EUROPEAN UNION

Structural Instruments 2014-2020

Competitiveness Operational Programme (COP)

Extreme Light Infrastructure - Nuclear Physics (ELI-NP) – Phase II

Large aperture LIDT data analysis: preliminary results and current work

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With special thanks to:

Daniel Ursescu, Dan Matei, Gabriel Bleotu, Chauvin Adrien (ELI Beamlines), Daniel Kramer (ELI Beamlines)

eli nuclear physics

IFIN-HH

Motivation & previous work in literature

nuclear physics

Motivation & previous work in literature (1)

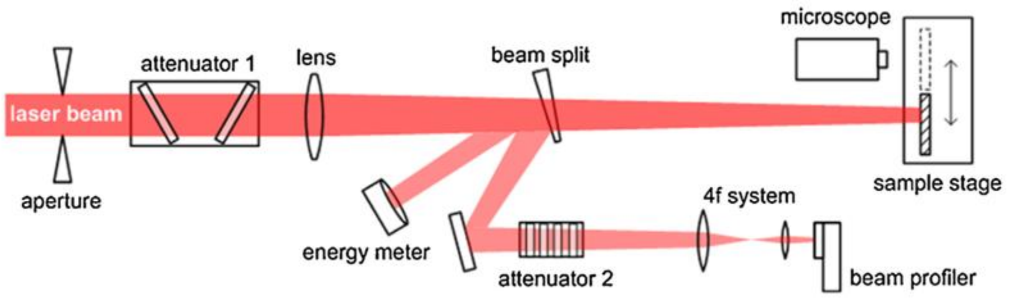


Fig. 1. The structure of single-shot LIDT test bench.

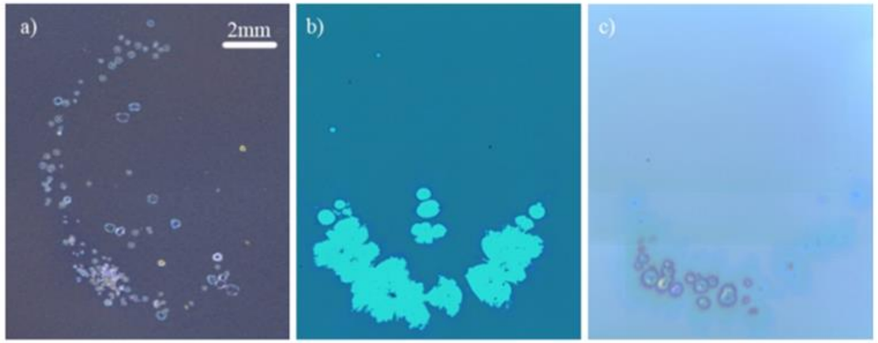


Fig. 5. The typical damage images of (a) HfO_2/SiO_2, (b) HfO_2/Al_2O_3 and (c) Ta_2O_5/SiO_2 under CCD microscopy with single-shot.

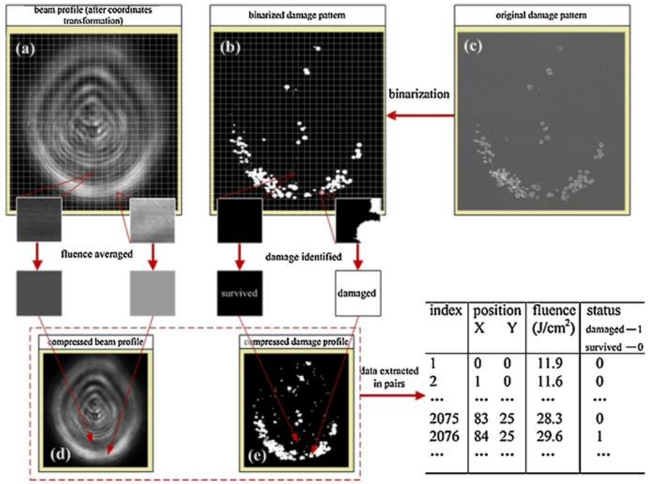


Fig. 4. The damage information extraction procedure. Compression process is performed on the beam profile (a) and damage pattern (b, c). By matching the compressed image of beam profile (d) and damage pattern (e), the damage information could be obtaind.

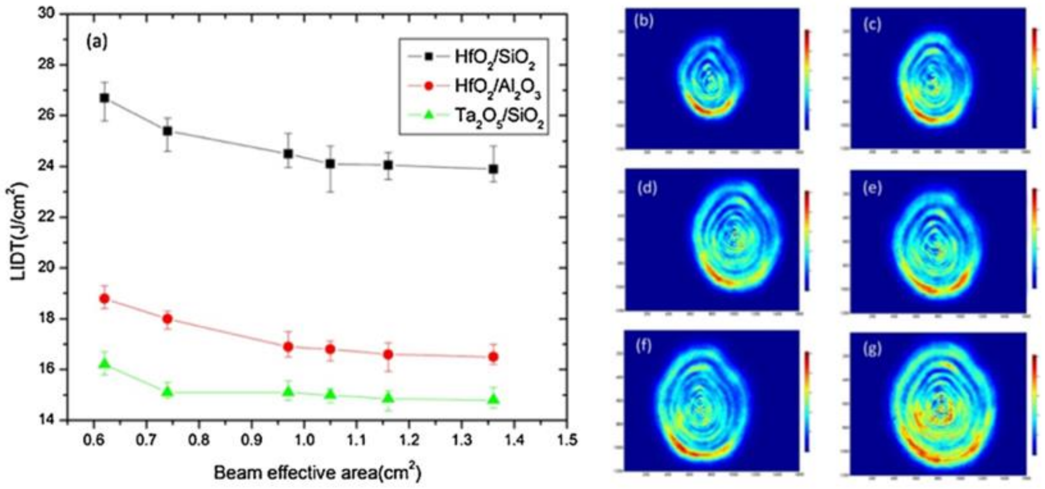


Fig. 10. The relationship between LIDTs and beam size on three type coatings.

Z. Liu, Y. Zheng, F. Pan, Q. Lin, P. Ma, and J. Wang, “Investigation of laser induced damage threshold measurement with single-shot on thin films,” *Applied Surface Science*, vol. 382, pp. 294–301, Sep. 2016, doi: 10.1016/j.apsusc.2016.04.093.

Motivation & previous work in literature (2)

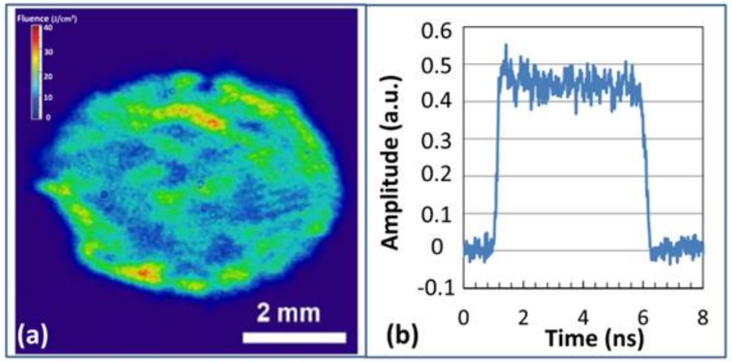


FIG. 3. (a) Spatial profile of the 7.3 mm diameter beam at the sample plane as measured by a CCD camera. The beam contrast is about 20%. (b) The corresponding typical Flat-In-Time (FIT) temporal profile at 351 nm of around 5 ns.

