can extend beyond the field of view in dispersion direction). The size of this rectangle depends on the camera selected. The blue rectangle in figure 3.1 refers to the N/1.8 camera, for the N/3.75 camera the blue rectangle nearly coincides with the white rectangle, and for the N/30 camera it occupies only the central  $0.5' \times 0.5'$  of the LUCIFER field. The inner, vertical blue lines enclose the area of unclipped spectra. For a slit positioned within this area, the spectrum fits completely on the detector. If the slit is outside this area, its spectrum will be clipped on one side. The positions of these lines depend on the camera, the filter and the grating selected. In addition, the line positions can be changed by modifying the extreme wavelengths and the center wavelength in the **WaveLengthRange** sub-menu of the **Config / Layout** menu.

Changing the extreme wavelengths has no physical effect, but is a good method to indicate the unclipped area for a spectral range of interested (e.g., if only one line is to be observed). The two numbers close to

the upper end of the blue lines indicate the central wavelength. Changing this number affects the grating tilt, which is limited to about  $\pm 5$  degrees. Central wavelengths which require a larger tilt are not allowed and will be ignored. The numbers close to the lower left and right corner of the blue rectangle are the (theoretical) extreme wavelengths imaged on the detector for a central slit (the actual wavelengths range may be smaller due to the band-filter used).

For better identification of the spectrally clipped areas, diagonal lines connect the corners of the blue rectangle indicating the usable detector area to the end points of the two blue lines limiting the spectrally unclipped area. For several instrument configurations, no unclipped area may exist. In this case, the blue diagonal lines change their color to red. If this happens, either choose a different instrument configuration or limit your wavelengths range.

The instrument configuration should be done in the following way:

1. Open the **LUCIFER** menu, click on the **Config / Layout** button and then on the dashed line in the sub-menu. This opens the `Config / Layout` sub-menu in its own window which does not close after each parameter selection.
2. Select your wavelength range by pressing one of the buttons in the **Band Filter** sub-menu. The optimum grating for this band filter is set automatically.
3. In case a different grating should be used, click the **Grating** sub-menu. The allowed gratings are high lighted. Some filters work only with one grating, e.g. for HK only GRATING 2 is available, for z only GRATING 1. For details on the gratings, please refer to the LUCIFER user manual.
4. Click the **WaveLengthRange** window to change the central wavelength and the desired upper and lower wavelength limits, if required.
5. Select the camera from the **Camera** sub-menu. Normally the N/1.8 camera is used for spectroscopy. Changing the camera during slit positioning is possible but is not a supported mode. When changing the camera, the width of the spectra from existing slits is not adjusted. Newly created slits will have the spectral width compatible with the camera selected. When storing and reloading such a setup, all spectra will be displayed with the width suitable for the camera used at storage time. Slit positions are not affected by camera selection!
6. Select the slit length and slit width from the **Slit Length** and **Slit Width** sub-menus (default values are 4 arcsec length and 0.5 arcsec width).
7. Close the `Config / Layout` window.

### 3.1.4 Reference Star Selection

Once the instrument and slit parameters are set, reference stars should be selected in the LUCIFER field of view. At least three reference stars are required to check and correct the telescope pointing and the instrument rotation angle. More than three reference stars will reduce the inaccuracies. Because the telescope pointing and the orientation of the instrument (the mask) on the sky, are derived from the reference star positions in the image, the reference targets should be taken from the same source (FITS image or catalog) as the science objects.

To select reference stars, click on the **Reference Targets** sub-menu, then select **add**. The white frame indicating the LUCIFER field of view becomes red, and an information window pops up; press the **OK** button after you have read the text. Then an input window appears into which the coordinates of the reference star can be entered. In case a FITS image is available, press the **Pick object ...** button. Another window appears which in its upper part shows a small area of the fits image around the cursor position. Move the cursor to a star in the fits image. When the star is close to the center of the **Pick Object** window, press the left mouse button. After a short time, a cross should appear at the center of the star, and its coordinates are displayed in the window. Now select the **Enter Object** window and



press `Enter`. A blue circle appears around the star, indicating that the reference star has been added to the list. Press the `Pick object ...` button in the `Pick Object` window to select the next reference star.

In case the cross is not centered on the stellar image, press the `Pick object` button in the `Pick Object` window again, and try to position the mouse pointer closer to the star before clicking the left mouse button. If the stellar image is larger than the window, reduce the zoom factor by clicking on the small `z` in the `Pick Object` window before starting another selection. To finish the reference star selection click twice the `Close` button in the `Enter Object` window.

