Data processing for all-sky monitoring based on Lobster-eye optics

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Czech Technical University in Prague
Faculty of Electrical Engineering

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Framework Program
of the European Union
Grant Agreement No. 871158

Outline

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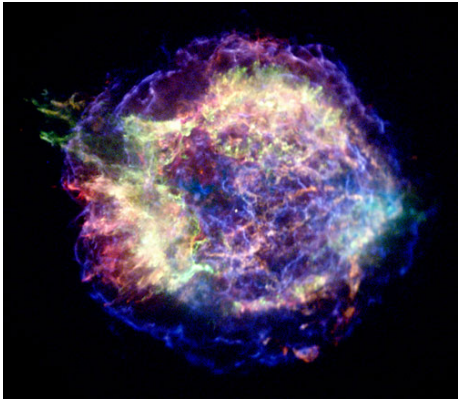
- Capture fast transients such as supernovae, gamma-ray bursts, etc.



NASA/CXC/MIT/UMass Amherst/M.D.Stage et al.

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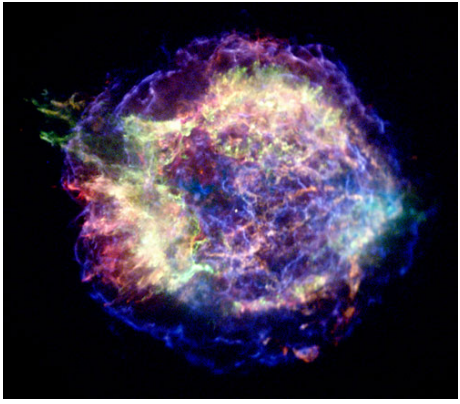

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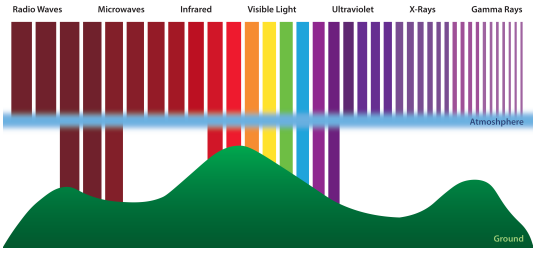

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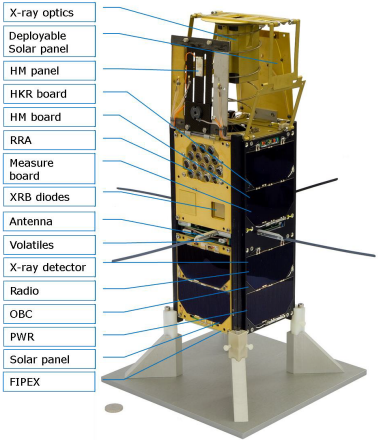

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- Create a wide field (all-sky) monitor for the X-ray spectrum
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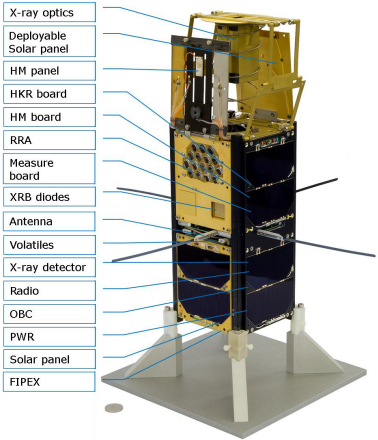
- Monitor placed on a satellite and send echo to more precise telescope
- Intended for use on small CubeSats such as VZLUSAT-1 with miniaturised lobster-eye optics.



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PyXLA: Python X-ray-tracing for Lobster-eye Application

- Software for simulating a Lobster-Eye optics
- Written in Python
- Can be used as a library or as a standalone application

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PyXLA: Steps

- Mirror stack creation

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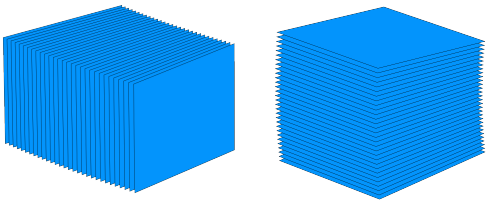
- Ray-tracing - Application execution