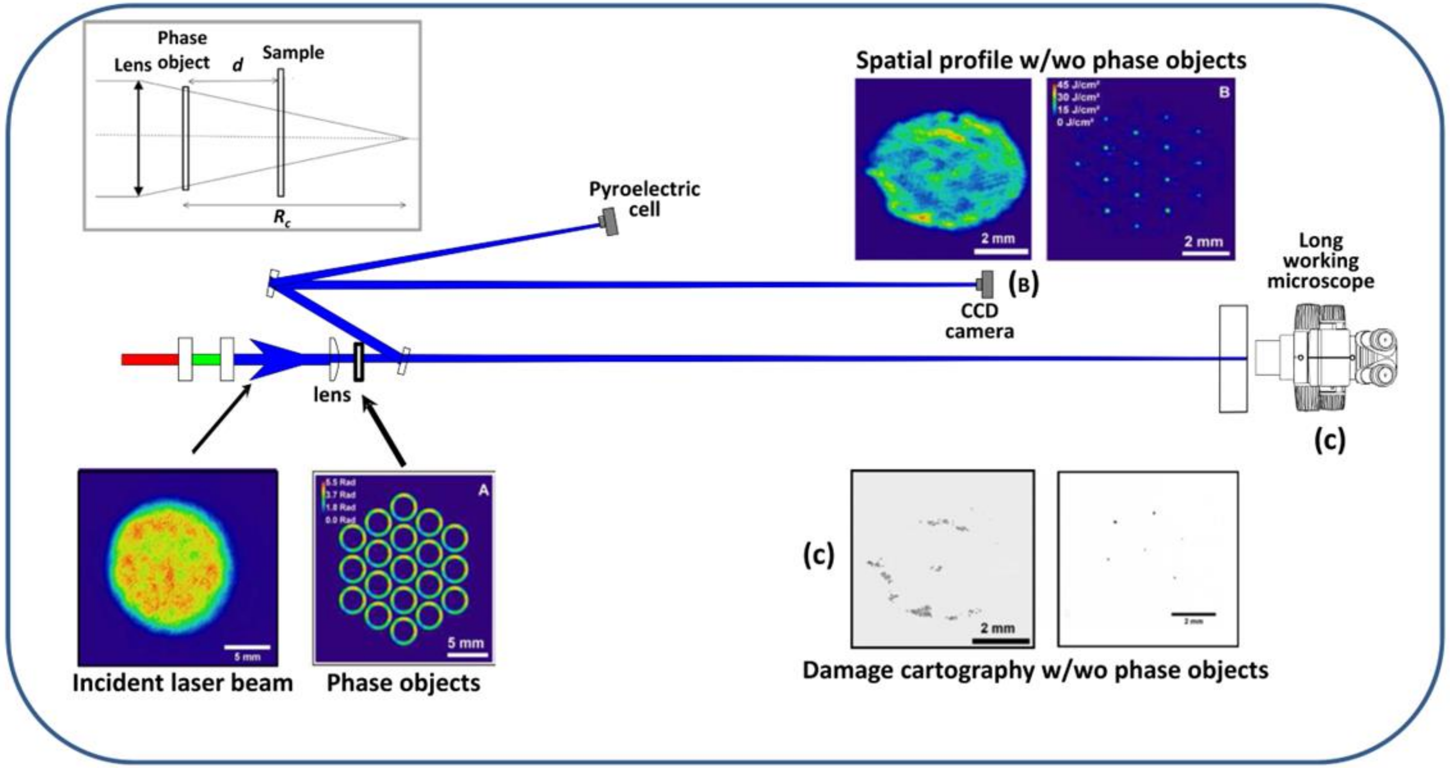
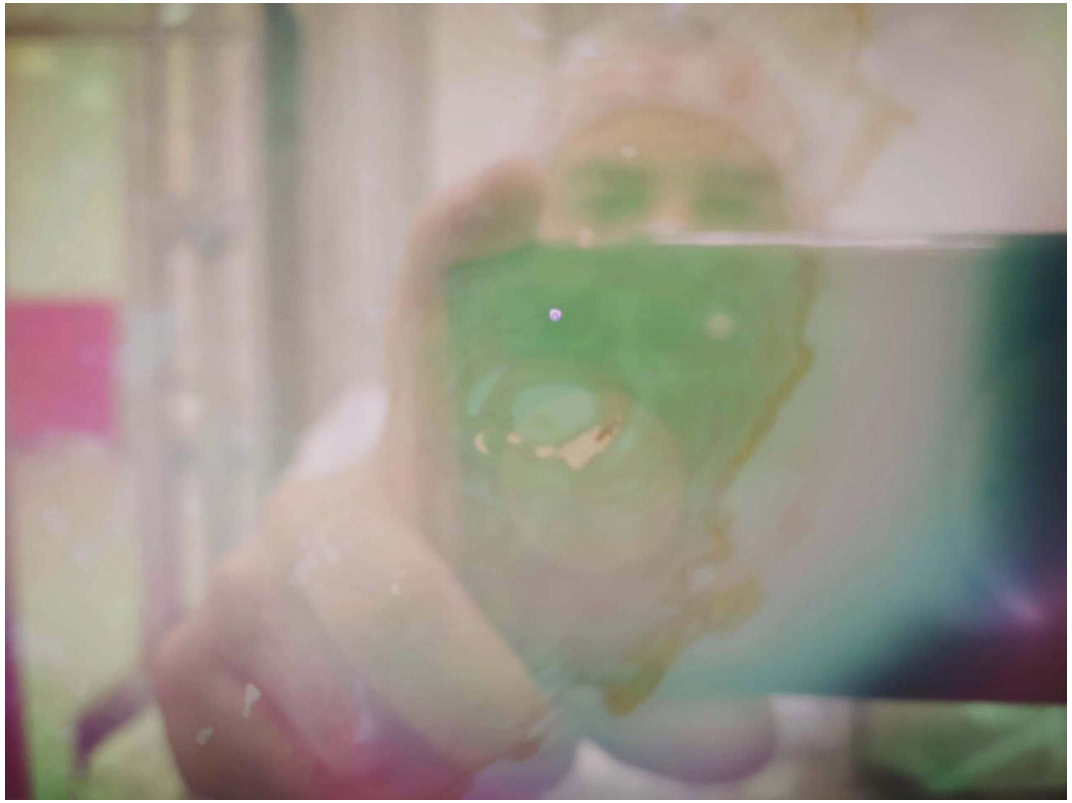


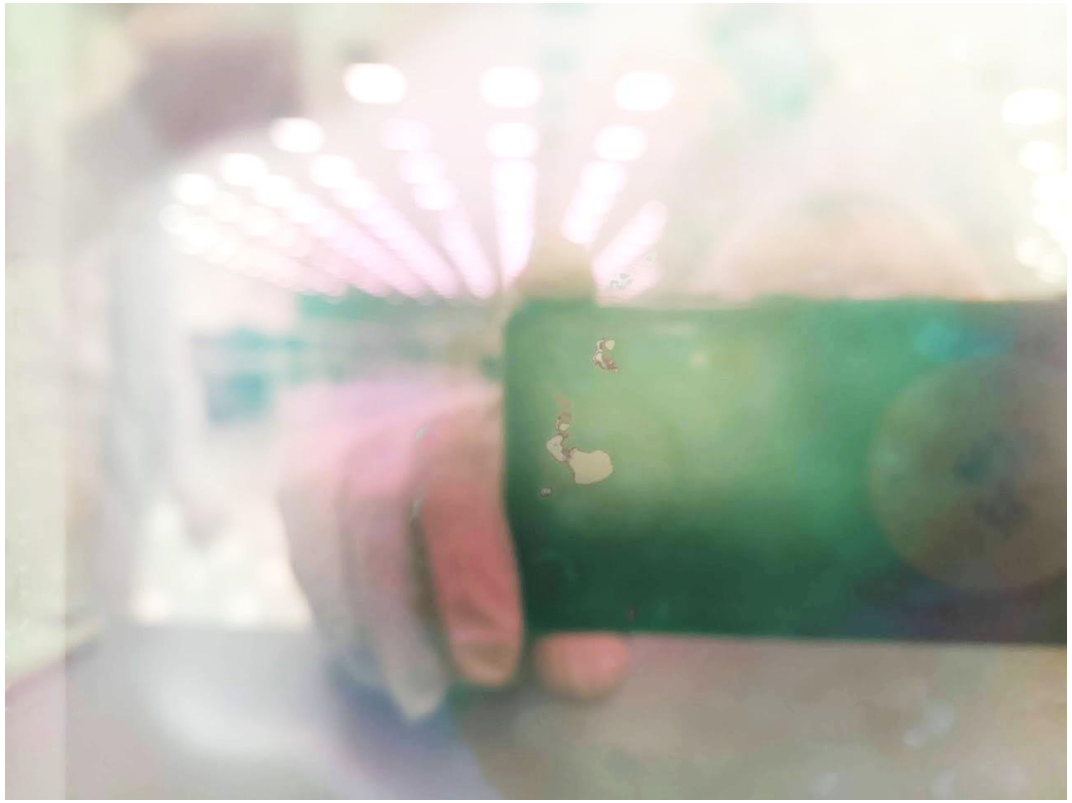
FIG. 2. Simplified experimental setup: Phase objects (A) are inserted between the focusing lens and a beam splitter that directs a part of the beam to diagnostics. A CCD camera (B) records the spatial profile on a plane equivalent to the sample plane. After each shot a long working distance microscope observes the irradiated area (C). The inset illustrates the focusing beam and the main distances.

L. Lamaignère et al., “A powerful tool for comparing different test procedures to measure the probability and density of laser induced damage on optical materials,” *Review of Scientific Instruments*, vol. 90, no. 12, Art. no. 12, 2019, doi: 10.1063/1.5122274.

Lack of knowledge can be... expensive



Diffraction pattern shaped damage

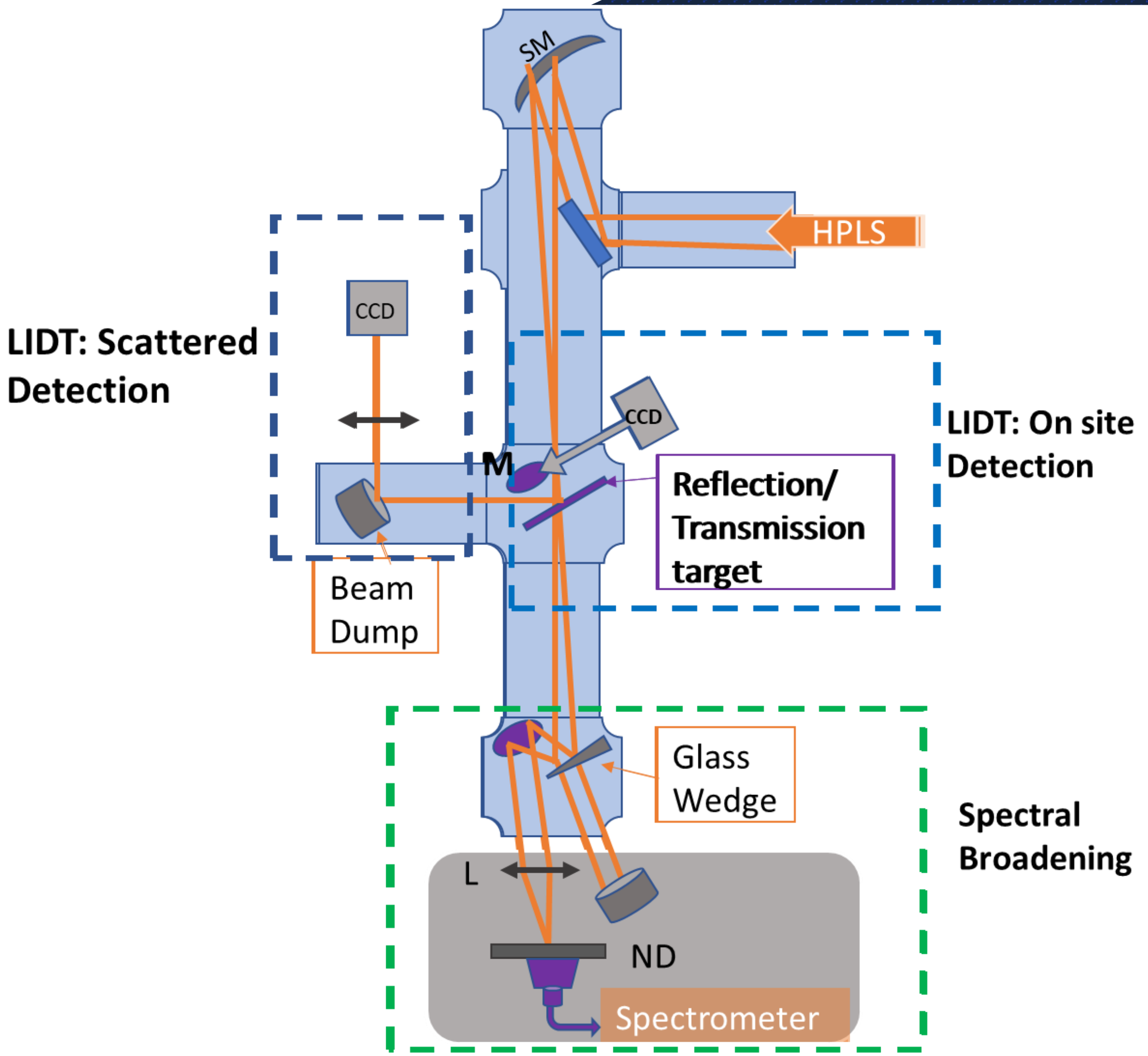


Small exfoliation

Large aperture LIDT is mandatory!