Reference stars must be positioned within the red rectangle. No check is made when the star is selected, but the positions can be verified by pressing `verify` in the `Reference Targets` sub-menu. The reference and the guide star positions are checked automatically before saving a mask, and the result of this check is displayed in an information window. In case one of the check fails, the observation cannot be executed!

### 3.1.5 Guide Star Selection

The procedure to select a guide star is the same as for a reference star. It is controlled by the `Guide Stars` sub-menu. When pressing the `add` button, a red polygon appears which indicates the guider patrol field. This field partially overlaps with the LUCIFER field. If possible, select a guide star outside the LUCIFER field. Take into account that the pickup unit of the guide probe covers about 1 arcmin x 1 arcmin on the sky, and is mounted on a solid bar. Therefore, if the guide star is inside or close to the LUCIFER field, an area of this size will be vignetted, and reflections from the probe can be visible in the image.

At least one guide star is required, and selection of the guide star is in the responsibility of the observer at the LBT. It may be necessary to rotate the mask in order to have a guide star inside the guider patrol field.

### 3.1.6 Slit Positioning

Once LUCIFER is configured, the slit parameters are set, and the reference and guide stars have been selected the slits can be positioned on the mask. Slit positioning can be achieved in 3 different ways:

1. A left mouse click anywhere within the usable field indicated by the white rectangle will create a slit at the cursor position.
2. Pressing the `Center Slit` button in the `Config / Layout` sub-menu opens the `Pick Object` window known from the reference target and guide star selection. Within the white rectangle, click the left mouse button, wait until the image in the `Pick Object` window moves with the mouse cursor, then drag the mouse until the source is located close to the center of the `Pick Object` window, release the mouse button, and wait until the source center position is indicated and the slit appears on the mask.
3. In case a catalog has been loaded, click on `Auto-Slit` in the `LUCIFER` menu. Slits will be positioned in the blue rectangle (or the white one whichever is smaller), starting with source position 1 in the catalog. In case the spectrum of a new slit would overlap with an already existing spectrum, this slit will not be generated.

Fig. 3.2 depicts a typical situation for creating slits using the `Center Slit` option. The FITS-image is the same as in Fig. 3.1, but the mask has been shifted off-center, and the image has been magnified by pressing the `Z` button above the pan window in the lower left corner of the SkyCat window. The cyan circles numbered 1 to 5 are centered on the reference targets. The yellow circle number 1 is centered on the guide star.

Slits number 7 to 16 have been generated using the `Center Slit` option. The `Pick Object` window shows the source on which slit number 16 has been positioned. Slit number 7 is outside the blue rectangle, its spectrum will be clipped on the red side. All slits are 1 arcsec wide, but their lengths and tilts have been set individually, e.g., to align the slit along the major axis of an object. The tilt of the major

