

# LOPSIMUL: Quick Numerical Simulator of Multi-Foil Reflective Optical Systems

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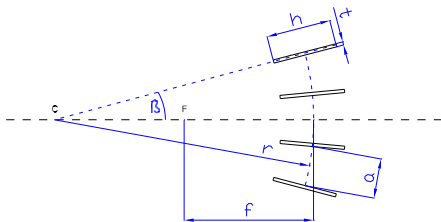


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# One-dimensional Schmidt lobster eye

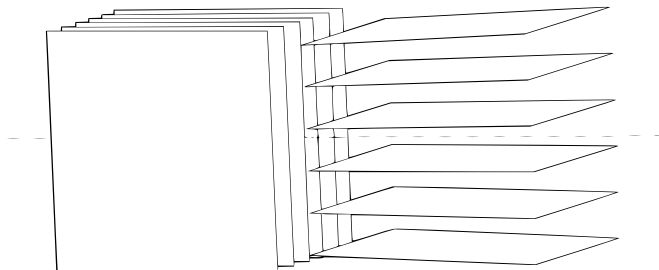


The system is composed of flat rectangular mirrors forming an uniform pattern around of a virtual cylinder of centre **C**. This set of mirrors is called stack. Point **F** is the focus.

- ▶  $r$  radius of the system
- ▶  $a$  mirror spacing
- ▶  $t$  mirrors thickness
- ▶  $h$  mirrors depth
- ▶  $N$  number of mirrors
- ▶  $\beta$  is angle position of a mirror; it is equal to grazing angle  $\beta$  if beams are parallel

Lobster optics is intended mainly for X-rays. Its main advantage is wide field of view

## Two-dimensional Schmidt lobster eye



Two orthogonally arranged stacks of mirrors form two-dimensional lobster eye.

# Why to develop a new algorithm and program

## Motivation

Develop the quick algorithm and consequently the software mainly for Schmidt and Angel lobster eye (usually used for X-rays).

## Result

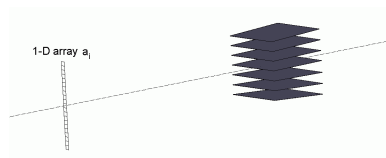
Extremely quick software, computing time is usually in order of seconds or less than one second on a common personal computer. The usage is more general than the lobster eye.

## Ideas of the algorithm

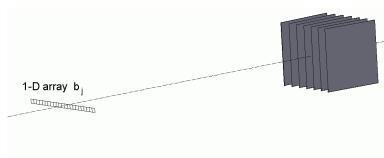
- ▶ Separation of dimensions: 3D problem  $\rightarrow$  two 2D problems that represents a small approximation
- ▶ Calculation of borders of reflections and shadows only that does not represent an approximation for flat mirrors.

The algorithm and consequently the software is possible to use for these types of optics that allows these simplifications. It covers any multi-foil optical system consisting of one or two orthogonally arranged stacks of flat mirrors. It is e.g. a case of optics that is similar to Schmidt lobster eye but spaces between mirrors are not equal. K-B system can be simulated in an approximation when curved mirrors are replaced by set of flat surfaces.

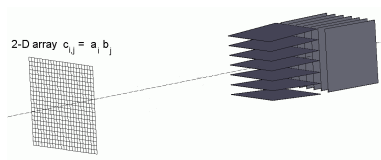
# Separation of dimensions



(a) First (horizontal) subsystem



(b) Second (vertical) system

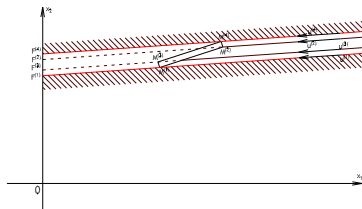


(c) Full 2D system

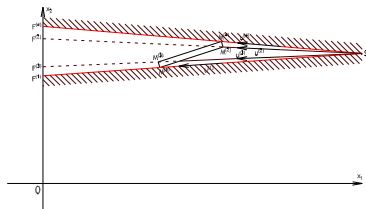
Figure: Separation of 2D system into two 1D systems

## Calculation of positions of shadows

It is useful to begin the calculations by calculating the position of the shades of mirrors. The mirror can have non-zero thickness and its border is defined by points  $\mathbf{M}^{(1)}$ ,  $\mathbf{M}^{(2)}$ ,  $\mathbf{M}^{(3)}$ ,  $\mathbf{M}^{(4)}$ .