Experimental setup

Experimental setup



Detection methods for LIDT:
Microscope (large spots)
Nomarski Microscope

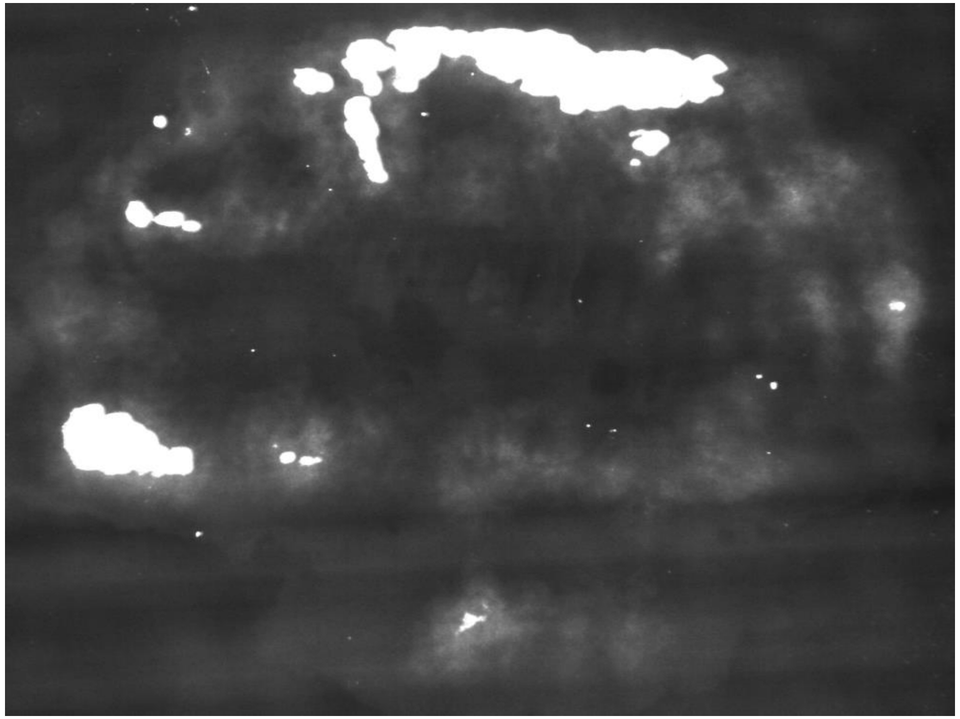
Samples:
Mirror 1 (Ag+3 layers SiTiO2), Mirror 2 (Ag+1 layer SiO2), 2 Chirped mirrors, FS, IDEX 2, IDEX 4, LASEROPTIK, Optoman, Optosigma, ZEONOR

Nr of shots: 1,10, 100, 1000, 10000
Energy: 8 mJ-160 mJ
Spot size: 3-7 mm
Pulse duration: 25 fs
Parabola 1.2 m

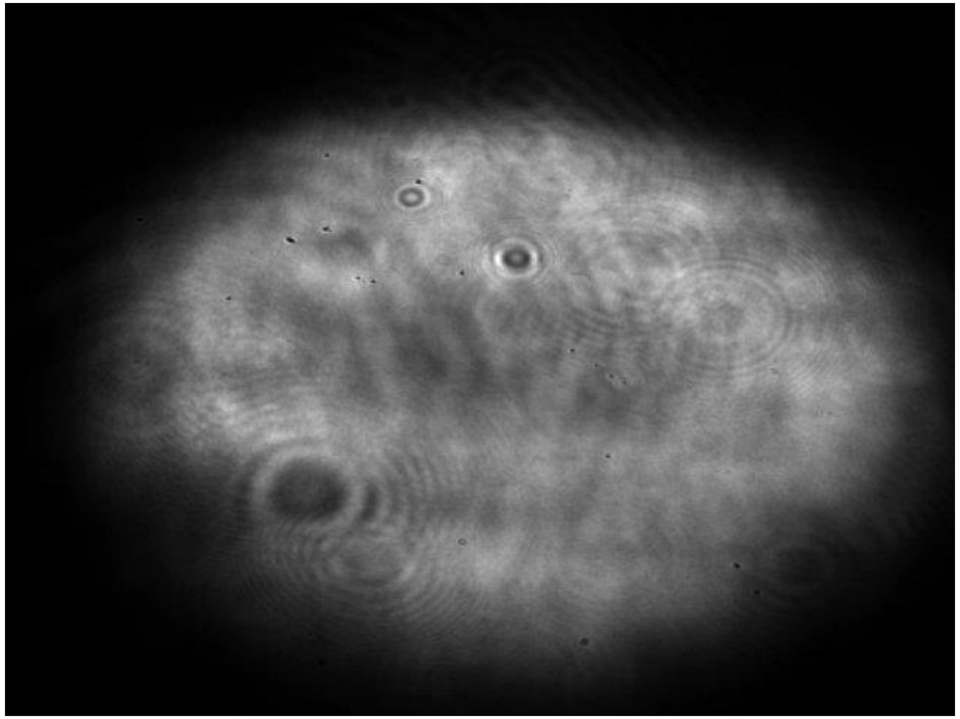
Experimental team: Gabriel Bleotu, Alice Dumitru, Cristian Alexe, Andrei Naziru, Stefan Popa, Dan Matei, Daniel Ursescu (ELI-NP), Tamas Somoskoi (ELI-ALPS)

Preliminary data analysis

Initial images



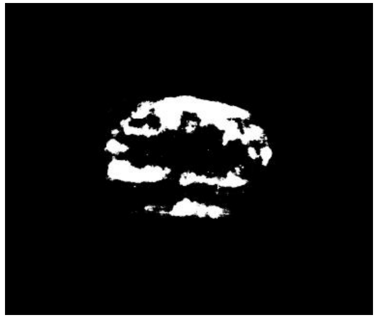
Damage image (from optical microscope)



Laser beam profile

LIDT data analysis: program components

Damage



Binarising

Bordering

Overlap analysis

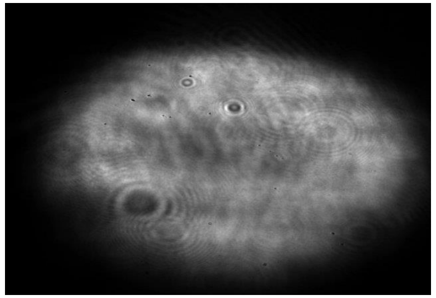
Rotation

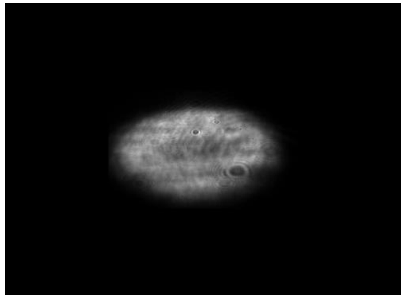
Bordering

Resizing

Translation

Laser





LIDT data analysis: resizing

Why?

- This ensures the profiles are of the same size, as the camera pixel size can differ from the size on the detector.

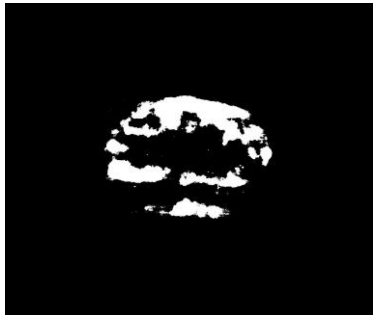
What?

- This algorithm finds the optimal parameters for resizing (with reference (0,0)) the laser intensity profile.

How?

- Variables to optimise: resizing parameters, intensity threshold.

LIDT data analysis: program components



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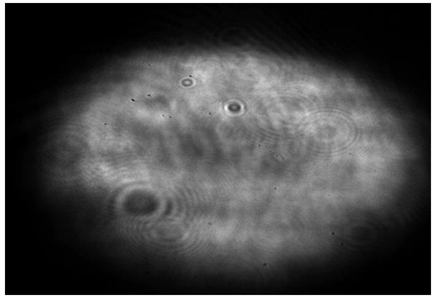
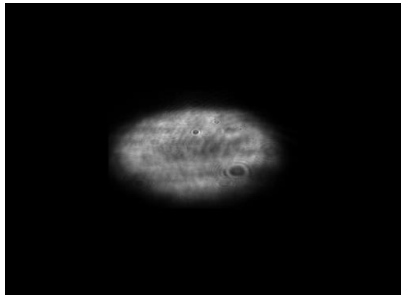
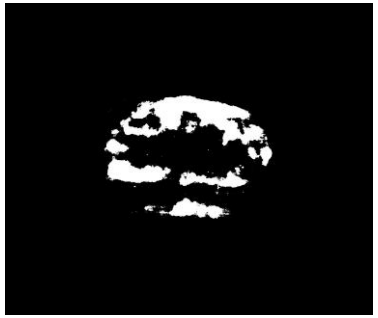




LIDT data analysis: program components



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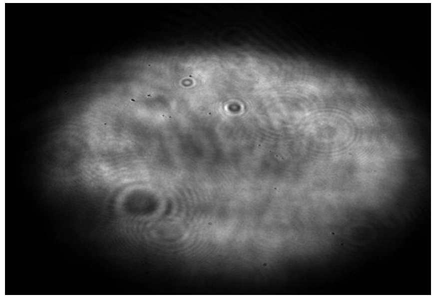
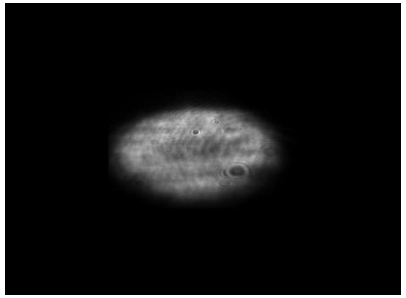
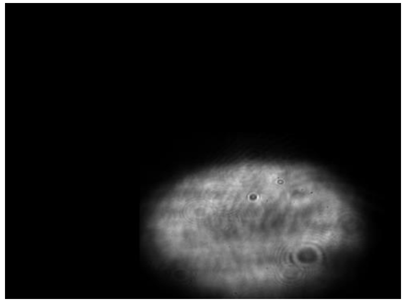






LIDT data analysis: translating

Why?