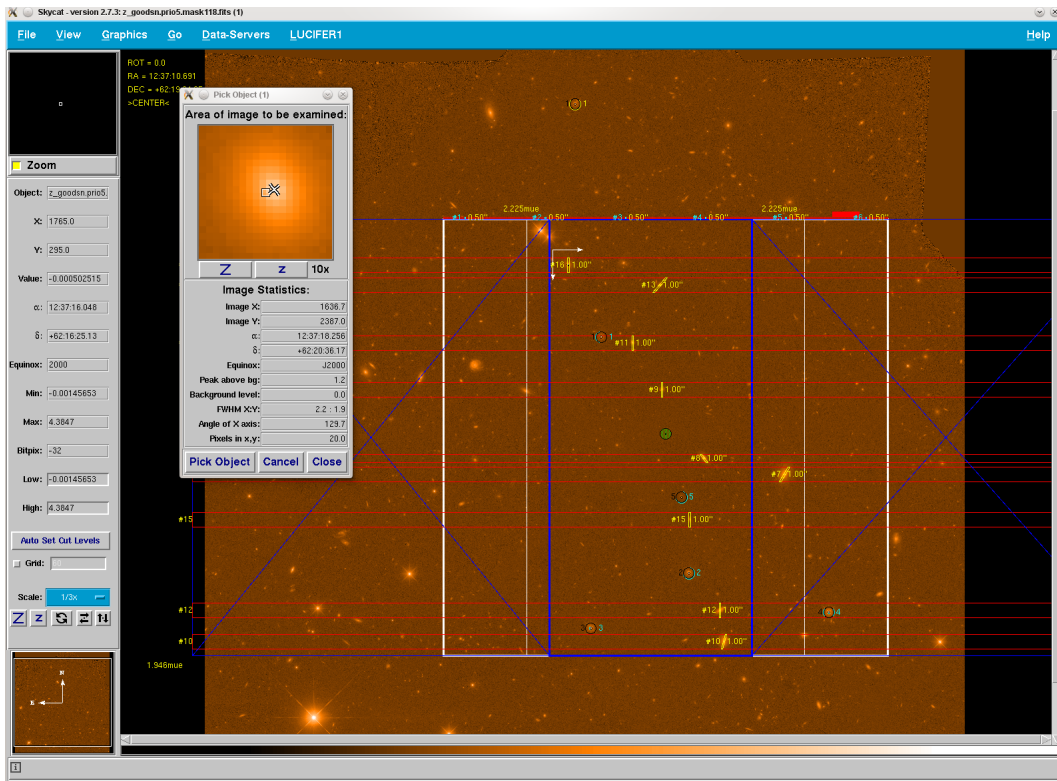


Figure 3.2: Screen shot of the slit generation process using `Center Slit`. The mask has been shifted, but not rotated relative to the image.

axis against the x-axis (horizontal in this case) is listed in the `Pick Object` window. The tilt of the slit is measured against the y-axis. The rotation angle of the slit is positive if it is rotated from the y-axis towards the x-axis.

Slit parameters can be modified by left clicking on the slit width label next to the slit image. In this case an entry window appears which lists the slit width and length in arcsec, the slit tilt in degrees, and the slit center position in mm from the mask center. When the `Enter` button in this entry window is pressed for the first time (even without changing parameters) two white arrows spanning a coordinate system are displayed, like the ones next to slit number 16 in Fig. 3.2. Their lengths correspond to 10 mm on the mask (in the telescope image plane), the arrows point towards the positive x- (horizontal line) and y-direction (vertical line). The lines should be helpful for changing the slit center position. The lines are deleted if the parameters of another slit are modified or if the image is redrawn (e.g. when zooming in or out).

Note that slit number 14 does not exist. It has been deleted, and the following slits are not renumbered. Slits can be deleted by either center clicking on the number label next to the slit, or by left clicking on one of the number labels at the edges of the spectral bars.

### 3.2 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 `B1` and `B2`. Their functions when clicking on the central green circle are:

- **B1**: mark current mask position
- **B2**: rotate LUCIFER1/2 (and hence the mask) counter-clock-wise on the screen. The default step-size is 5°. The step-size can be controlled from the **Rotation Step** button in the **LUCIFER1/2 Config/Layout** menu.
- **Shift B2**: rotate LUCIFER1/2 (and hence the mask) clock-wise.
- **B1** and move: Changes telescope pointing position (and hence moves the mask)

The function of the right mouse button **B3** is for measuring distances, as in the default SkyCat setup. Click the right mouse button to define a reference position, release the button, then drag the mouse, the angular distances between the actual cursor position and the reference position is displayed in arcsecs or in arcmin:arcsecs. To stop the measurement, press the right mouse button again.

**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 of 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 scroll command line option, as is done by lms.sh).

### 3.3 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 using the calibration source. 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 mask. 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. A minimum of 3 reference stars are needed for this alignment, but 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 5.7.

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.

### 3.4 Finding Guide Stars for the LBT

LMS can be used to verify if there are appropriate guide stars in the patrol field of the auto-guider. 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 and stray light. 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 on-line catalogs which can be overlaid 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 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 (defocus is caused by the deviation of the cylindrical mask from the focal sphere). The back image of the accessible detector area on the focal plane is presented by a blue rectangle. The two vertical blue lines inside this rectangle 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 5.10). 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 boarder 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.

*Hint:* Using the `Config/Layout` menu from the `LUCIFER1/2` menu is rather tedious because it closes after each setting. This can be avoided by clicking on the dashed line at the top of the `Config/Layout` menu. The click creates a stand alone configuration window which stays open until explicitly closed by the user.

### 3.6 Creating Slits

Beside the basic key bindings for mask positioning (see section 3.2) and the LUCIFER menu items, LMS provides the following bindings:

- press `B1` to create a MOS-slit within the LUCIFER field (white square)

- press **B1** on the slit number label at the edge of the detector contour (blue rectangle) to purge the slit
- press **B1** on the slit width label to configure this slit (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).

