Phase conjugation with Zelda wavefront sensor

A manual closure of a loop on the MITHIC bench

Raphaël POURCELOT

Apprentice engineer – Optical service – LAM / M1 Student in Institut d'Optique Graduate School – Palaiseau (91)

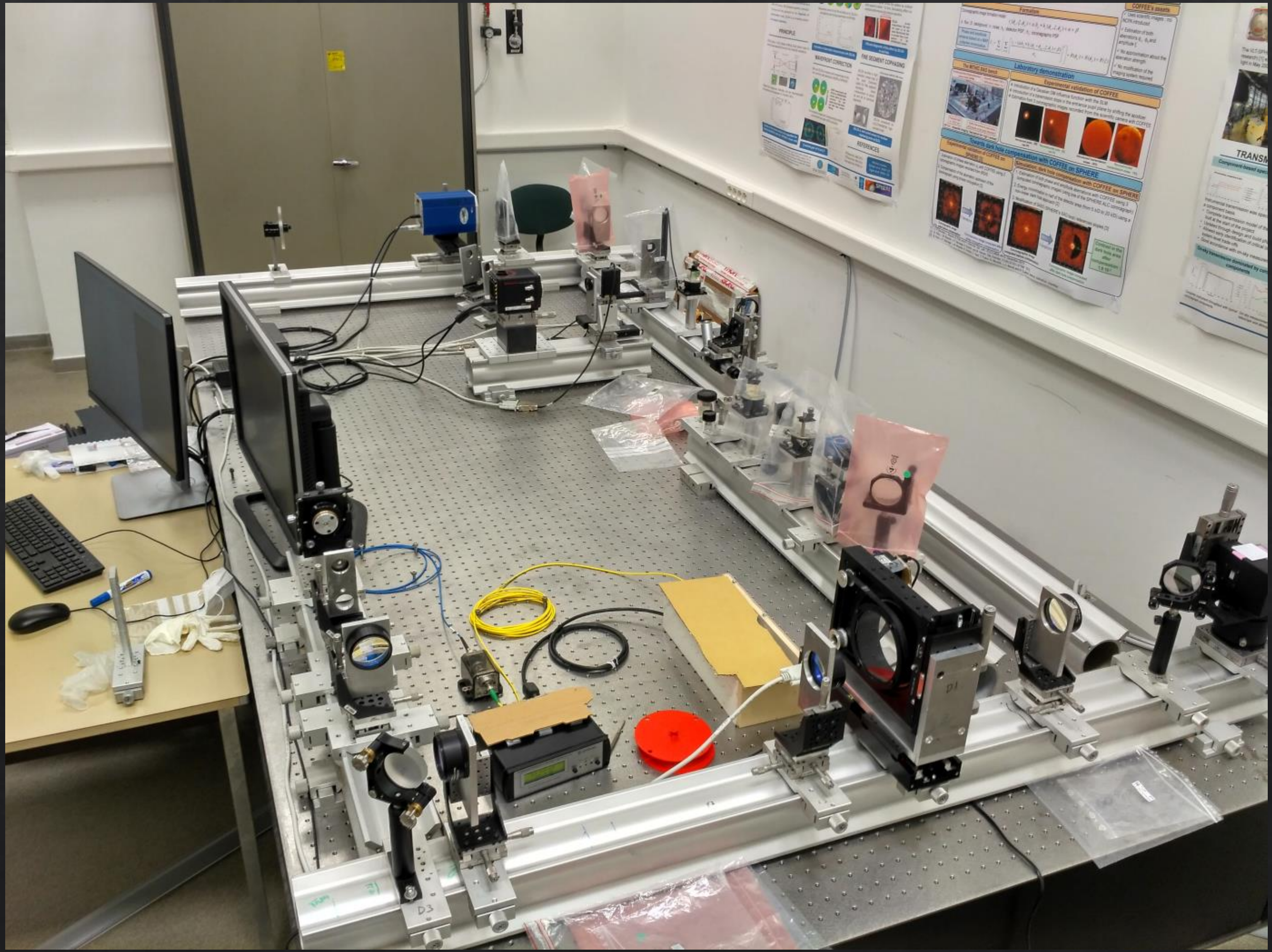
In collaboration with Kjetil DOHLEN, Arthur VIGAN, Jean-François SAUVAGE, Thierry FUSCO