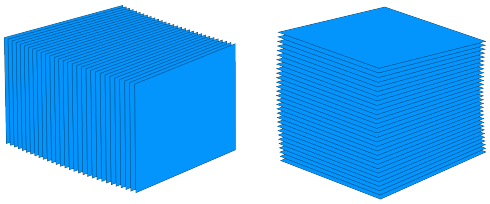
PyXLA: Mirror stack creation

- Number of mirrors



PyXLA: Mirror stack creation

- Number of mirrors
- Thickness, width, length and spacing



PyXLA: Mirror stack creation

- Number of mirrors
- Thickness, width, length and spacing
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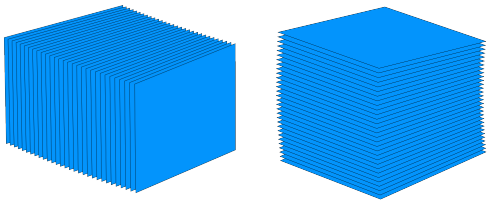

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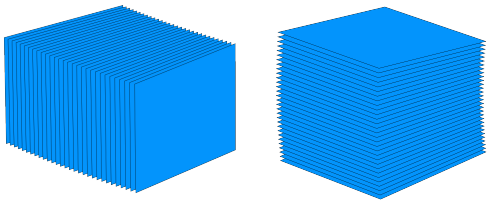
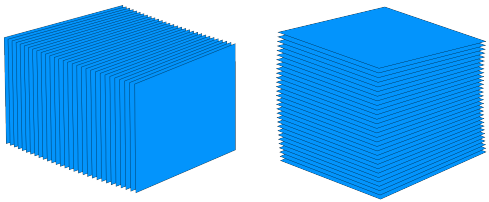
- Grazing angle of incidence can be specified as a data file or a fixed value for any angle (e.g. from CXRO library)



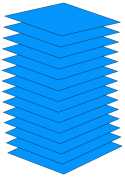
PyXLA: Mirror stack creation

- Number of mirrors
- Thickness, width, length and spacing
- Focal length
- Grazing angle of incidence can be specified as a data file or a fixed value for any angle (e.g. from CXRO library)
- Spatial position of the entire mirror stack according to application requirements



PyXLA: Detector

- Custom chip resolution from 1x1 pixel



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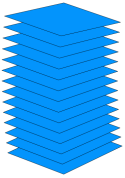

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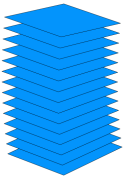
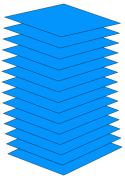


PyXLA: Detector

- Custom chip resolution from 1x1 pixel
- Variable pixel pitch which can be rectangular or square
- Variable detector position
- Predefined Timepix chips



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- Ray tracing principle
- Source is treated as an array of rays with defined spacing
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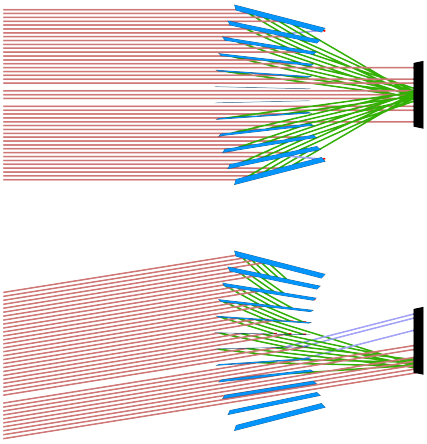
- Source/s can be placed in 3D space to simulate real constellation

PyXLA: Simulation

- REX – Rocket EXperiment



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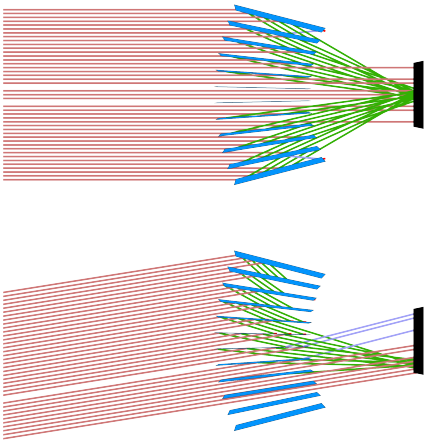
PyXLA: Simulation

- REX – Rocket EXperiment
- 1D Lobster-eye optics
  (150 mm× 75 mm× 0.35 mm)



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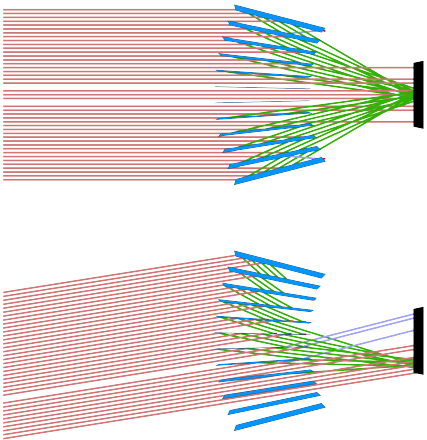