Slit positions are not checked for plausibility, but

1. slits are created only if the mouse pointer is inside the LUCIFER field (white square),
2. the mouse pointer is outside the green central dot,
3. the mouse pointer is outside the inner circle around a reference star,
4. the mouse pointer is outside the red rectangles indicating the areas occupied by the spectra of already created slits.

This has the following consequences:

1. If a slit is generated close to the edge of the field of view, part of the slit might be outside the field.
2. If a slit is created close to the spectrum of another slit, the spectra can overlap.
3. When the slit position or the slit length is modified via the slit parameter entry form window, the slit might be shifted outside the field, or spectra might overlap.

It is in the responsibility of the user to check that the slits are inside the field of view and that spectra do not overlap.

**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 algorithm 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 or on reference stars:** 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 outside the green circle, 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. The same procedure applies to the inner circle around a reference star. In case a slit is to be placed on a reference star, activate the `Center Slit` functionality, click outside the circles around the reference star, and when the image in the `Pick Object` window becomes active, move the mouse pointer on the source.

**Modifying slit parameters:** The last two lines of the slit parameter entry form display the slit center position (in mm on the mask measured from the mask center). 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 arrows correspond to 10 mm on the mask. The arrows point in positive x (parallel to the dispersion direction) and y direction. This coordinate 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. 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!

**Auto-Slit option:** In case a catalog has been loaded into SkyCat, selecting the `Auto-Slit` item in the LUCIFER1/2 automatically places slits on the sources listed in this catalog which are located inside

the blue rectangle defining the spectrally unclipped area. In case the unclipped area is larger than the LUCIFER field, slit positions are limited to the field. Slits are placed starting with the first catalog position inside the blue rectangle. The program then goes down the list and checks for each source if it is inside the blue rectangle. If so, the program checks if the spectrum from the slit on this object would interfere with other spectra. If not, the slit is created. No other criteria are involved in slit placement. Therefore, high priority objects should be placed at the top of the catalog. For details on how to set up a local catalog refer to chapter 4.

### Slit constraints

1. Individual **slit lengths** are restricted to 20 arcsec for mechanical stability 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.
2. In LMS, the **number of slits** has been limited to 200. In practice, this limit should never be reached, because it implies an average slit length of about 1 arcsec, which is impractical.

## 3.7 Saving Masks

When all slits have been created, the mask configuration has to be saved. At this point three files, all with the same name, but with different suffixes are created: \*.lms, \*gbr, \*.epsf.

The `lms` file contains the information for telescope pointing and instrument rotation, all slit parameters, including slit center coordinates in WCS units (not for the 6 reference apertures) and in mask coordinates (mm x and y), the WCS coordinates of the reference targets and of the guide stars, as well as the LUCIFER configuration parameters. This file can be reloaded to restore the session. It is also used as input to produce the telescope control system script for observation with this mask.

The `gbr` file contains the information required for cutting the mask and the slits, including the mask contour, the holes for mounting of the mask, and the mask ID. Freeware programs like *gerbv* are available on the web for viewing this file. Visual inspection can be useful to check the masks before cutting or to clarify the mask identity by comparing an image taken through the mask with the gerber file image.

The `epsf` file contains a mask image for direct viewing in case no gerber file viewer is available. This image does not contain the mask ID!

**File name conventions:** The `lms` file has the format `luci<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 

LUCIFER1/2	Config / Layout	ProjectName
------------	-----------------	-------------

 menu. If no project is specified, the file name reduces to `luci<d>.<ddd>..lms`.

**Mask name and mask identification number:** Each mask has a unique identification number (ID, `lms` keyword `INS.MASK.ID`), and a mask name (`lms` keyword `INS.MASK.NA`). The ID is cut into the mask sheet. When saving a mask setup, a third keyword `INS.MASK.NAID` is created and also stored 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 sub-string `ddd` contains the three digit number of the LMS internal counter, `cccccccc` 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 900 101 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 ID.

Before the mask is saved, a project name should be defined. Otherwise the file names differ only by the three digit counter, and it can easily happen that files submitted from different groups have the same names. This can cause confusion when the `lms` files have to be assigned to the corresponding masks.

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## Chapter 4. Local Catalogs

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In case no FITS image is available for slit positioning, a local catalog can be used instead. Catalogs can be downloaded from the web or generated by the user. SkyCat provides tools for downloading, storing, and editing catalogs.