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

High-contrast imaging

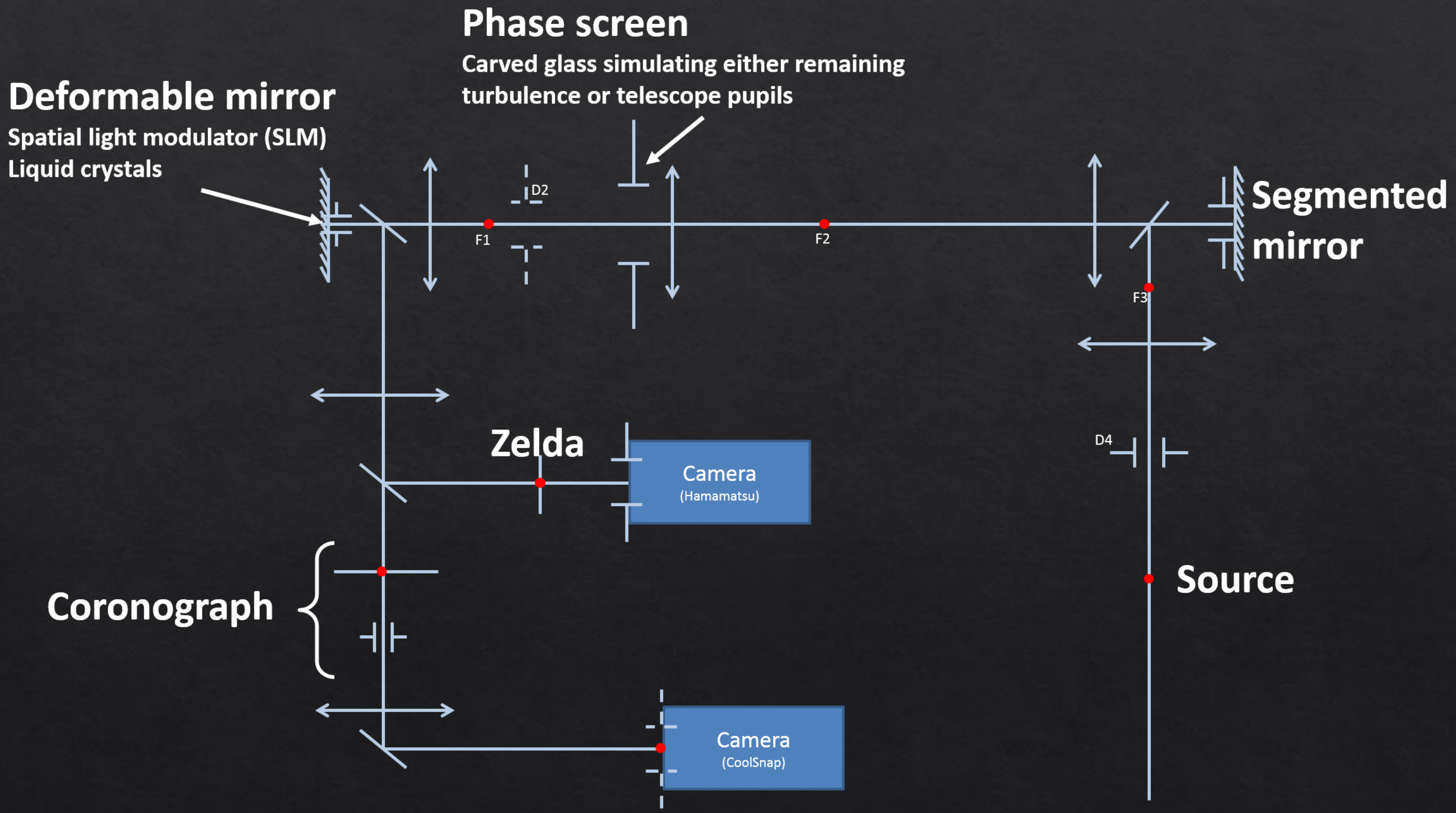
- MITHIC : experimental test bench used to validate concepts for High-Contrast imaging
- High-contrasts :~10^9 for future instruments
- Deleting light by interferences
- Need of a very flat wavefront to avoid speckles (nanometric RMS)

MITHIC (Marseille Imaging Testbed for HIgh Contrast)

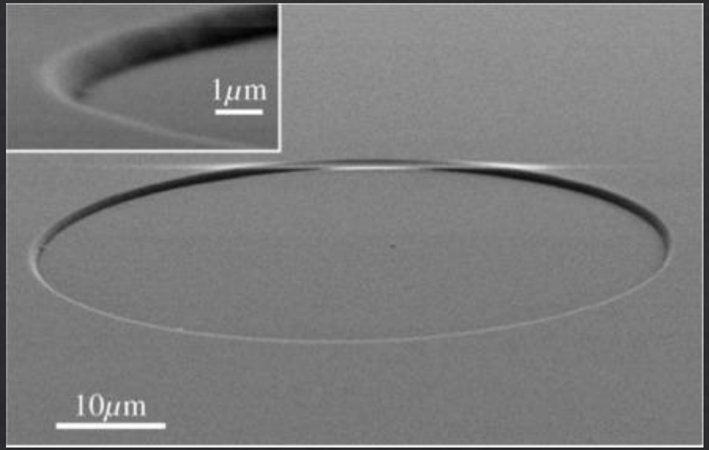


MITHIC : principle

Wavelenght used : λ = 670 nm



ZELDA (Zernike sensor for Extremely Low-level Differential Aberrations)



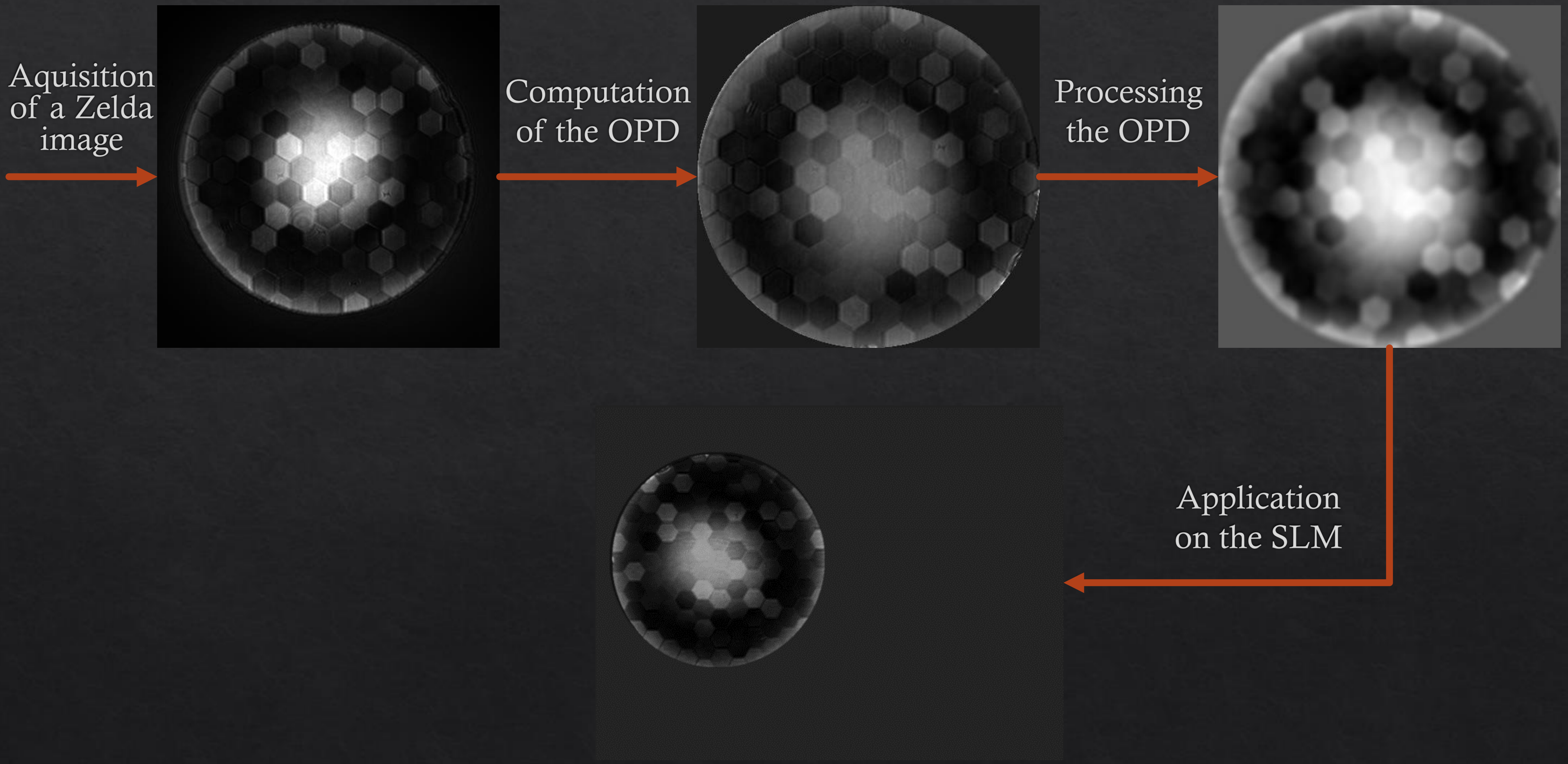
- Phase mask introducing a λ/4 phase shift on a half of the PSF (a diameter of approx. F*λ ~ 60 μm)
- Invented by Zernike in the 30's (for microscopy) ; Nobel prize in 1953
- Transforms the phase defects into intensity defects (in the pupil plane)
- Short linearity range but a high sensibility (sub-nanometric)