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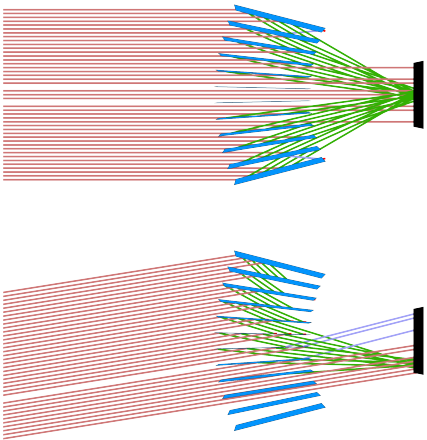

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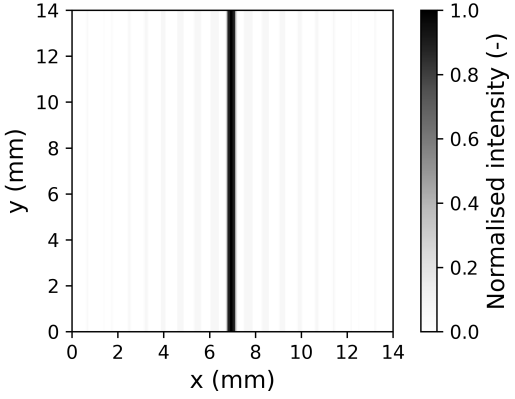

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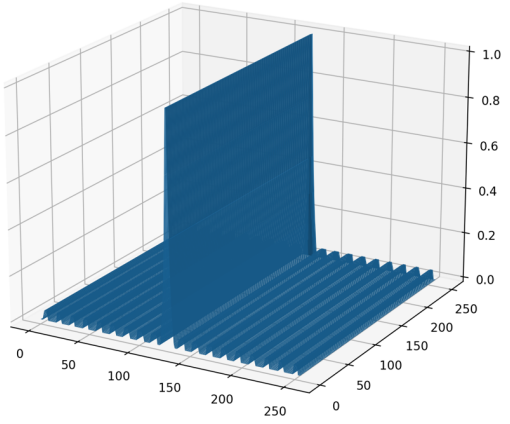

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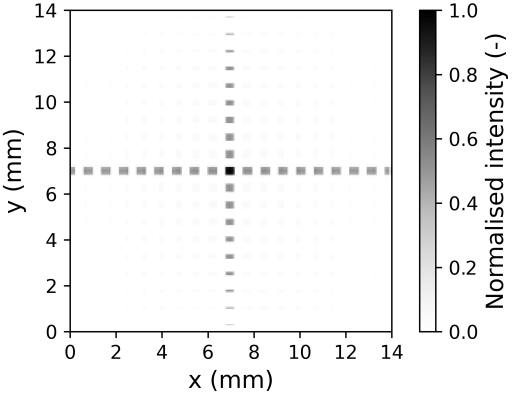

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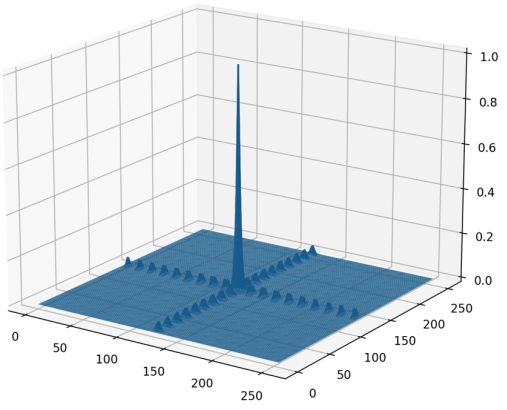

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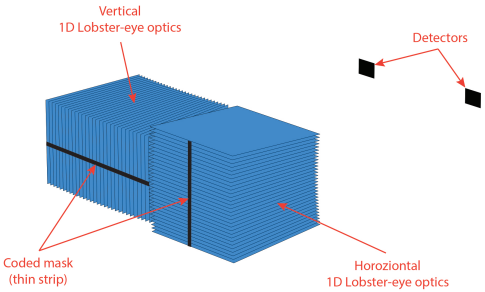

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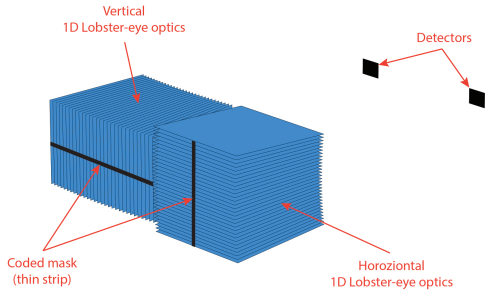
- Ability to simulate a Lobster-Eye optics with a rectangular detector
- Possible to add a coded mask