In this chapter we first describe the catalog format required by SkyCat and LMS, then we explain how to set up a local catalog from a remote catalog query, and finally we elaborate on generating catalogs from the scratch.

### 4.1 Catalog Format

Here we give a concise description of the catalog format. A detailed description can be found in chapter 2 of the Astronomical Catalog Library User Manual (4).

Local catalogs are implemented as simple ASCII files in *tab table* format. This is the same format that is used to return query results from remote catalogs. The results of catalog queries are always returned in the format of a *tab separated table* of values. The column headings are separated from the data by a dashed line:

```
Title
# comments
Keyword: value

...
ID          RA          DEC          MORE          PREVIEW
--          --          --          ----          -
NGC5457-FD2 14:02:22.489 +54:17:58.29 M=http://...  P=http://...
NGC5457-FLD2 14:02:22.489 +54:17:58.29 M=http://...  P=http://...
...          ...          ...          ...          ...
```

Lines starting with # are considered as comments and are ignored. `Keyword: value` combinations specify the catalog from which the data are extracted, non-standard usage of columns, and how to plot the sources. This information is used by SkyCat.

The line containing `ID`, `RA`, `DEC`, ... specifies the meaning of the values in the columns listed below and is mandatory. The keywords have to be tab separated. For usage with LMS, the first three columns are required. Any number of other source parameters (e.g. magnitude, redshift, size, priority) can be included here, but have no effect for usage with LMS. The columns `MORE` and `PREVIEW` have special meanings, and are not visible in the query result window. The two columns contain HTTP URLs pointing to locations providing more information on the source and images, respectively. In case the columns are not empty, the buttons `More Info` and `Preview` below the list window are activated if the corresponding source is highlighted. Under SkyCat 2.7, `More Info` tries to launch Netscape, which is no longer available on most systems.

The column headings are separated from the data by a dashed line. For the `Auto-Slit` function, LMS uses the first three columns only. Again the columns are tab separated. The `ID` can be any unique character string composed of alphabetic characters, numbers, and underscores. `RA` and `DEC` are listed in `hh:mm:ss.ss` and `±ddd:mm:ss.sss` format for equinox J2000. The valid keywords and formats are summarized in the following table:

Meaning	Keywords accepted by LMS	Value
unique identification	character strings containing ID, Id, name, target, star, object	catalog source name/number
right ascension	RA, Ra, ra	position in format hh:mm:ss.ss, J2000
declination	DEC, Dec, dec	position in format ±ddd:mm:ss.ss, J2000

## 4.2 Creating a Local Catalog from a Web Search

The simplest way to create a local catalog is to search one of the catalogs available on the web. These catalogs are accessible from SkyCat via the `Data-Servers` `Catalogs` menu which displays a list of catalogs. Clicking an item of this list opens a query window. In case a FITS image has already been loaded, press the `Set From Image` button in the window to set the search area in the catalog (defined by the center coordinates and the maximum radius). In case no FITS image has been loaded, the center coordinates and the search radius (in arcmin) have to be entered manually. The minimum radius should be set to zero, otherwise an annulus between minimum and maximum radius is searched. The limiting object magnitudes and the maximum number of objects listed can also be defined (entering these numbers is not mandatory). Once the search area and the other parameters are defined, press the `Search` button to start the query.

A list of sources with names, coordinates and additional parameters appears (the additional parameters are catalog specific), and the source positions are marked either on an empty virtual field or on the FITS image. To see the sources symbols, it may be necessary to adjust the image brightness by dragging the mouse cursor along the color bar below the main window. In case you are satisfied with the source list, save it as a local catalog by opening the `File` menu in the query window and then select `Save as ...`. Use the extension `cat` to save the list in the PREP directory.

In case only a few objects from a long source list are plotted, have a look at the `Options` `Set Plot Symbols ...` menu in the query window. In the upper part, the plot symbols window lists the parameters used to define plot criteria, the symbol plotted, and other parameters (symbol size, conditions, etc.). Several criteria can be combined and attributed to different plot symbols. Usually, the size of the plot symbol is related to the source brightness, e.g. by entering a relation like  $(20 - \$Fmag) * 3$  in the line `Size`. In addition, special conditions can be selected for plotting a source. E.g.,  $\$e == 1$  in the line `Conditions` prevents the plot of sources with an eccentricity differing from one. All these values can be set and modified by the user.