Goals of the work

- Closing a loop between Zelda and the SLM (simulating a deformable mirror):
  - without any interaction matrix (non-automized bench => « slow » speed of measurement)
  - Phase conjugation principle

- Stabilizing the loop
  - Non optimized because of geometrical/gain problems

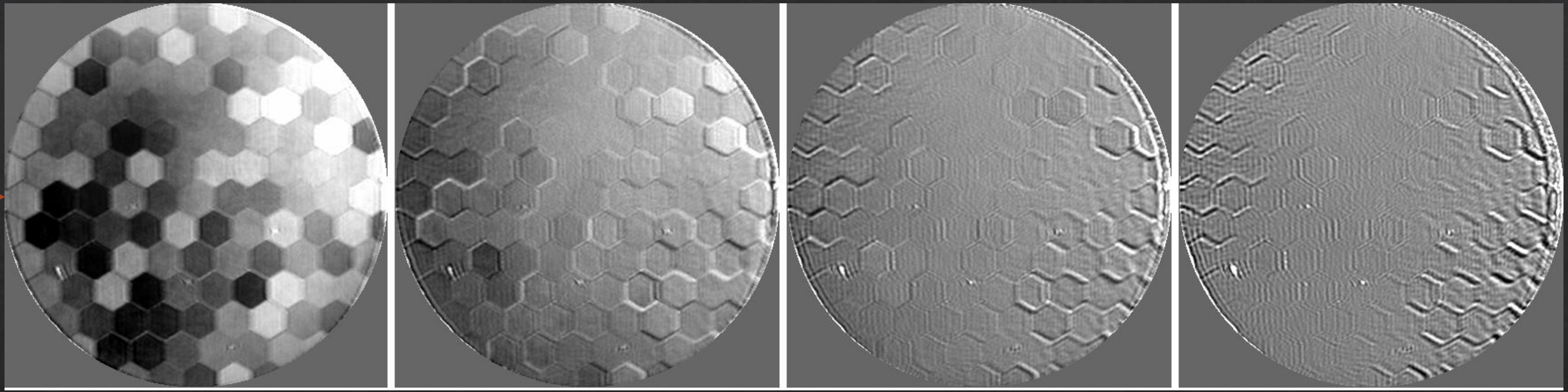
Princple of the phase conjugation



First encouraging results

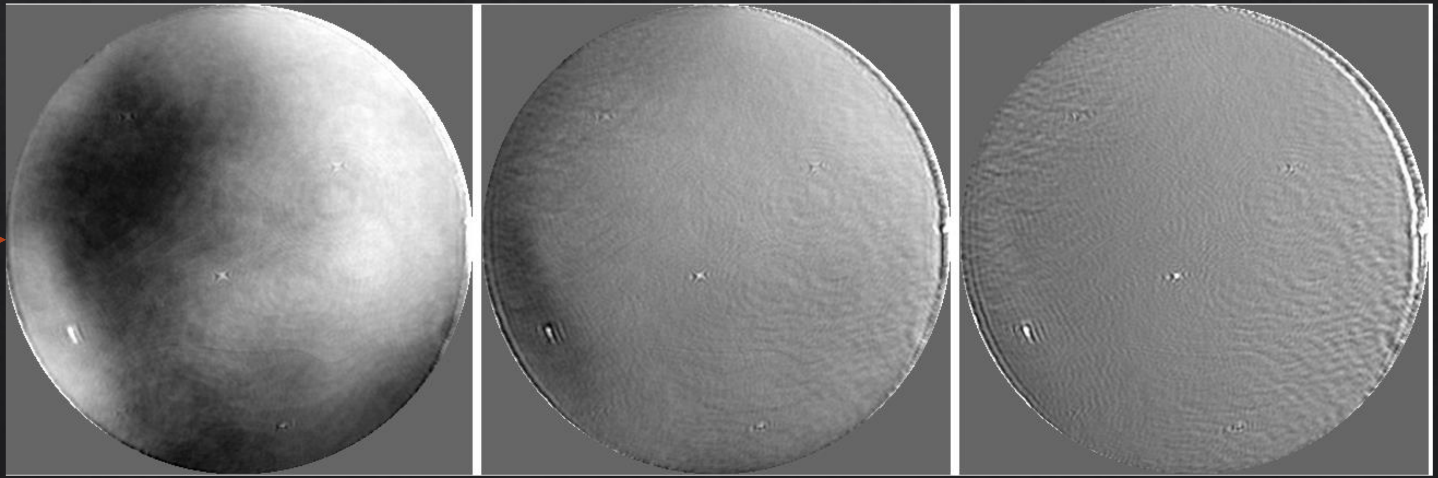
Aberrations introduced on the phase screen:

Segmented pistons

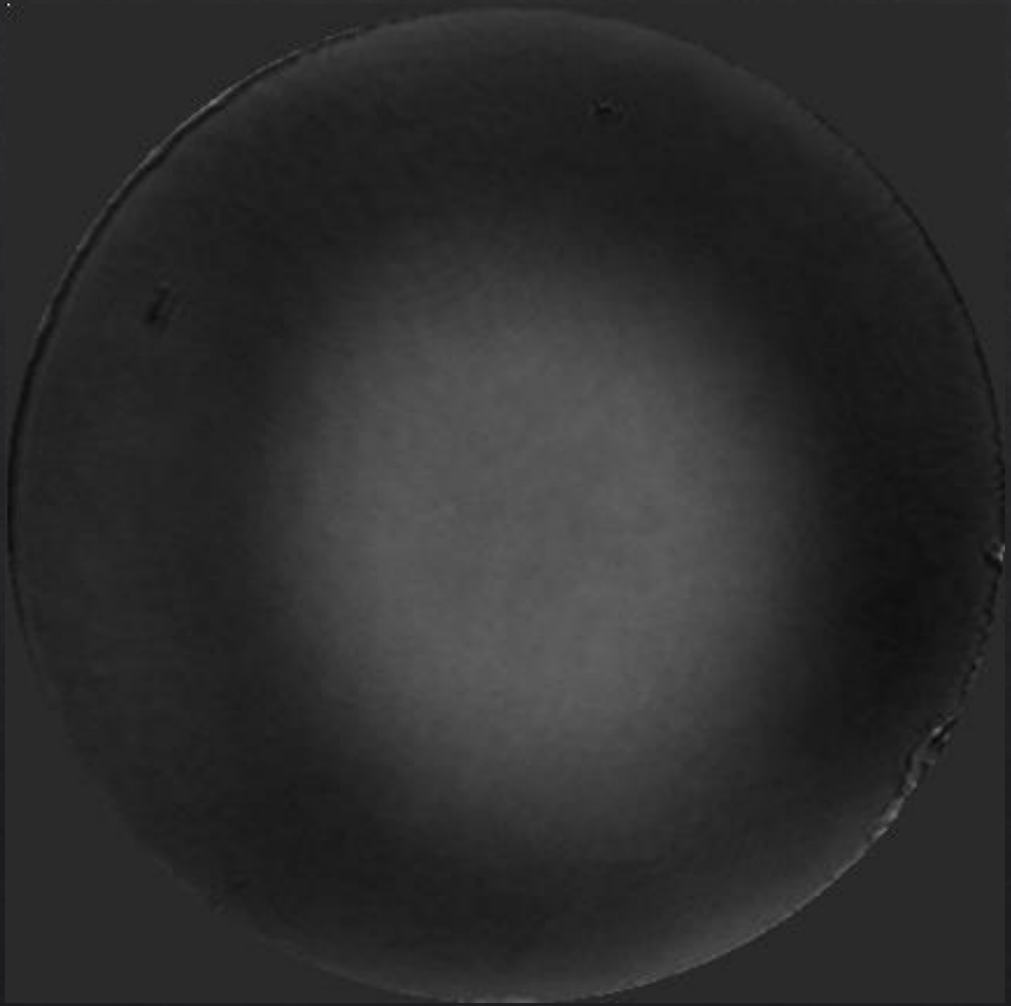


Not corrected – RMS ~80 nm | After one iteration | After 2 iterations | After 3 iterations – RMS~40 nm

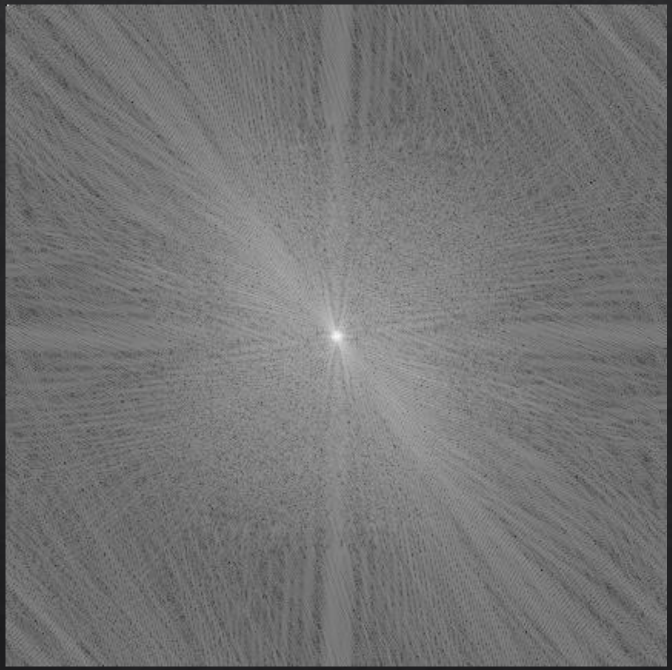
Random Zernike Polynoms (simulating Non-Common Path Aberrations)