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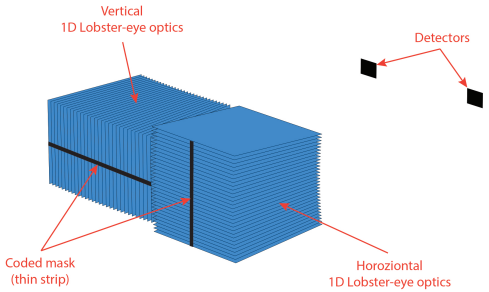
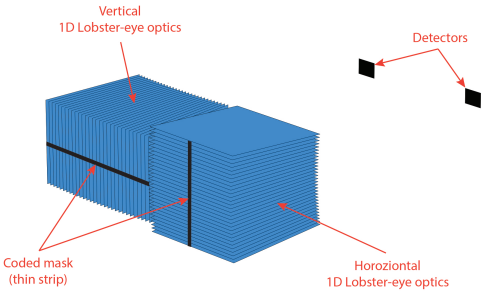


PyXLA: Usage

- Ability to simulate a Lobster-Eye optics with a rectangular detector
- Possible to add a coded mask
- Ability to simulate several sources with different intensity
- A system with more than one detector must be simulated separately



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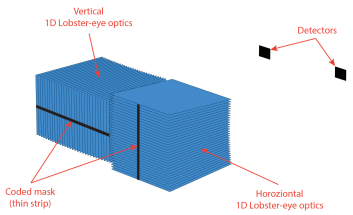
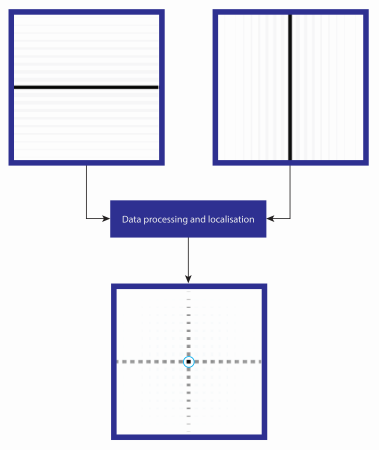
Point Source Localisation: Idea

- Localisation of point sources directly on-board of a Cubesat





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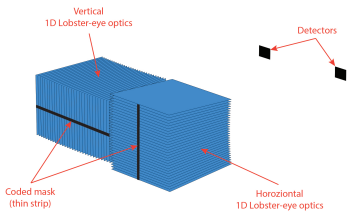
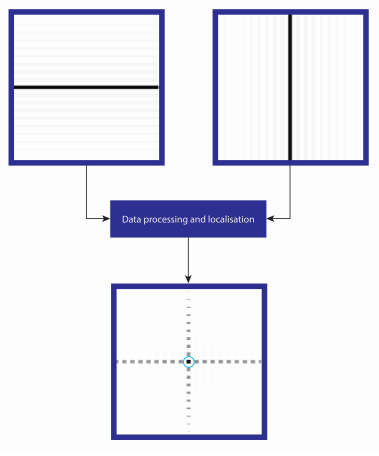
Point Source Localisation: Idea

- Localisation of point sources directly on-board of a Cubesat
- Using two independent 1D Lobster-Eye optics and two detectors





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Point Source Localisation: Idea

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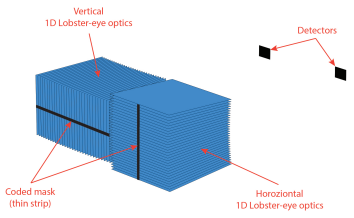
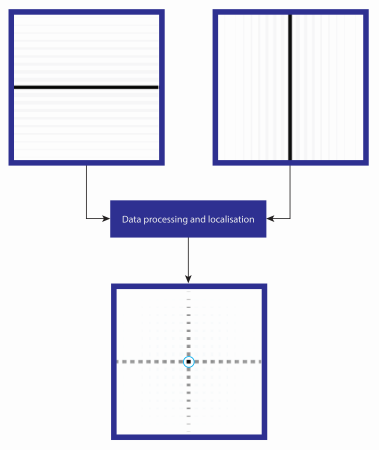
- Using two independent 1D Lobster-Eye optics and two detectors
- Post-processing of the two images