*Remark:* The syntax for calculations and conditions is the standard Tcl/Tk syntax, i.e., the value of a variable `e` is `$e`.

The second menu item in the query window, `Edit`, works only on local source lists. Therefore, a list loaded from a catalog server, has to be locally stored and then reloaded before it can be edited. Editing includes removing of a selected source, adding new sources, and editing parameters of a selected source. New sources can be entered by typing their coordinates and ID into the input window. Alternatively, in case an underlying FITS image is available, the `Pick Object` mode can be used in the same way as for reference target and guide star selection. Unfortunately, the coordinates are not automatically transferred from the `Pick Object` window to the `Enter object` entry form. However, the values can be copied and pasted between the two windows.

The `LUCIFER` menu in the query window can be used to add magnitude and priority columns which have no effect in the present LMS version. This may change in upcoming versions.

## 4.3 Building Your Own Catalog

With the format information from section 4.1 it is relatively simply to build a local catalog. Just execute these steps:



1. In a text editor, create a new empty file.
2. Type in the row with the header information for the catalog. At least three tab separated keywords (e.g. ID, Ra, Dec) are required, more can be added, but have no effect in LMS.
3. Type the next line which contains only dashes.
4. Enter the tab separated parameters for the first source: a name and the coordinates in the format specified in the table at the end of section 4.1.
5. Enter the tab separated parameters for the other sources, one source per line.
6. Save the file with the extension `cat` in the PREP directory.

Now this local catalog can be loaded into SkyCat. Start LMS as usual, then open the menu `Data-Servers` and `Local Catalogs`. In this menu click the last line `Load from file ...`. In the file selection window, go to the PREP directory and select your catalog file, then press the `OK` button, the catalog is loaded and the catalog query window containing the source list pops up. If you load the catalog for the first time, you will not see any source positions plotted. The reason is that no plot symbol has been defined in the catalog header.

To define the plot symbols proceed as follows:

1. In the catalog window click the `Options` menu and then `Set Plot Symbols ...`.
2. A new window with the title *Plot symbols for <filename>* appears, and a message pops up that no plot symbols have been defined for this catalog.
3. The uppermost sub-window lists the columns used for plotting and the plot parameters assigned to these columns. The window should be empty at this stage.
4. In the columns window mark a column in the *Not Used* field and move it to the *Used* field by clicking the lower blue arrow. More than one columns can be selected. Plot conditions and symbol size can only be defined for columns in the *Used* field.
5. Use the default plot symbol (circle) or select a different symbol by clicking on the blue bar in the line `Symbol` and then select one of the symbols displayed.
6. In the same way select the symbol color by clicking on the line `Color`, or keep the default value (black and white) which is best suited for colored background.
7. Next define the symbol size by entering a number or an expression in the line `Size`. You can always use a number, a typical value is 3 to 10, depending on the image size. In case a magnitude column has been chosen, the plot symbol size can be defined by the magnitude. For example, if `mv` has been chosen, the plot symbol size can be defined as  $(15 - \$mv)$ , which plots a zero magnitude star as a circle with diameter 15, and a ten magnitude star with diameter 5. Objects fainter than 15 magnitude are not plotted in this case. The default units for the symbol size are image pixels.
8. In case a column like `mv` has been selected for plotting, a condition should be specified to avoid error messages in case no magnitude is listed for a source. For example type  $(\$mv < 15)$  in the line `Condition`. Several conditions can be combined, like  $(\$mv != "") \&\& (\$mv < 15)$ , where the first conditions prevents application of the plot size expression to symbols with undefined `mv` (which causes an error message). Conditions can be defined only for columns listed in the *Used* field.
9. When all required parameters have been defined, press the `Add Symbol` button. The plot parameters should appear in the uppermost sub-window.
10. Press the `Apply` button. The symbols should be plotted on a virtual field (or on a FITS image if loaded).
11. Close the plot symbol window.

12. Save the settings using the **File** **Save as ...** menu of the catalog window. You can overwrite your original catalog, source data have not been changed, but several lines containing the catalog file name and the plot parameters have been added to the header.

All plot parameters can be modified at any time via the **Set Plot Symbols ...** sub-menu.

#### 4.4 Local Catalogs and Auto-Slit

As already mentioned, the *Auto-Slit* function can be used to position slits automatically on catalog positions. First you have to load a local catalog or do a query on one of the catalogs available on the web via the SkyCat menu. Then the mask has to be initialized, and positioned in the field.