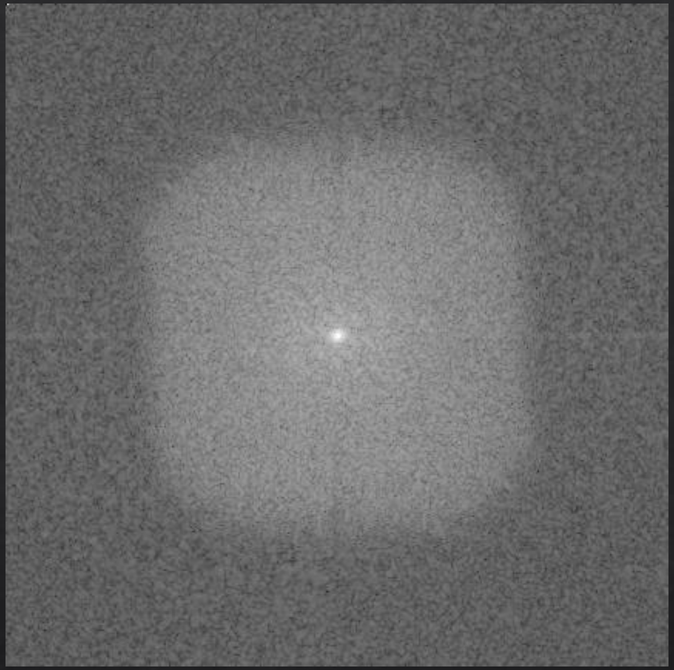
Some correction errors



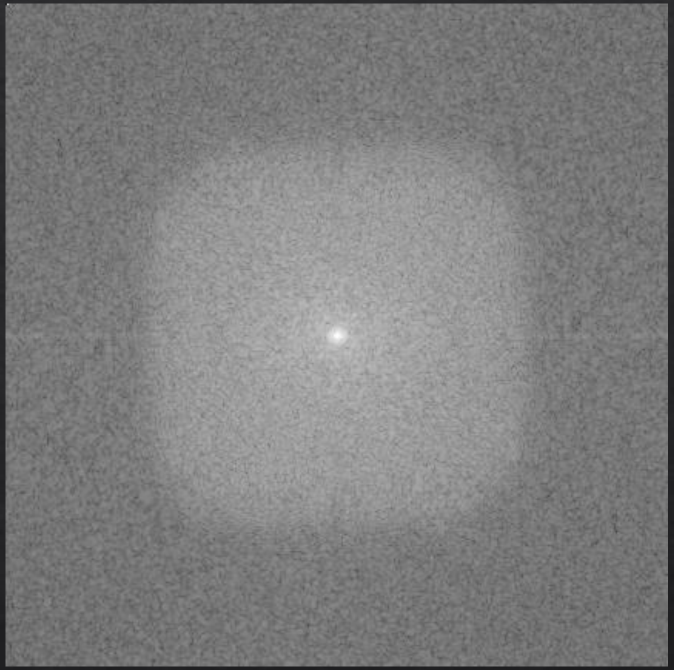
Fourier transform analysis



« Non-apodised » pupil

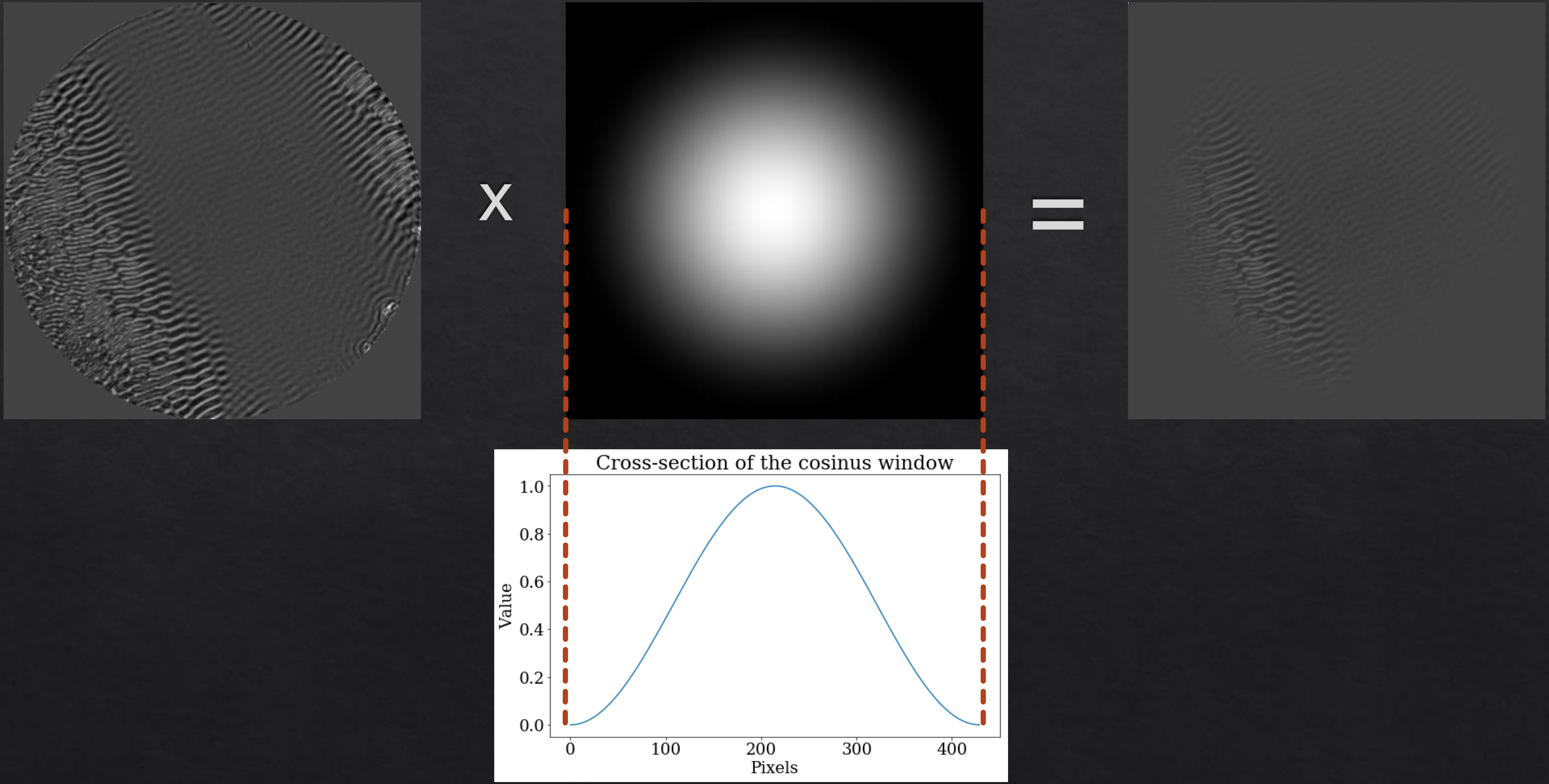


« Apodised » pupil



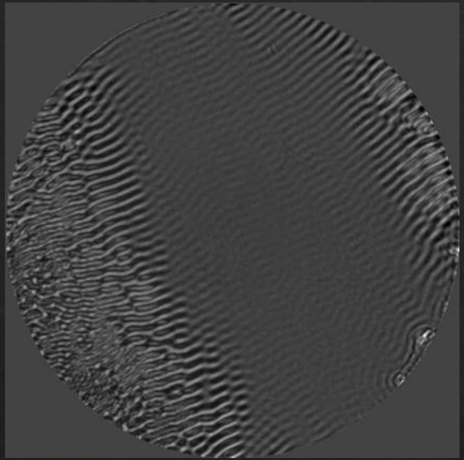
« Apodised » pupil -
Filtered sequence

Apodised pupil



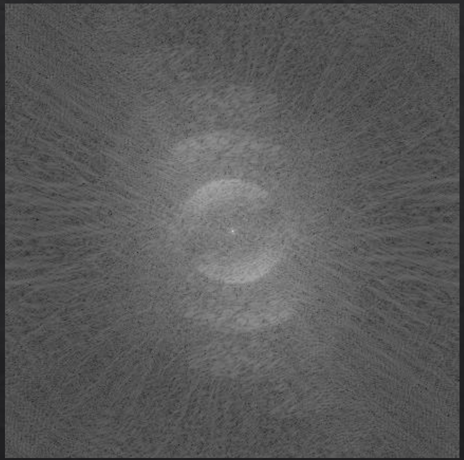
Filtering

- How do we « measure » filter ?