- This ensures that for the data analysis part of the algorithm, the two images match in position.

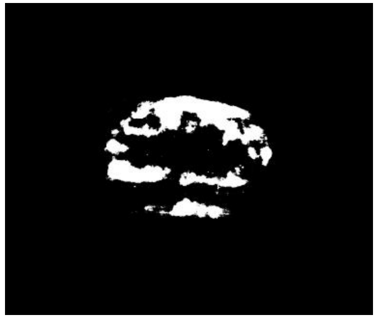
What?

- This algorithm finds the optimal parameters for translation.

How?

- The variable to be optimized: number of laser pixels above intensity threshold matching with damaged pixels.

LIDT data analysis: program components



Binarising

Bordering

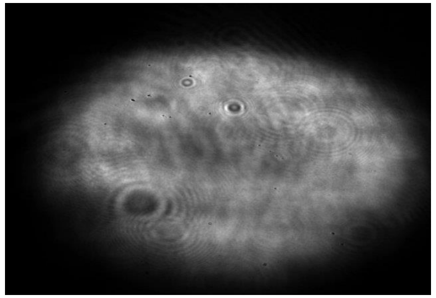
Overlap analysis

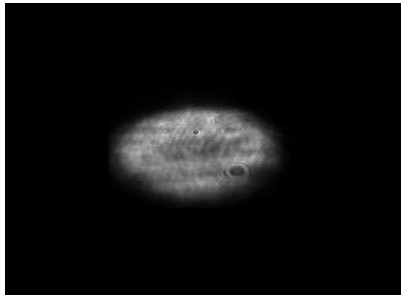
Rotation

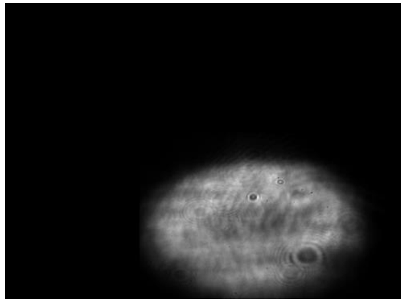
Bordering

Resizing

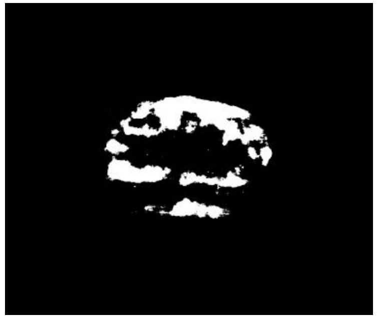
Translation







LIDT data analysis: program components



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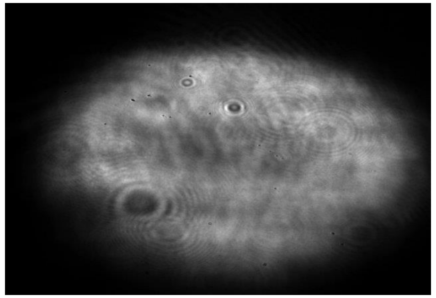
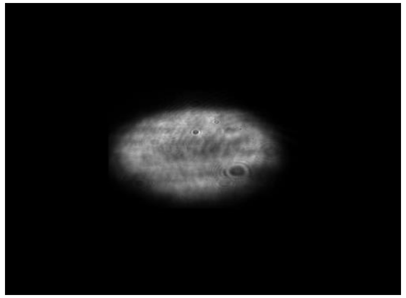
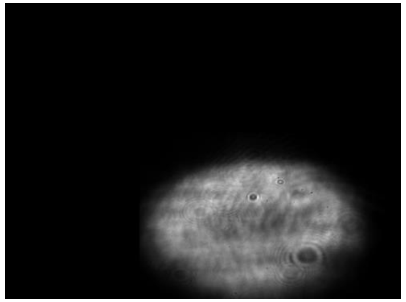
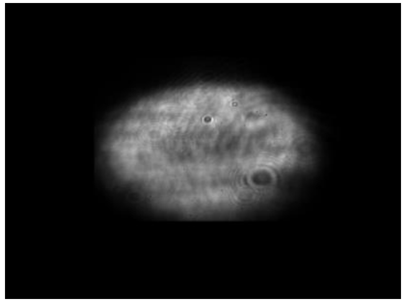
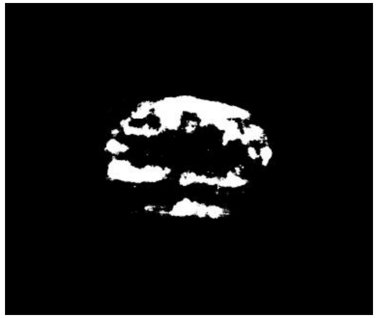