Slits can now be positioned on the catalog sources by pressing the **Auto-Slit** button in the *LUCIFER* menu. The program goes through the catalog starting with the first source, it first checks if the source is inside the white rectangle of the LUCIFER field. If this is the case, a slit is positioned on the source. For the following sources, the same position check is made. If the source is inside the white rectangle, another test is made to check if the spectrum from this source would overlap with spectra from already positioned slits. If this is not the case, a slit is positioned on this source, otherwise the source is skipped.

After entering reference targets (from the same catalog) and guide stars, the mask can be saved. At this instance, the objects on which slits have been positioned are deleted from the catalog loaded into SkyCat (but not from the original catalog) and from the SkyCat main window. In the lms file, the catalog source names are entered behind the `INS . TARGxxx . NAME` keyword of the corresponding slits.

In case there are sources left in the field, you can shift the mask image so that these sources are inside the white rectangle. After dropping the mask at the new position, the previous slits are deleted from the image, and you can press the **Auto-Slit** button again. New slits are then positioned on the remaining sources. After entering reference targets and guide stars this masks can also be saved. Again, the sources on which slits have been positioned are deleted from the catalog and from the screen.

This procedure can be continued until the catalog is empty. The session can be interrupted after saving a mask. In this case, the last version of the catalog should be saved under a new name (using the **File** **Save as ...** menu in the catalog window). This catalog file can be reloaded later to continue the slit positioning session.

##### **A known problem with Auto-Slit:**

When slits are positioned using *Auto-Slit*, and reference targets and / or guide stars are positioned by typing their coordinates into the *Enter Object* window, some slit images and circles around reference and guide stars are slightly offset relative to symbols representing the catalog objects (by less than 0.5 arcsec). This seems to be related to the pixel size of the internal graphics screen (relative position changes with zoom) and does not affect the correct positioning of slits and does not affect the accurate slit positioning. The slit coordinates stored in the lms file are identical to the object coordinates listed in the catalog.

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## Chapter 5. LMS Menu Reference

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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
Reset Mode	section 5.2
Load Setup	section 5.3
Quit Mode	section 5.4
Auto-Slit	section 5.5
Save Setup	section 5.6
Reference Targets	section 5.7
Guide Stars	section 5.8
Status Panel	section 5.9
Config/Layout	section 5.10

### 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 or the catalog field. 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 ( $0.5'' \times 0.5''$ ) are positioned. The mask ID-number, indicated by a red rectangle is also cut in this area. The blue rectangle is the back projection of the accessible detector area onto the focal plane, its size changes with the camera selected. For the two blue lines inside the rectangle refer to the `Labels` option in the `Config/Layout` sub-menu.

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 ( $= (-1) \times$  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 Reset Mode

Pressing this button deletes all slits, but keeps the reference targets and the guide stars.

### 5.3 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.

## 5.4 Quit Mode

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

## 5.5 Auto-Slit

The automatic positioning of MOS slits requires a catalog which lists at least source names and source positions. Slits will be positioned on the catalog positions, even if an FITS image with deviating source positions has been loaded together with the catalog. Remember to take the reference targets also from the catalog, and not from an underlying image!

Automatic MOS slit positioning works for several on-line catalogs like GSC, SIMBAD, NTT archive, USNO, as well as on user-defined catalogs. These catalogs have to be compliant with the requirements for astrometric accuracy (section 2.4.1) and for target catalogs to be used with SkyCat and LMS (chapter 4).

The Auto-Slit program takes the current mask coordinates (RA and DEC) and position angle (PA). Starting from the top of the catalog, the program searches for targets located inside the blue rectangle defining the area of unclipped spectra (or within the white square limiting the field, whichever is smaller). If a target inside the blue rectangle is found, the program checks if the spectrum of a slit centered on this target interferes with the spectrum of any of the already existing slits. If this is not the case, the slit is positioned on the target, otherwise the target is skipped.

Auto-Slit does not move or rotate the mask. Therefore, the best mask position and orientation has to be set before starting the Auto-Slit function.

Since Auto-Slit positions the slits on the targets in the order they appear in the catalog, this order becomes important for crowded fields. High priority sources should be positioned at the top of the catalog.

## 5.6 Save

This saves the current mask settings and creates three files in the `$INSROOT/.lms/SET` directory, using the syntax: `<mode>.<counter>.<projectname>.<ext>` where

- `<mode>` is always `luci1` or `luci2` in LMS
- `<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 5.10.3
- `<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 three, but for better alignment accuracy five to seven reference sources must be specified before saving the mask.