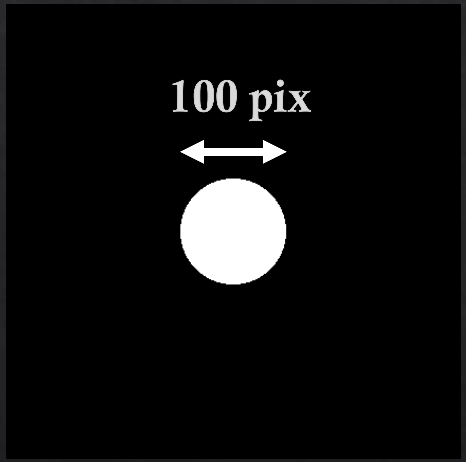
Calculated OPD

FFT →



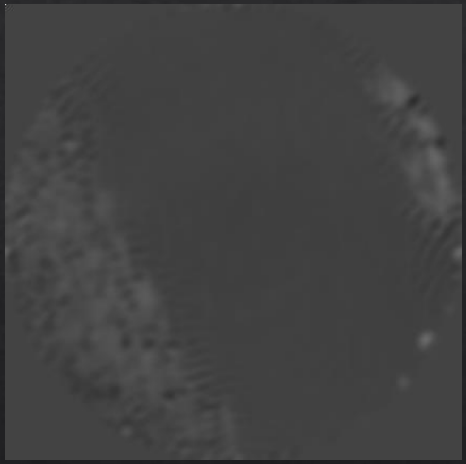
FFT of the OPD

X



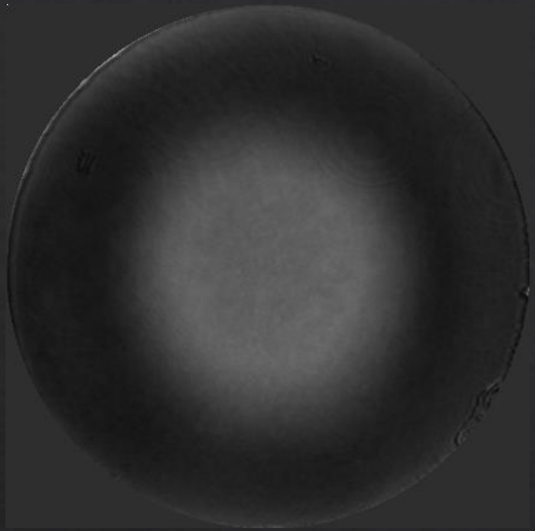
Filter « 100 »