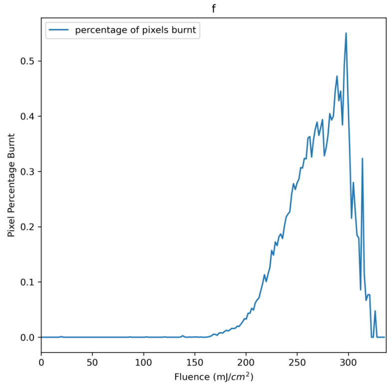
LIDT data analysis: program components



Binarising

Bordering

LIDT curve



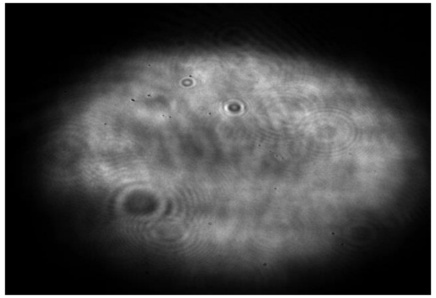
Overlap analysis

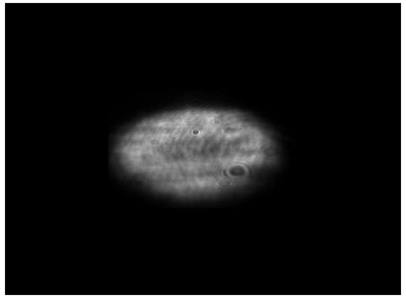
Rotation

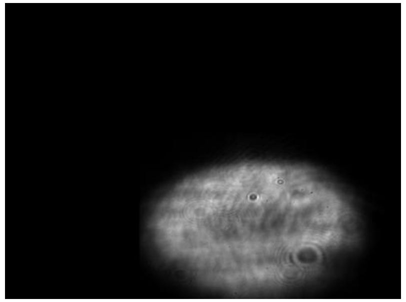
Bordering

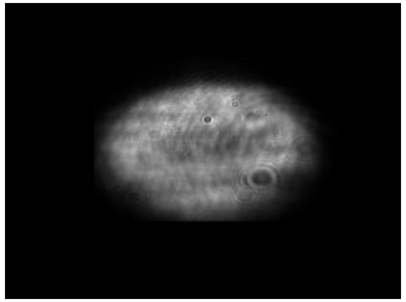
Resizing

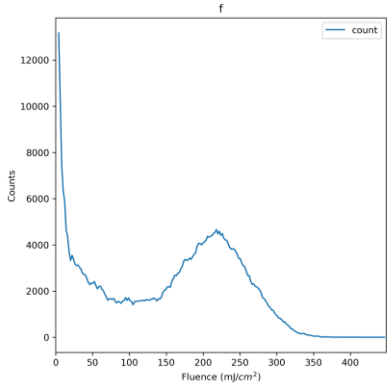
Translation









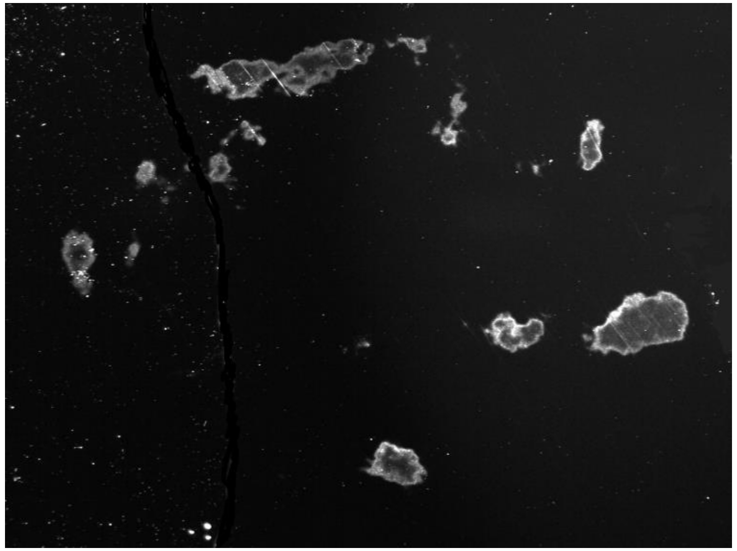
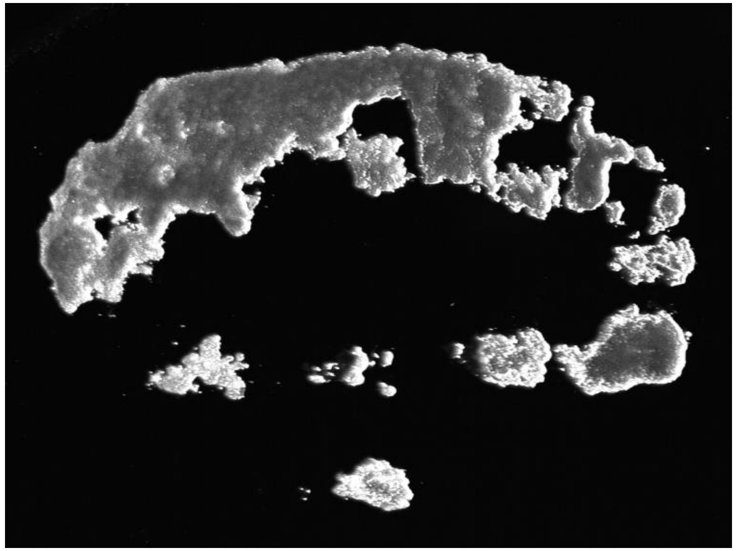
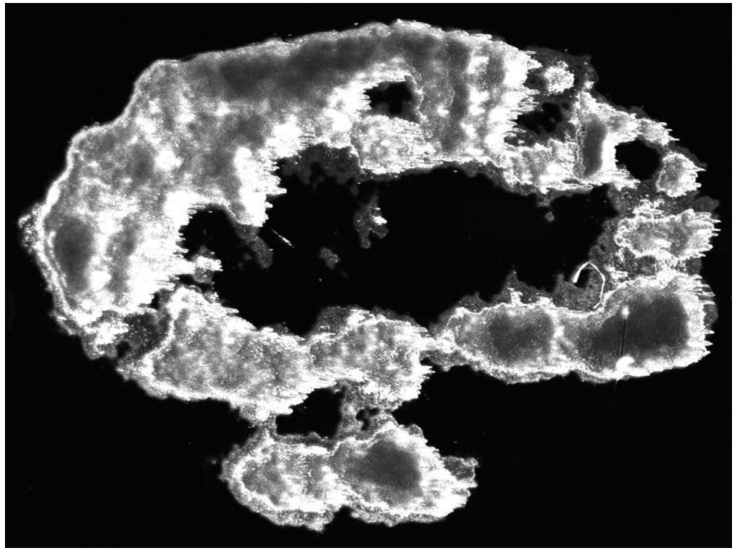


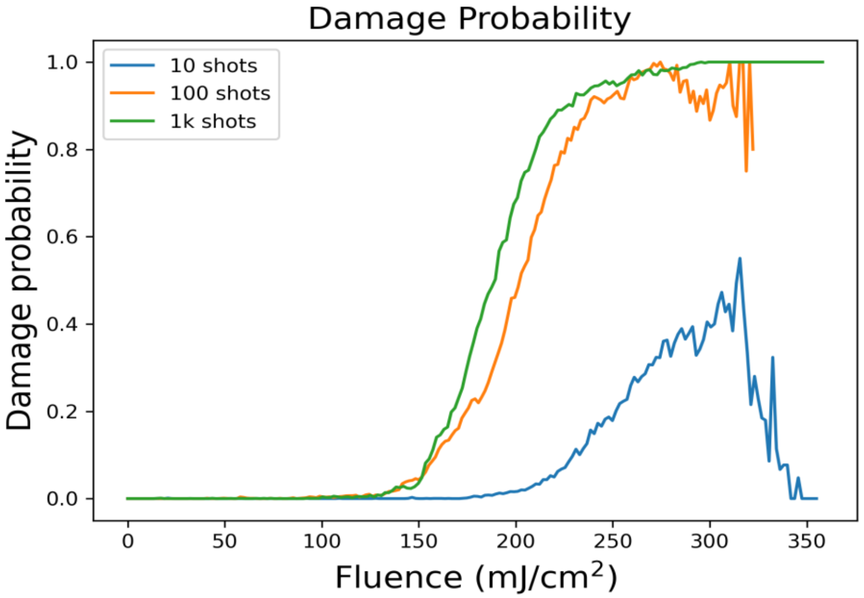
Laser profile histogram

LIDT data analysis: samples used

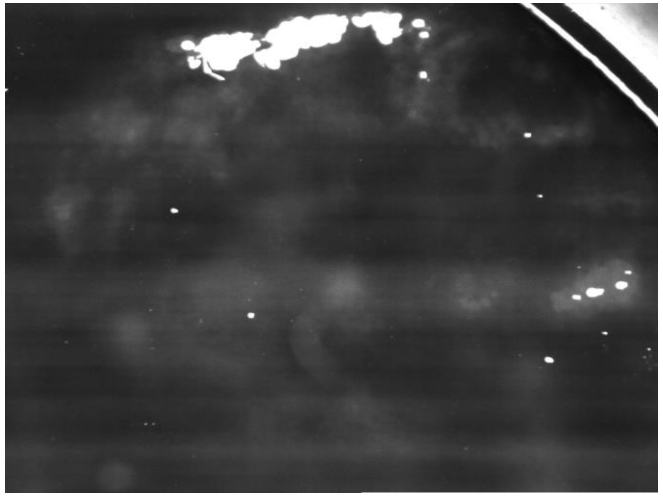
Sample Analysed	Number of shots	Observations
Ag (SiO_2)	10	The damage profile was well defined, hence the LIDT curves were less noisy and with much clearer boundaries between damaged and undamaged.
Ag (SiO_2)	100	
Ag (SiO_2)	1000	
CMHT	500	Due to less well defined damage (and poorer picture quality), the curves are also less well defined and have a lot more noise.
CMHT	1000	
CMHT	10000	