## 5.7 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    to add reference targets. Purge reference targets by a comma separated list (e.g. 7,3) in the  menu. The  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  in the `Enter Object` window twice.

The sub menus are

- to plot the reference targets on the screen
- to list the reference targets and their positions
- 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).
- to purge individual reference targets from the list; e.g. enter 1,4 to purge targets #1 and #4
- to check that all reference targets can be handled by LUCIFER
- to delete the complete list of reference targets

## 5.8 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 can be extracted from different sources than science objects / reference stars.
2. Guide stars are not observed 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 at least 1 arcmin outside the LUCIFER field to avoid vignetting and stray light from the auto-guider..
3. The auto-guider 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.

## 5.9 Status Panel

The button  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.

## 5.10 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.

### 5.10.1 Instrument Configuration

This section defines the LUCIFER hardware options and the overall slit parameters. Slit parameters can be modified individually after slit creation.

- The first menu item is the dashed tear-off line. Clicking on this line opens a new window for the configuration menu. This window stays open until you explicitly close it. The sub-menu closes automatically after each click.
- **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 effects newly created slits, but not already existing 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 re-draw 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  $\pm 5^\circ$ , 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 3 LUCIFER cameras, N/1.8 (0.25"/pixel, for spectroscopy), N/3.75 (0.12"/pixel, for seeing limited imaging), or N/30 (0.015"/pixel, for diffraction 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 effects the blue rectangle (accessible array area 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. The N/30 camera is presently not available, and has been added for completeness and later use. Its field is only 30" x 30", and the spectral range is very limited.

- **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 losing spectral coverage in K).

### 5.10.2 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 rectangle). 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.

### 5.10.3 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. `< 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. More important, at the telescope the lms files are required for the MOS acquisition procedure. In case no project is defined, two lms files can by chance have the same name (i.e., the same number), which can lead to acquisition of the wrong field. Therefore, a project name should always be chosen to make the lms file names more unique.

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.



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## Chapter 6. Technical Masks

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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 file-name extension `.lms` to `.adf` and load the technical mask as any other user defined set-up. When, e.g., the `LMSROOT/lib/mos/luci1.004.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.

MASK ID	Tag	ADF	mode	contents
990 063	PINHOLE	luci1.063.standard.adf	technical	pinhole array
990 001	PINHOLE	luci1.001.standard.adf	technical	pinhole array
990 031	BLIND	luci1.031.standard.adf	technical	blind mask
990 034	SLIT_100	luci1.034.standard.adf	single slit	1.00 arcsec longslit
990 029	SLIT_075	luci1.029.standard.adf	single slit	0.75 arcsec longslit
990 032	SLIT_050	luci1.032.standard.adf	single slit	0.5 arcsec longslit
990 065	SLIT_025	luci1.065.standard.adf	single slit	0.25 arcsec longslit

Table 6.1: List of LUCIFER technical masks

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## Appendix A. Guider Patrol Field

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The auto-guider is installed in front of LUCIFER. A movable 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.

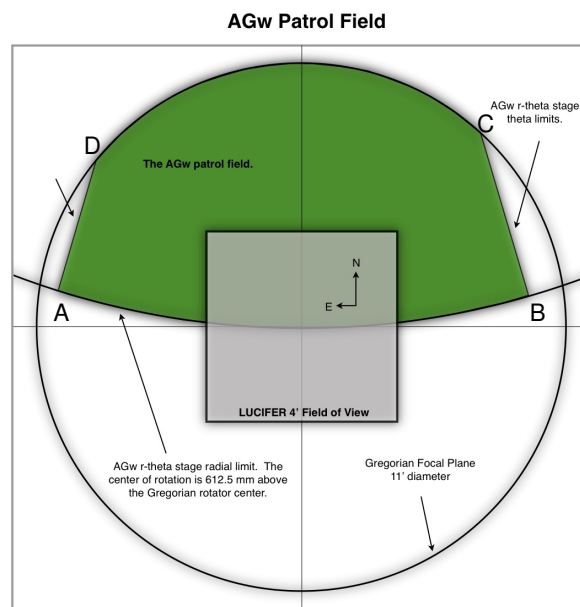


Figure A.1: The LBT guide star patrol field.

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 1 arcmin width along the edges of the LUCIFER field 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 a circle of 612.5 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!