FFT^{-1} →

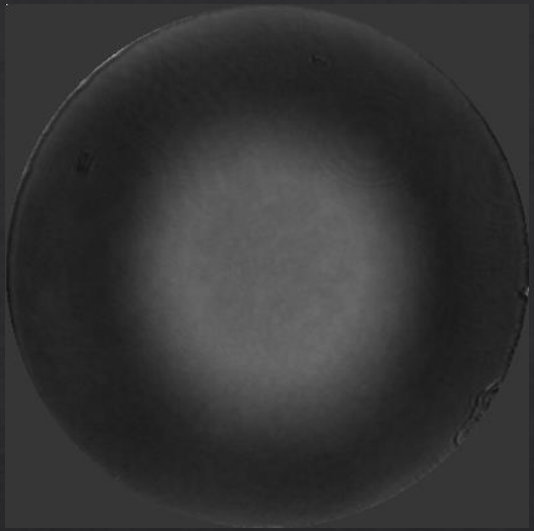


OPD to be sent to the SLM

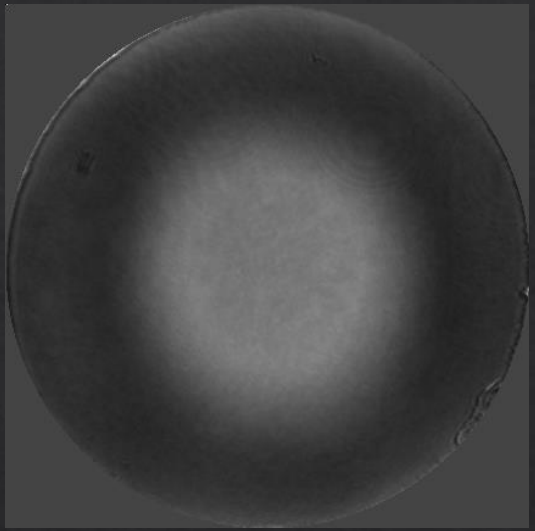
Different filter values



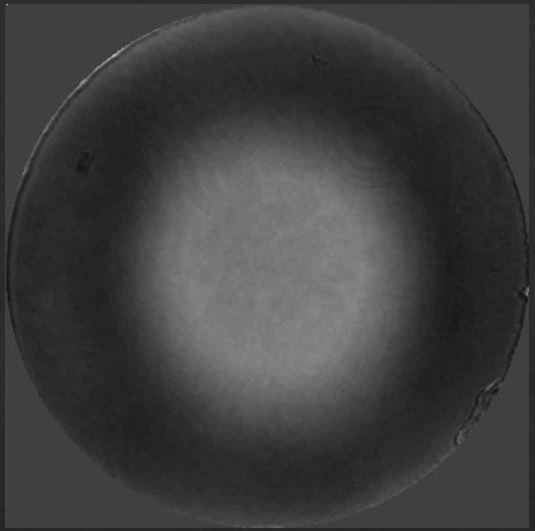
Without filtering



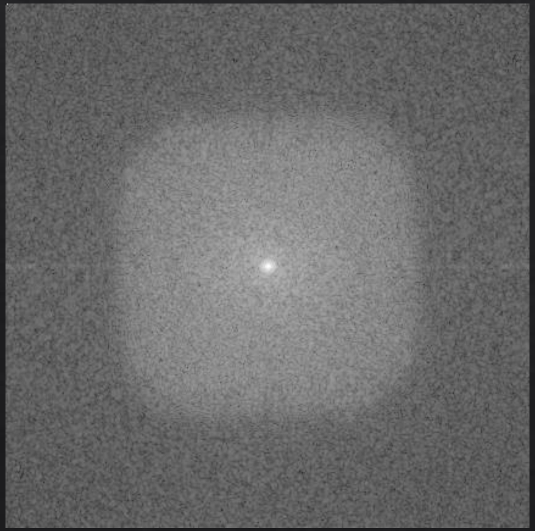
Filter value : 100

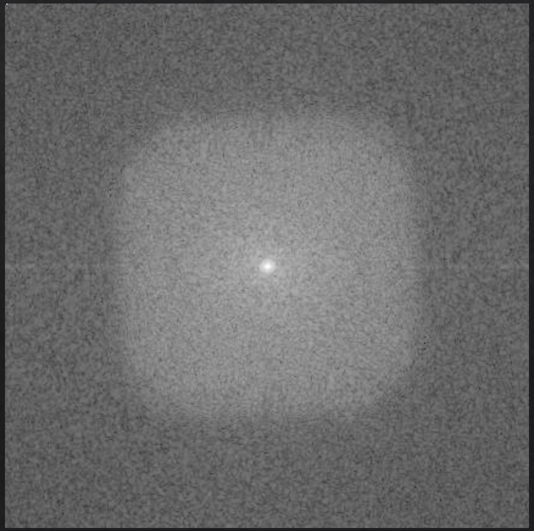


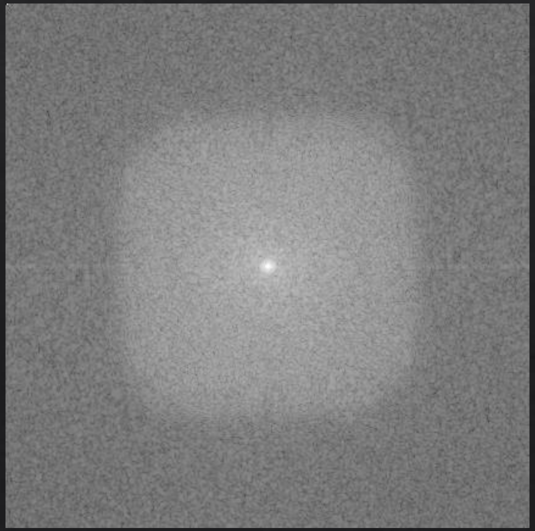
Filter value : 50

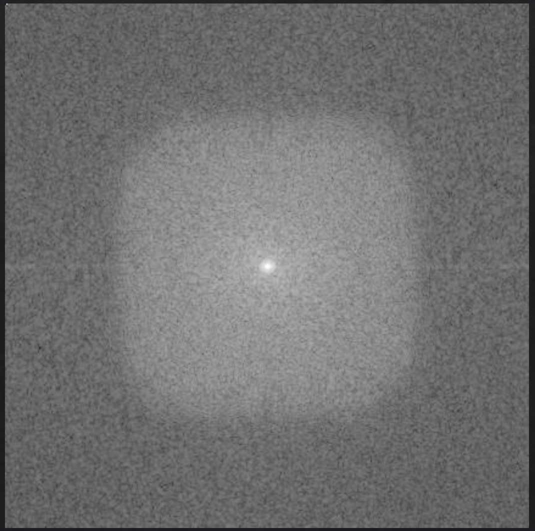


Filter value : 20

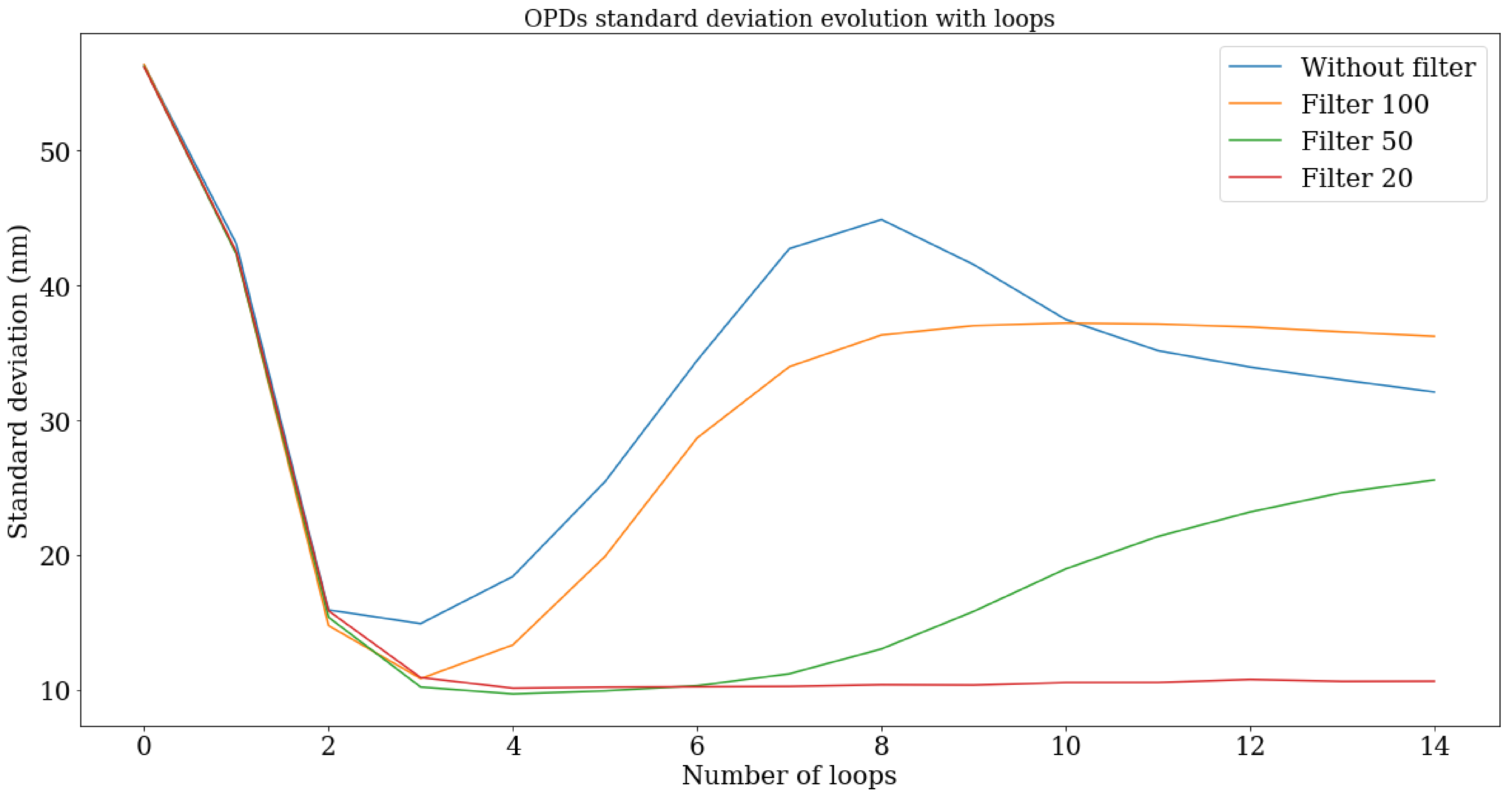