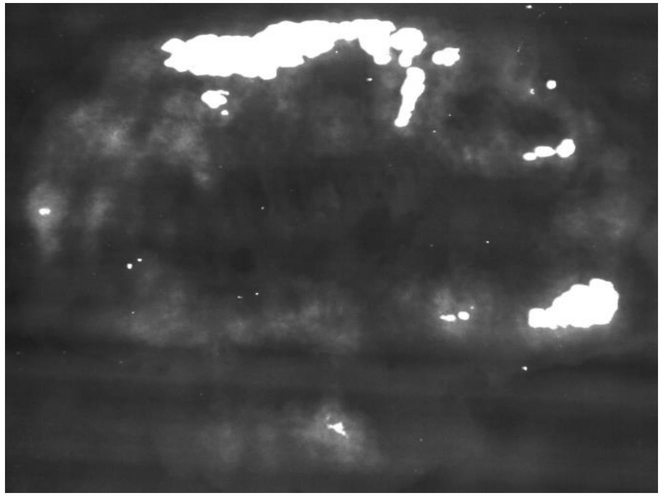
Ag (SiO_2): 10, 100, 1k shots

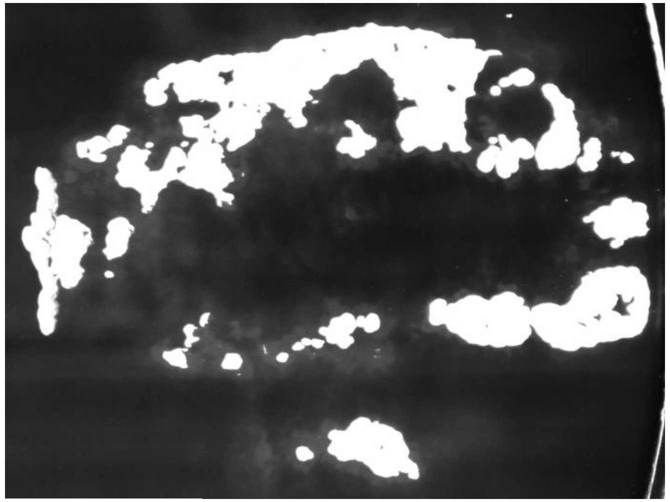




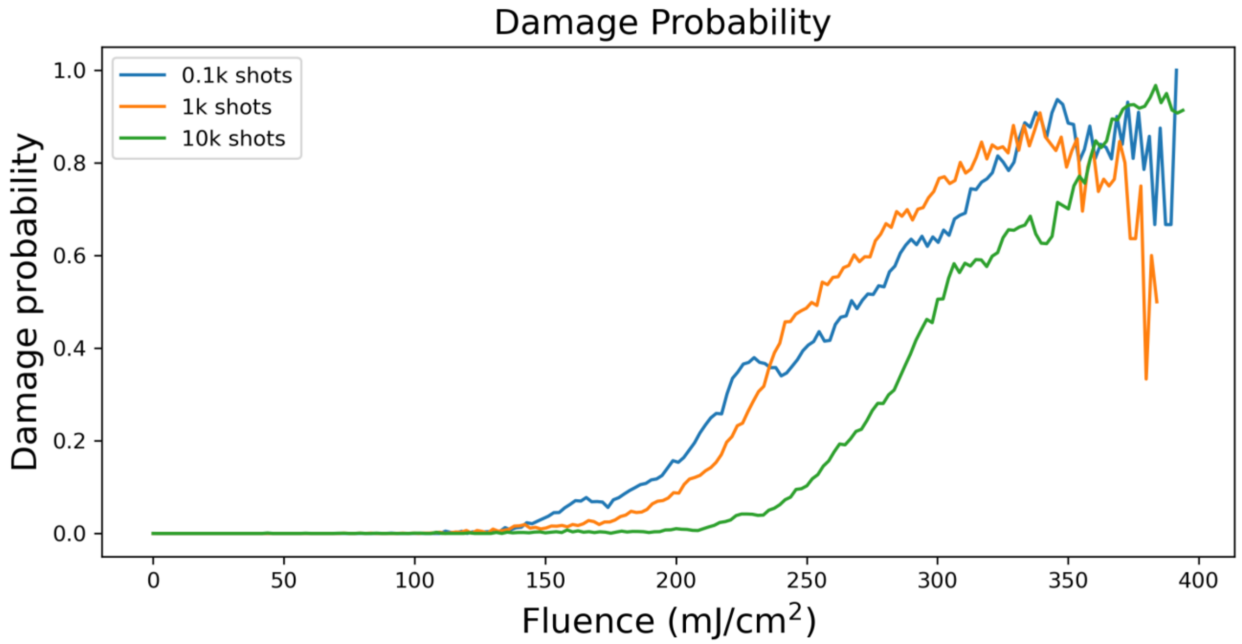


CMHT: 500, 1k, 10k shots



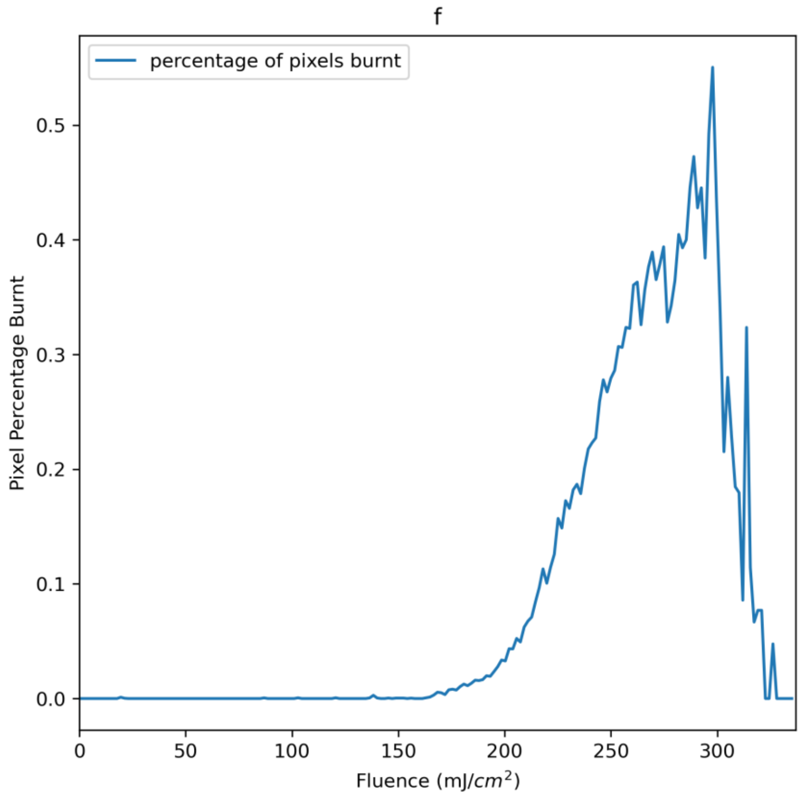


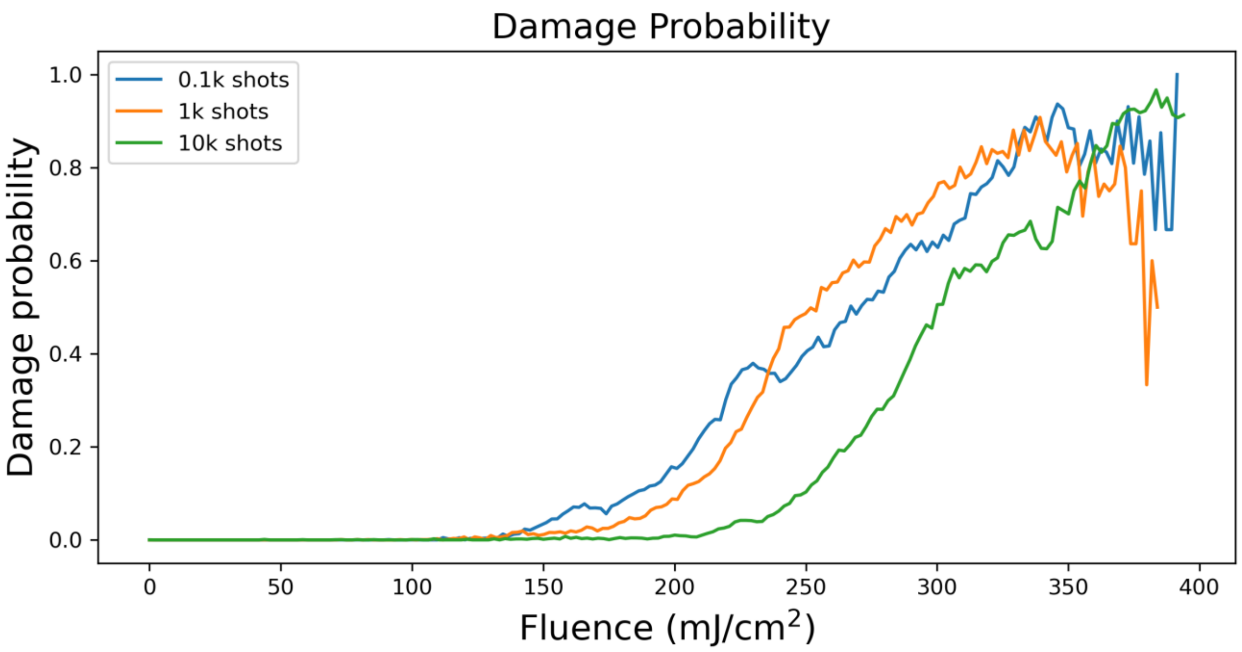




LIDT data analysis: limitations

- Current results are promising, but…





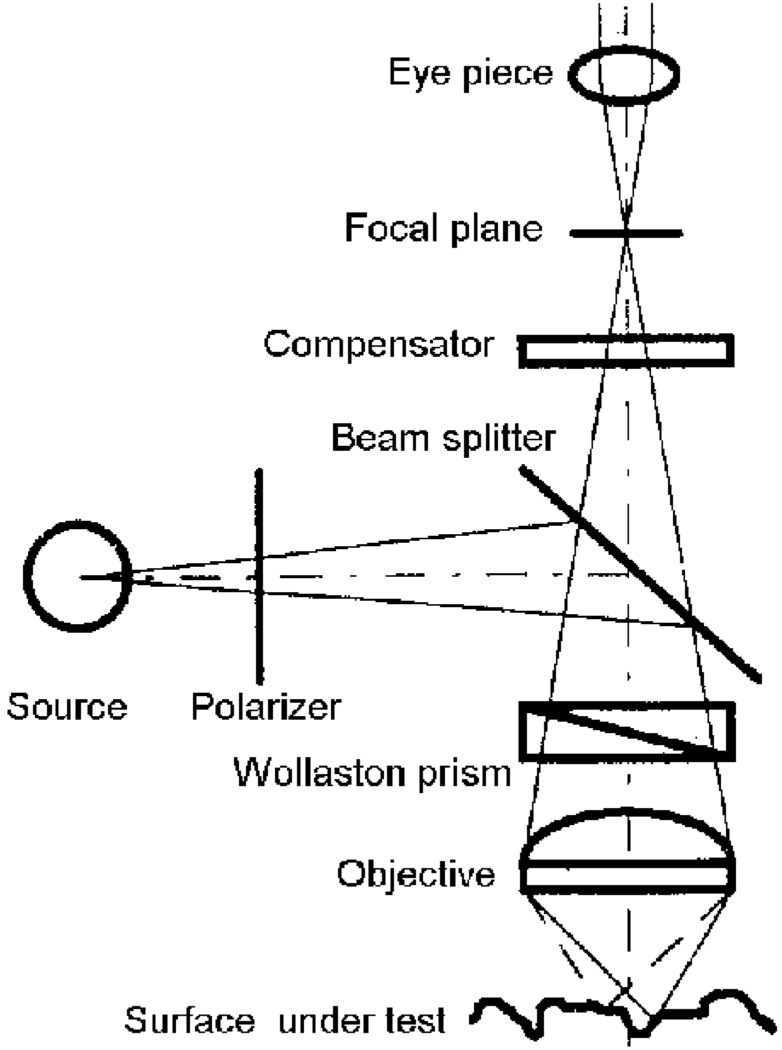
Accuracy < 75%, noise+can't estimate total damage threshold.

Some results seem to be… inconsistent

Current work & outlook

Nomarski microscope

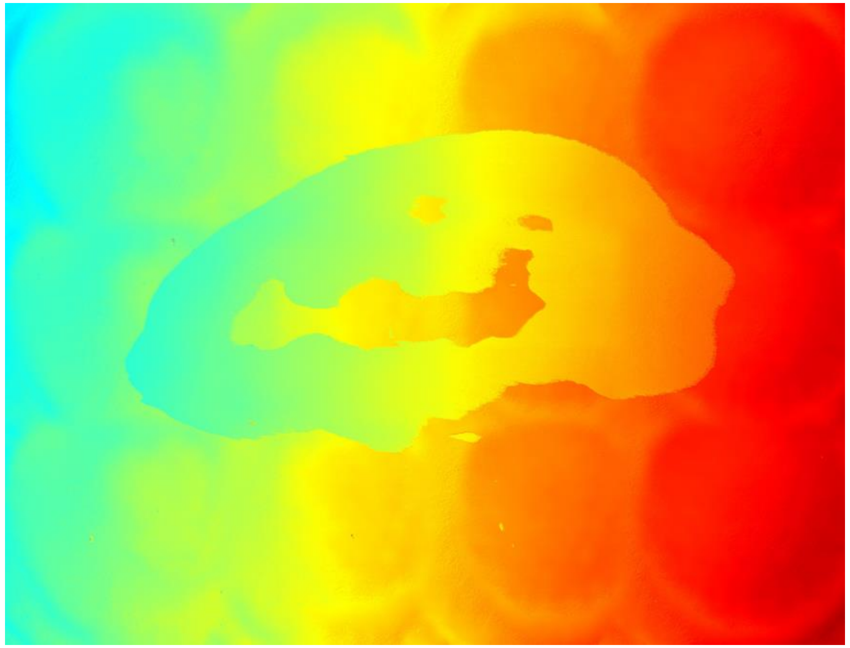
With special thanks to:
Chauvin Adrien
Daniel Kramer
from ELI Beamlines



(Differential interference contrast microscopy)

Current work: issues to solve

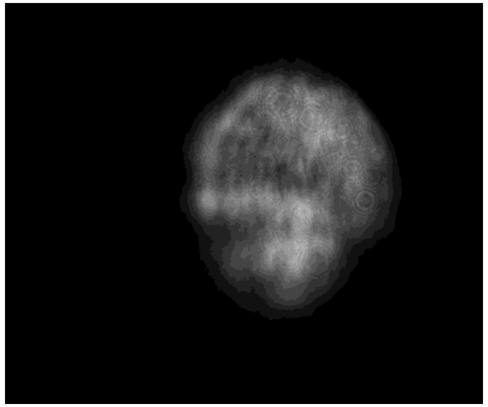
Damage profile

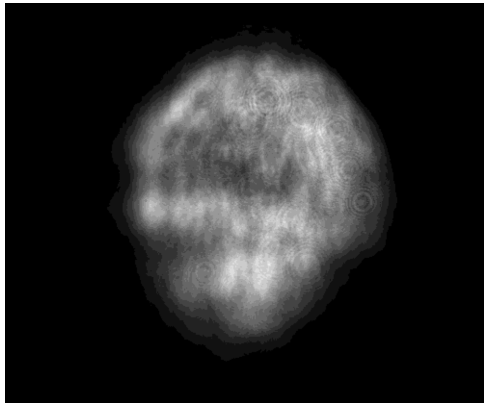


Quite intense periodic noise patterns!