(a) Parallel beams



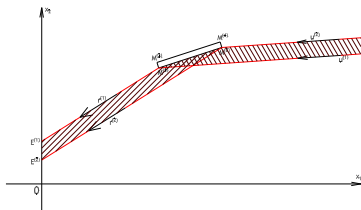
(b) Divergent beams

Equation for position of points  $F^{(j)}$  is simple:

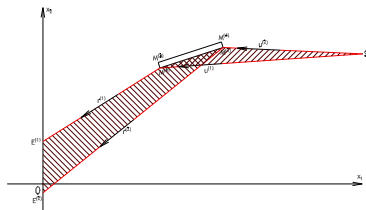
$$F_2^{(j)} = M_2^{(j)} - M_1^{(j)} \frac{u_2^{(j)}}{u_1^{(j)}} \quad (1)$$

The shadow lays between the minimal and maximal value of  $F^{(j)}$ ,  
 $j = 1 \dots 4$ .

# Calculation of positions of reflections



(c) Parallel beams



(d) Divergent beams

Direction of the reflected ray is calculated by equation

$$\mathbf{r}^{(j)} = \mathbf{m} \mathbf{m} \left( \mathbf{u}^{(j)} \right)^* \quad (2)$$

Positions of the borders of the reflection are calculated by equation

$$E_2^{(j)} = M_2^{(j+2s)} - M_1^{(j+2s)} \frac{r_2^{(j)}}{r_1^{(j)}} \quad (3)$$

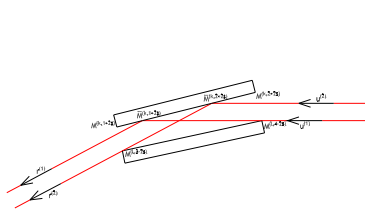
Mirror direction vector  $\mathbf{m}$  is defined as

$$\mathbf{m} = \mathbf{M}^{(2)} - \mathbf{M}^{(1)} / |\mathbf{M}^{(2)} - \mathbf{M}^{(1)}| \text{ or}$$

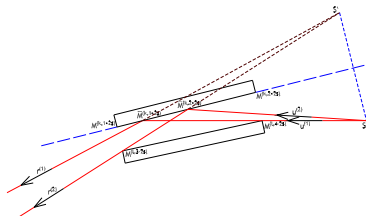
$$\mathbf{m} = \mathbf{M}^{(4)} - \mathbf{M}^{(3)} / |\mathbf{M}^{(4)} - \mathbf{M}^{(3)}|.$$



# Shadows between mirrors



(e) Parallel beams



(f) Divergent beams

It can happen (in a case of lobster eye it commonly happens) that a mirror is not illuminated fully but it is shadowed by other one. The full analysis of shadows between mirrors could be done. However, to save computing time, this analysis is done within a stack only and with the adjacent mirror only.

Full description of the algorithm is published in paper *Exp. Astron.* (2016) 41:377-392; DOI 10.1007/s10686-016-9493-2

# LOPSIMUL - Overview

The screenshot displays the LOPSIMUL software interface, which is divided into several main sections:

- CONTROL PANEL:** Located in the top-left, it contains input fields for detector and source positions (x, y, z in mm), detector resolution (40 um), and optics rotation (yaw, pitch, axis in deg). It also features buttons for 'Set', 'Retrieve', 'Center spot', 'Clear', and 'RUN SIM'.
- LOPSIMUL Profile:** A graph in the top-center showing Intensity [ER] on the y-axis (0 to 400) versus Position [mm] on the x-axis (-15 to 5). A single sharp peak is visible at approximately 0 mm. The graph includes a 'Strip size' input set to 1 and buttons for 'OK', 'Save x profile...', 'Save y profile...', and 'Save both...'. Below the graph, it states: 'Max value = 305.092. Strip size X FWHM = 6 pixels = 0.24 nm'.
- RESULTS, MESSAGES:** A terminal window in the bottom-left showing analysis results for 'Channel 1 analysis' and '2D image analysis'.

```
Channel 1 analysis:
Min refl = -0.194562 nm pixel:250
Max refl = -0.194562 nm pixel:260
RM effective collecting length = 9.20954 nm
RM width = 0.44 nm
FWHM = 0.2 nm

2D image analysis
RM spot integral = 2181.03
Peak at [-1.27636e-015, -1.27636e-015]nm = [255, 255] pixel on detector.
Peak at [-1.27636e-015, -1.27636e-015]nm in global coordinates.
Peak value=305.092.

Spot of >10% of intensity of peak
Spot area = 69 pixels = 0.1104 nm^2
Spot integral = 8920.94
Gain = 884

-----
Spot area = 21 pixels = 0.0336 nm^2
Spot integral = 5112.08
Gain = 1521
```
- GRAPHS:** A window in the top-right with a red title 'GRAPHS' and a scale bar showing 400.
- CALCULATED IMAGE:** A window in the bottom-right showing a 2D image with a red title 'CALCULATED IMAGE'. It includes checkboxes for 'Logarithmic', 'Color', and 'Invert colors', and a 'Save Image...' button. The cursor is at [288 px, 10 px] = [1.3 mm, -9.82 mm] with an intensity of 0.

# LOPSIMUL - Control panel

## Setup:

- optics arrangement, generation of lobster eye
- mirrors reflectivity
- source type (parallel, point, ...) and position
- simulation options
- simulation of manufacturing errors by generation of random deviations of mirrors positions

## File menu

(any mirror position is allowed if it is defined in the file)

## Quick setup of main parameters

Movements of detector of 0.1mm, 1mm, 1cm, 1m

Generate demo optics for first usage by new users

Detector position		Source position	
x	0 mm	x	0 mm
y	0 mm	y	0 mm
z	0 mm	z	57.2958 mm
Detector resolution			
40 um			
Optics rotation			
yaw	0 deg		
pitch	0 deg		
axis	0 mm		

Use these parameters

Forgot these parameters

Center the spot (corner positions of reflections)

Clear the image

Run simulation (if "Auto run after data change" options is off)

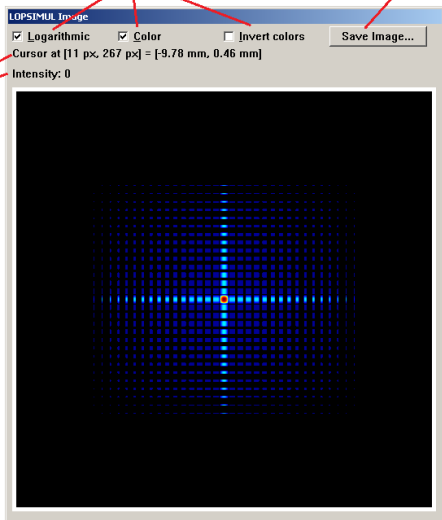
# LOPSIMUL - options

- ▶ Integrated generator of lobster optics, other optics can be imported via input datafile. The datafile contains position of vertices of mirrors.
- ▶ X-ray sources: parallel beam, point, linear, "flower 7"
- ▶ Few built-in models of reflectivity, any model of reflectivity can be imported to the program in the form of data table grazing angle vs. reflecting coefficient.

# LOPSIMUL - Image window

Imaging options

Save image dialogue



Currently, .bmp and .png formats are supported.