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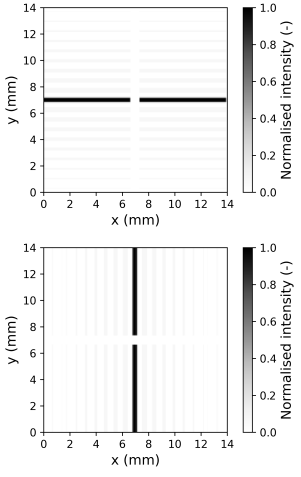
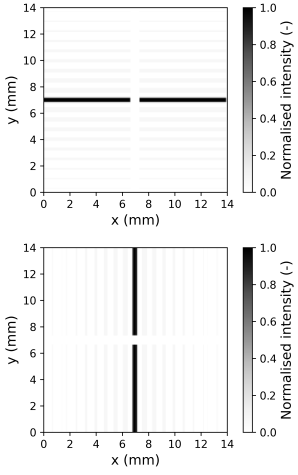
Point Source Localisation: Input images

- Images from two independent 1D Lobster-Eye optics



Point Source Localisation: Input images

- Images from two independent 1D Lobster-Eye optics
- Coded mask for more precise point source localisation



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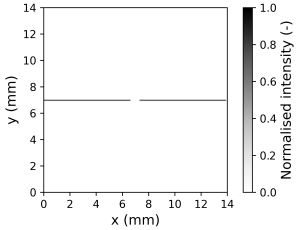
- Deconvolved input images with PSF for each image



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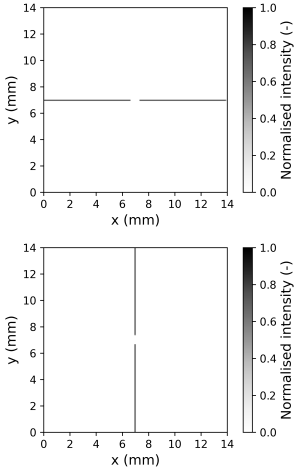

Point Source Localisation: Data-Processing - First Approach

- Images from two independent 1D Lobster-Eye optics
- Coded mask for more precise point source localisation
- Deconvolved input images with PSF for each image $\rightarrow \mathbf{H}, \mathbf{V}$
- Matrix multiplication of both images to get the potential point sources ($\mathbf{I}$)

Potential position

$$\mathbf{I} = \mathbf{H} \times \mathbf{V}$$

Point Source Localisation: Data-Processing - First Approach

- Images from two independent 1D Lobster-Eye optics
- Coded mask for more precise point source localisation
- Deconvolved input images with PSF for each image $\rightarrow \mathbf{H}, \mathbf{V}$
- Matrix multiplication of both images to get the potential point sources ($\mathbf{I}$)
- Create a binary mask ($\mathbf{B}$)

Potential position

$$\mathbf{I} = \mathbf{H} \times \mathbf{V}$$

Binary mask creation

$$\mathbf{A} = \mathbf{H} \cdot \mathbf{V}$$

$$\mathbf{B}(x, y) = \begin{cases} 0, & \text{if } \mathbf{A}(x, y) > T \\ 1, & \text{otherwise} \end{cases}$$

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- Resulting image ($\mathbf{R}$)

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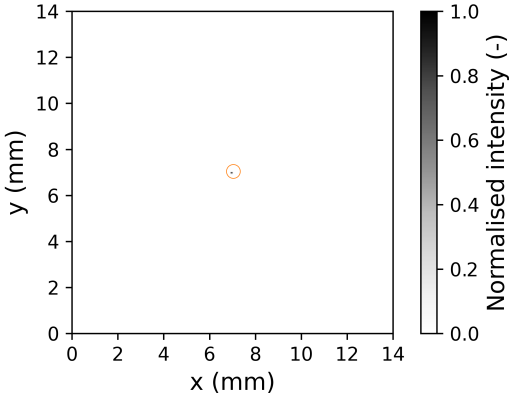
Resulting image

$$\mathbf{R} = \mathbf{I} \cdot \mathbf{B}$$

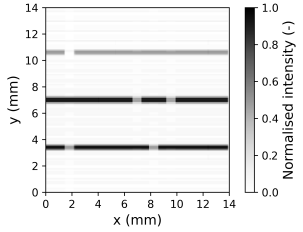
Point Source Localisation: Issues

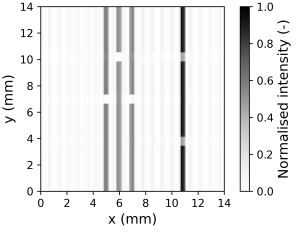
- Trivial for one point source in FOV



Point Source Localisation: Issues

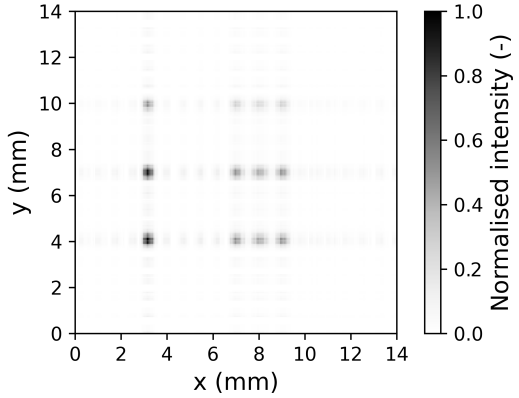
- Trivial for one point source in FOV
- Difficult for multiple sources after matrix multiplication