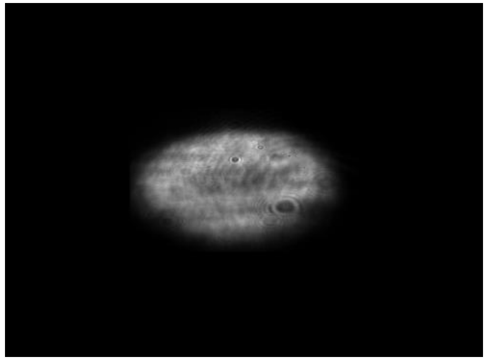
TBD: Rotation algorithm, neglected due to relatively small errors from lack of one and inefficiency time wise. (<4%)

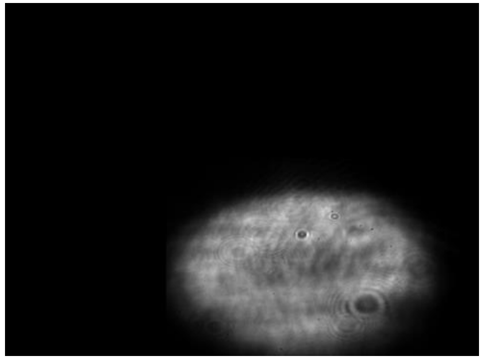
Laser profile





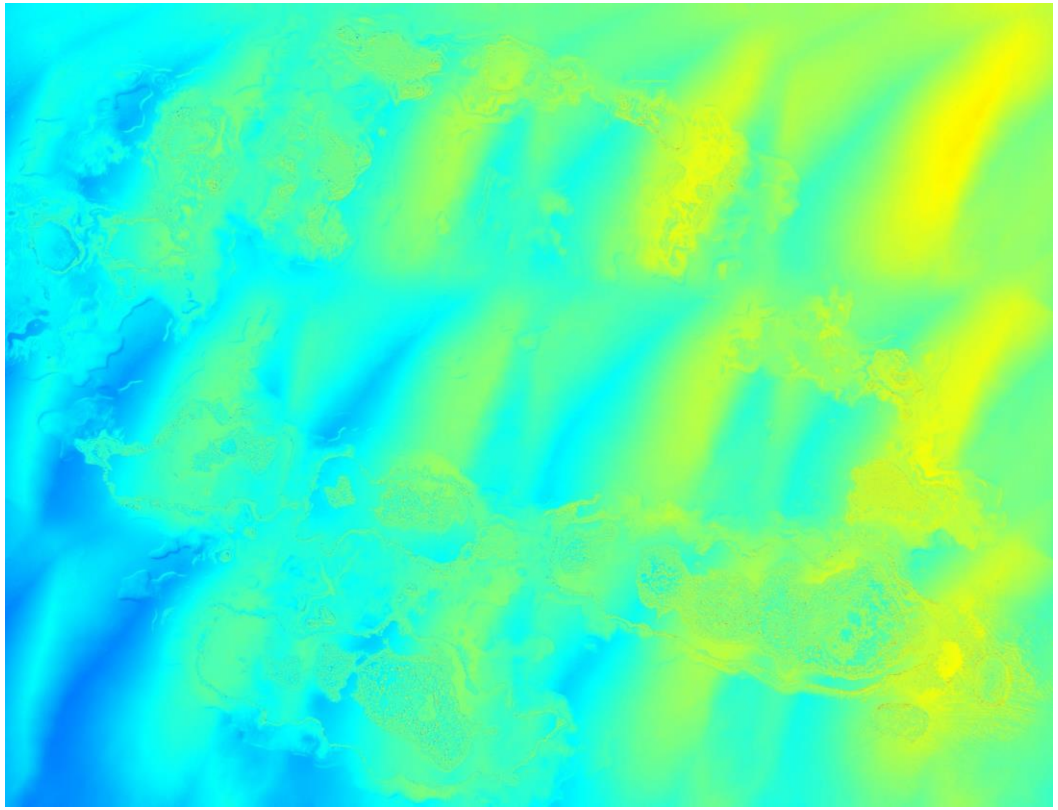
Defocus changes laser profile size, also energies per shot/angle of sample were different.

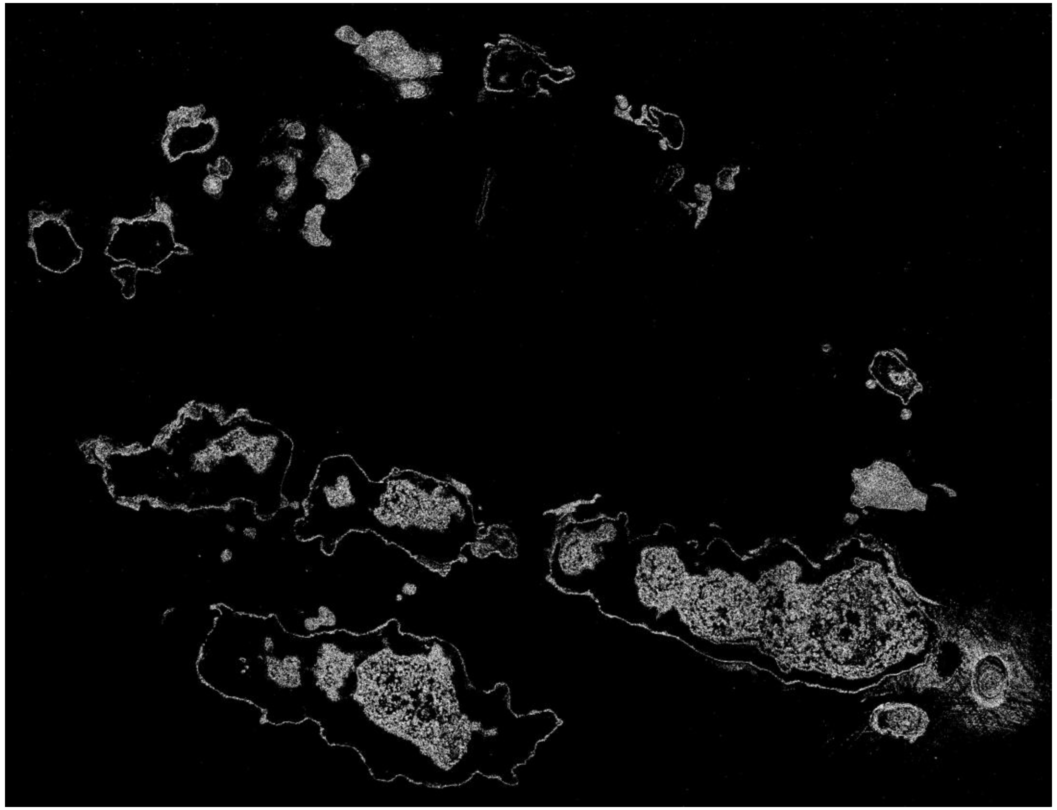




Resizing program isn’t very accurate, and now we have both the laser profile and damage with real coordinates.