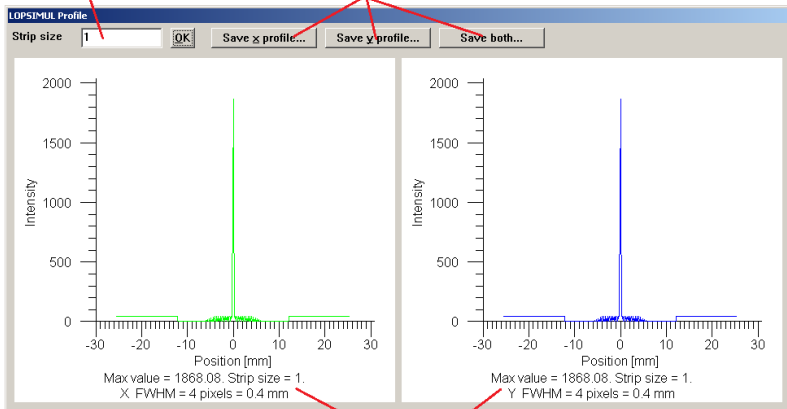
Data table as a text file that can be easily processed in other software is saved here, too.

When mouse cursor is moved over the image, detector and real coordinates of the corresponding point are shown together with intensity

# LOPSIMUL - Graphs window

Data can be filtered - intensity values can be replaced by average values of a strip of pixels of given size. If strip size is set to 1, this filtration is not applied.

Save dialogues (.bmp, .png and tables in a form of text files to be processed by other software)



Maximal value (after the filtration) and FWHM are calculated and displayed.

# LOPSIMUL - Results window

```
C:\prace_info\lopsimul.104a\bin\lopsimul.exe
-----
EVALUATION
-----

Channel 0 analysis:
Min refl      = -0.192899 nm  pixel:253
Max refl      =  0.192899 nm  pixel:257
MM effective collecting length =  9.96985 nm
MM width      =  0.5 nm
FWHM          =  0.3 nm

Channel 1 analysis:
Min refl      = -0.194562 nm  pixel:253
Max refl      =  0.194562 nm  pixel:257
MM effective collecting length =  9.20954 nm
MM width      =  0.5 nm
FWHM          =  0.3 nm

2D image analysis
MM spot integral = 9181.83
Peak at 10. 01nm = (255, 255) pixel on detector.
Peak at 10. 01nm in global coordinates.
Peak value=1860.88.

----- Spot of >10% of intensity of peak -----
Spot area      =  9 pixels =  0.09 nm^2
Spot integral   =  2347.58
Gain           =  928

----- FWHM spot -----
Spot area      =  5 pixels =  0.05 nm^2
Spot integral   =  6829.81
Gain           =  1286
```

Channel analysis gives

- ▶ Min refl, Max refl = border position of all reflections.
- ▶ MM effective collecting length = effective collecting length[2] related to the area bordered by Min rel and Max refl, i.e. by border rays that are reflected.
- ▶ MM width = width of focal image bordered by Min refl and max refl. It is not exactly equal to difference of Min refl and Max refl because of non-zero pixel size.
- ▶ FWHM = halfwidth of focal image.

# LOPSIMUL - Results

The analysis of full 2-D image gives:

- ▶ MM spot integral = sum of intensities of all pixels laying within area bordered by Min refl and Max refl. I. e. it is total intensity in a rectangular box bordered by all double-reflected rays.
- ▶ Peak position in pixel coordinates.
- ▶ Peak position in millimeters related to global coordinate system.
- ▶ Intensity of the peak.

For areas defined by FWHM and 10% rule, it is also calculated:

- ▶ Size of the area in pixels and square millimeters.
- ▶ Spot integral = sum of intensities of all pixels laying within this area.
- ▶ Gain



Where LOPSIMUL can be obtained?

- ▶ Downloaded at [www.lopsimul.eu](http://www.lopsimul.eu)

How much does it cost?

- ▶ Usage of LOPSIMUL is free of charge.

There is an ask, anyway:

- ▶ If results obtained by LOPSIMUL are published anywhere (e.g. in article, paper, thesis, report, etc.), users are asked to mention there that this program was used and that the program uses simplified ray-tracing algorithm published in *Exp. Astron.* (2016) 41:377-392; DOI 10.1007/s10686-016-9493-2. Include citation of this paper and program homepage [www.lopsimul.eu](http://www.lopsimul.eu), please.

THANK YOU FOR THE ATTENTION