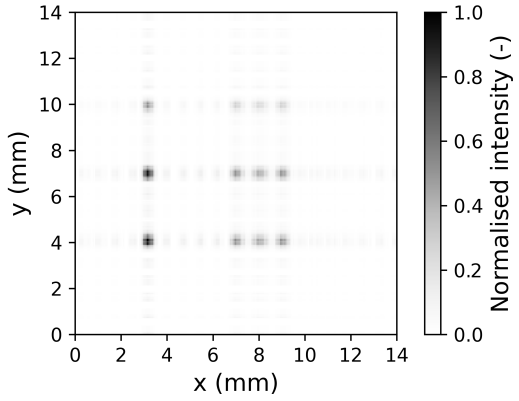
Point Source Localisation: Issues

- Trivial for one point source in FOV
- Difficult for multiple sources after matrix multiplication
- Real and virtual sources in the potential source image ($\mathbf{I}$)



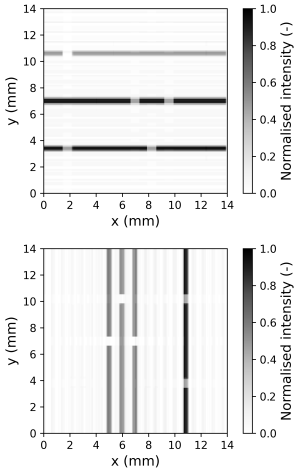
Point Source Localisation: Issues

- Trivial for one point source in FOV
- Difficult for multiple sources after matrix multiplication
- Real and virtual sources in the potential source image (**I**)
- Necessary to improve the algorithm



Point Source Localisation: Min/Max Search

- Line focus gives H/V direction



O. Nentvich, M. Urban, et al. “Lobster eye optics: Position determination based on 1D optics with simple code mask”. In: vol. 11108. 2019. ISBN: 9781510629097. DOI: 10.1117/12.2528505

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- Line focus gives H/V direction
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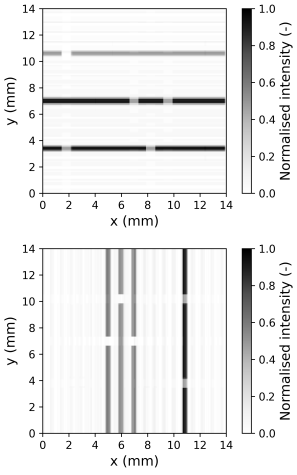

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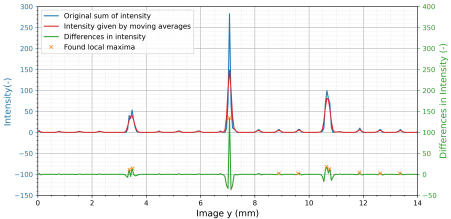

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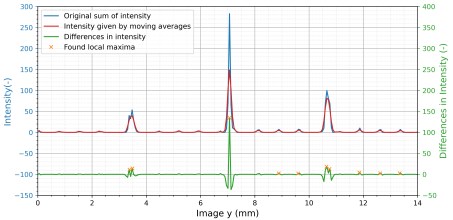
- Moving averages for a low photon count



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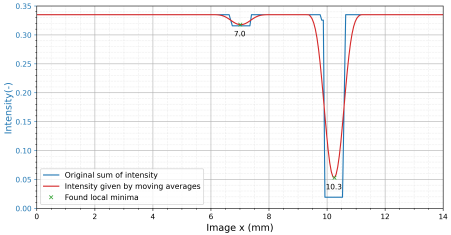
- Search for local minima in the gaps



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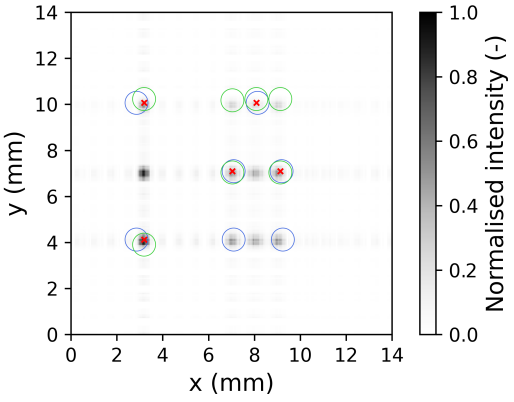
- Find all possible locations of point sources