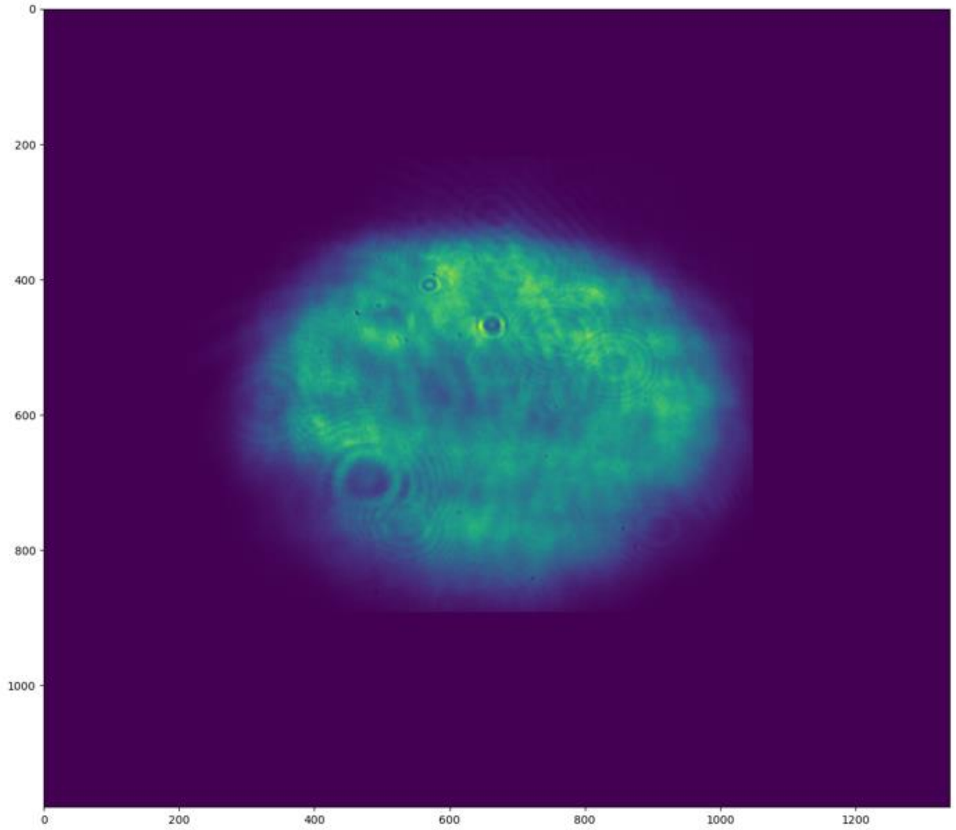
Current work: periodic noise patterns

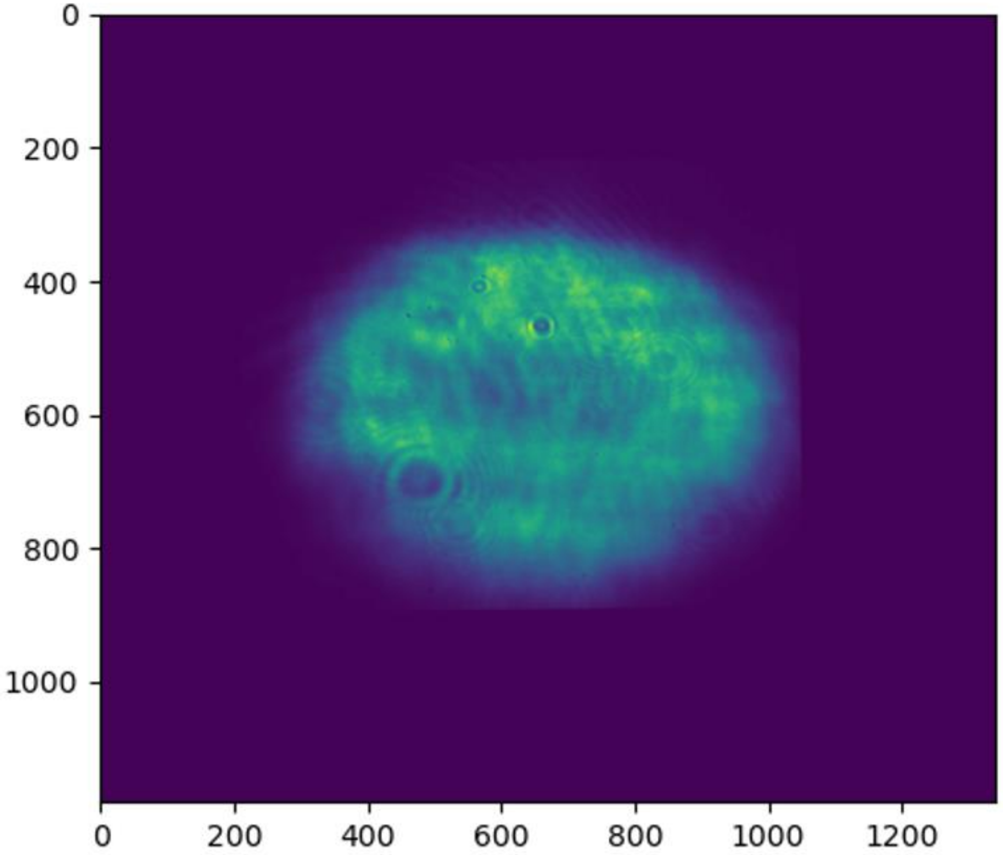




Too much noise? Use a Laplacian! (and a high enough threshold for the Laplacian values)

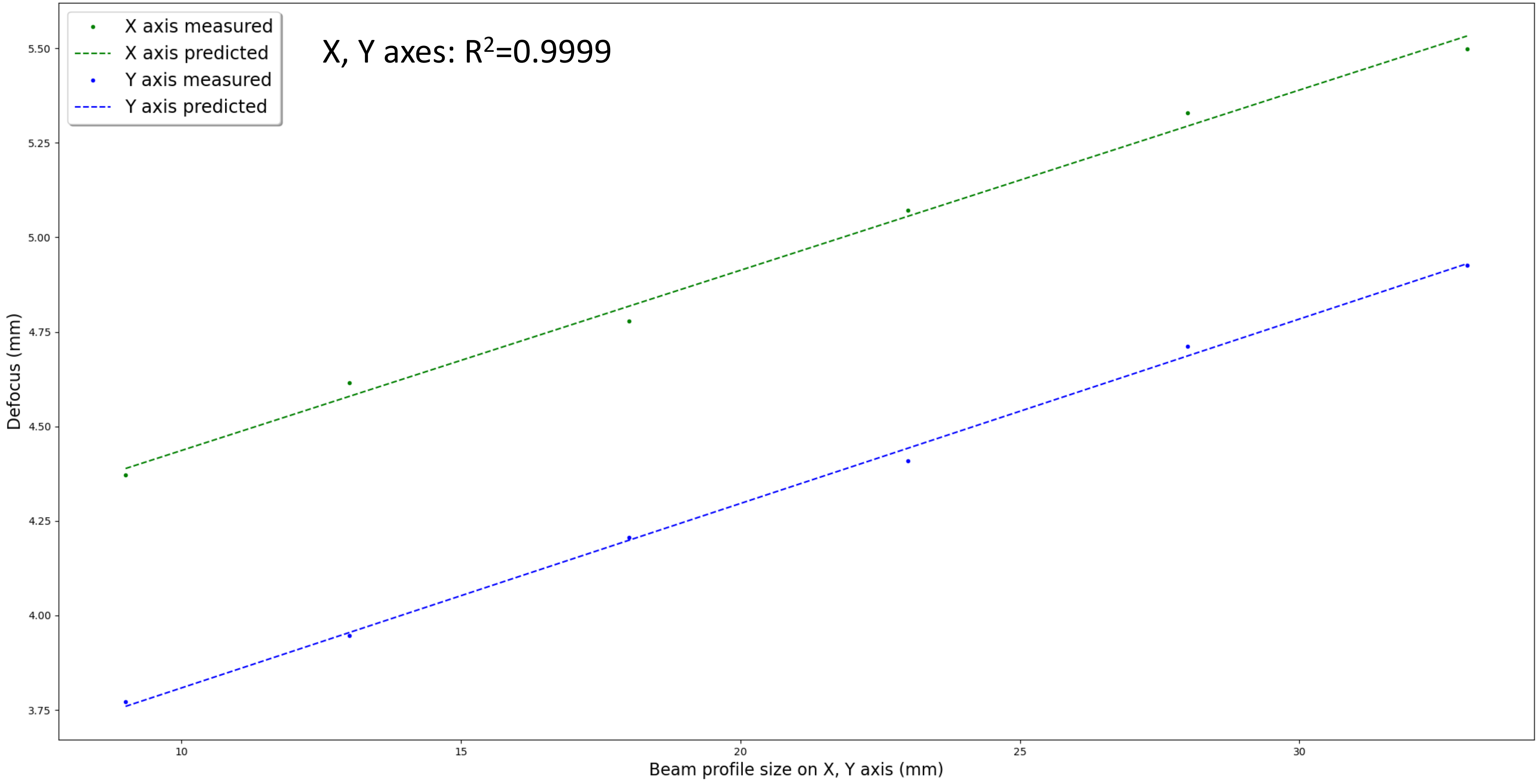
Current work: new rotation algorithm





Our rotation was off only by 0.0122 radians (0.7 degrees) to the optimal one, accuracy only improved by 0.12%! (85.52->85.66%)

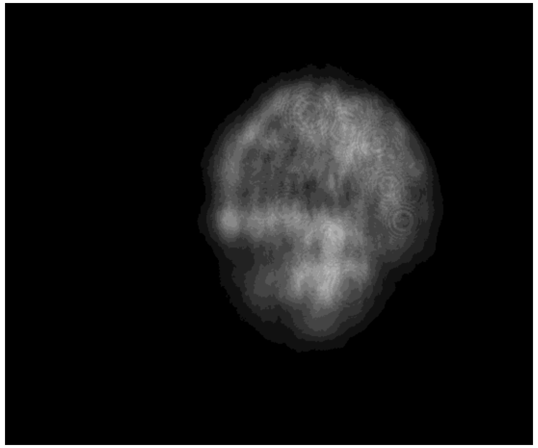
Current work: dependence on defocus



Current work: resizing

```
imageProperties::imageInfo::phase::group::channel::length::x[0] 2.5153344178579338
imageProperties::imageInfo::phase::group::channel::length::x[1] 2.5153344178579338
imageProperties::imageInfo::phase::group::channel::length::x[2] 2.5153344178579338
imageProperties::imageInfo::phase::group::channel::length::y[0] 2.5001120507412447
imageProperties::imageInfo::phase::group::channel::length::y[1] 2.5001120507412447
imageProperties::imageInfo::phase::group::channel::length::y[2] 2.5001120507412447
imageProperties::imageInfo::phase::group::channel::length::z[0] 0.008093946315729
imageProperties::imageInfo::phase::group::channel::length::z[1] 0.008093946315729
imageProperties::imageInfo::phase::group::channel::length::z[2] 0.008093946315729
```

Pixel size values from Nomarski microscope in µm



Camera pixel size: 3.45 µm x 3.45 µm

For each axis:

$$\text{Resizing factor} = \frac{\text{Pixel size of damage profile}}{\text{Pixel size of laser profile (3.45 µm)}}$$

Conclusion and project outlook

- First large aperture LIDT experiment performed with fs laser pulses;
- Data analysis provided results for Ag (SiO_2) and chirped mirrors.
- Large aperture LIDT will yield much better statistics -> better characterisation of damage thresholds for materials, possibly uncover damage mechanisms;
- Work in progress: better algorithms, better damage and laser image
- The results should help in characterizing damage more accurately, control it better, reducing the risk of damage and pushing the boundaries further with any current or future experimental setups to higher powers.
- Possible use in testing mirrors produced by the upcoming COMP facility at ELI-NP.