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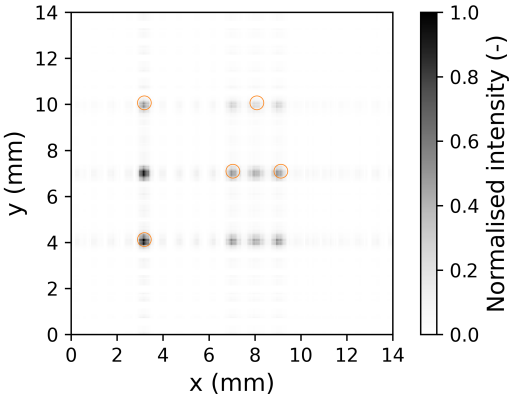

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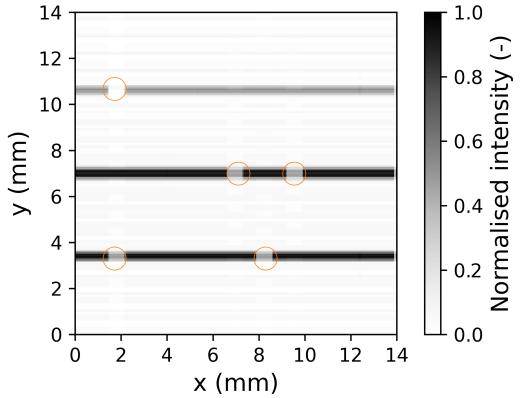
- Search for local minima in the gaps
- Find all possible locations of point sources
- Is one image enough?



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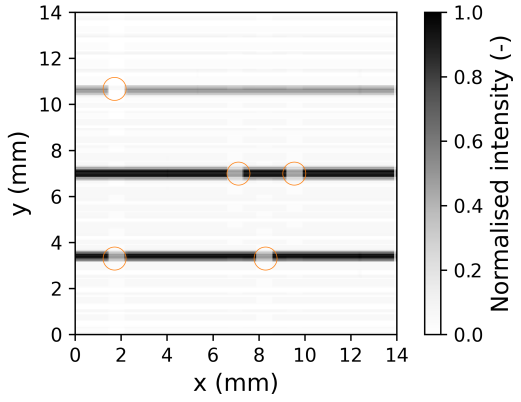
- Moving averages for a low photon count
- Search for local minima in the gaps
- Find all possible locations of point sources
- Is one image enough?
- Not for precise determination



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Outline

Conclusion

- Presented two topics which I have been worked on

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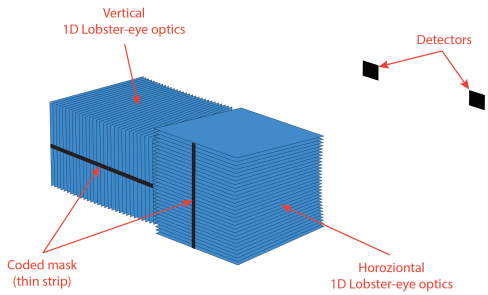
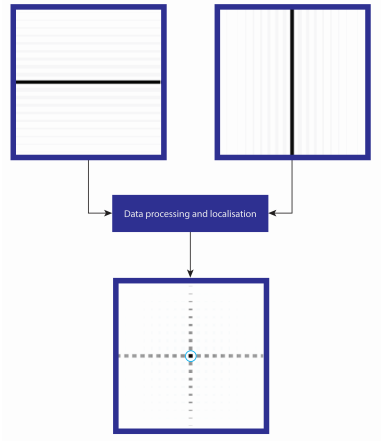
- PyXLA – simulation software for Lobster-Eye optics



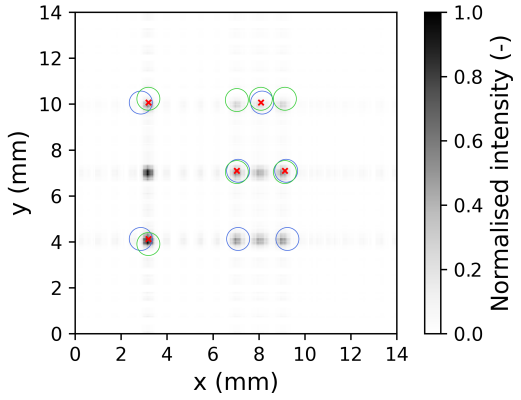
Conclusion

- Presented two topics which I have been worked on
- PyXLA – simulation software for Lobster-Eye optics
- Processing the images from two independent Lobster-Eye optics



Conclusion

- Presented two topics which I have been worked on
- PyXLA – simulation software for Lobster-Eye optics
- Processing the images from two independent Lobster-Eye optics
- Point source localisation by using two algorithm



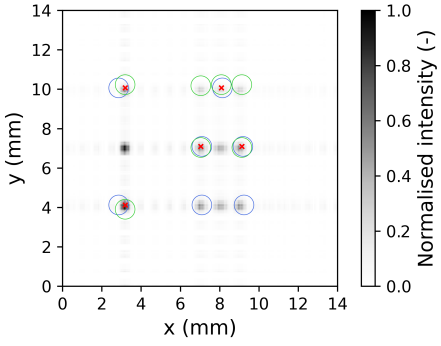
Thank you for your attention

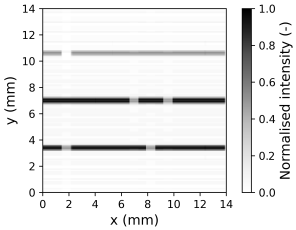
Questions?

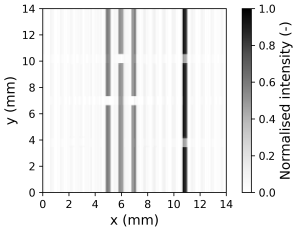
Outline

Comparison of Different Intensities

- Uniform Source

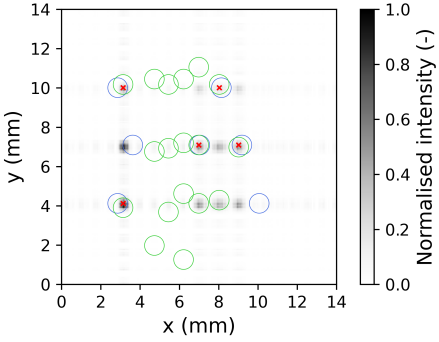


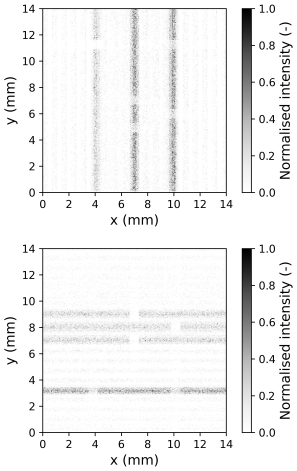




Comparison of Different Intensities

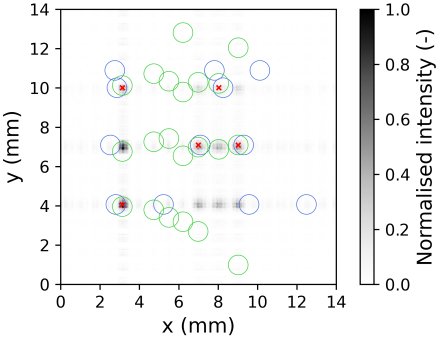
- approx. 50 000 photons

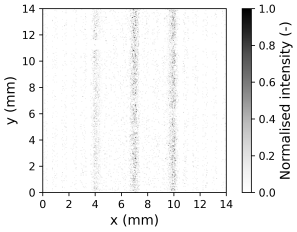


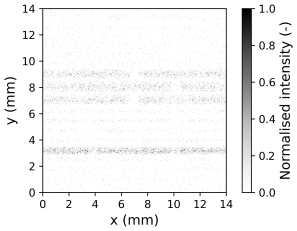


Comparison of Different Intensities

- approx. 10 000 photons

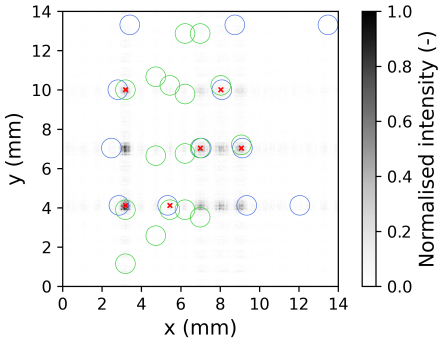


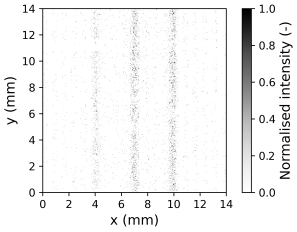


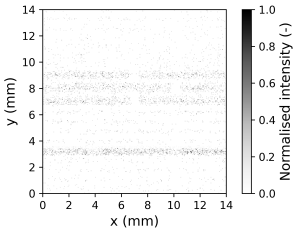


Comparison of Different Intensities

- approx. 5000 photons







Comparison of Different Intensities

- approx. 1000 photons