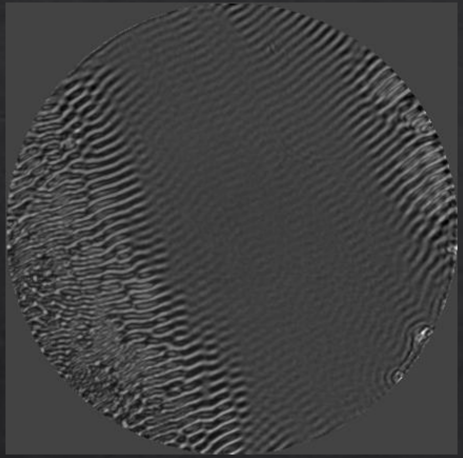


Filtering



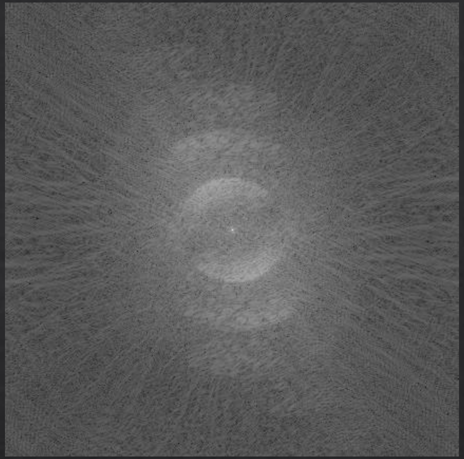
OPDs standard deviation evolution with loops
Without filter
Filter 100
Filter 50
Filter 20
Standard deviation (nm)
50
40
30
20
10
0
2
4
6
8
10
12
14
Number of loops

Apodised filtering



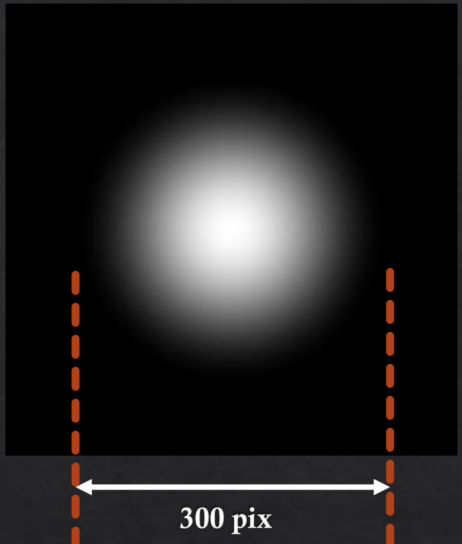
Calculated OPD

FFT →

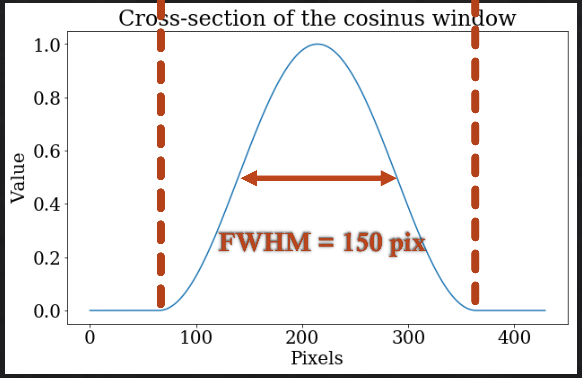


FFT of the OPD

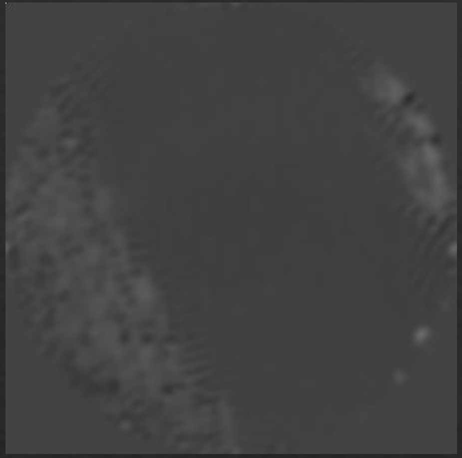
X



Filter « 300 »

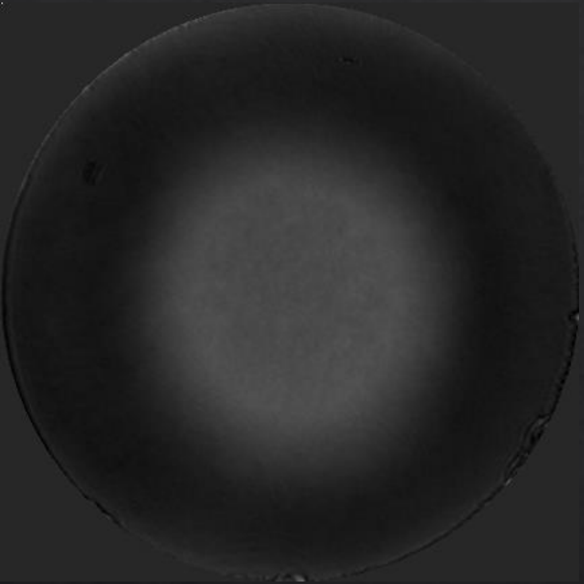


FFT^{-1} →

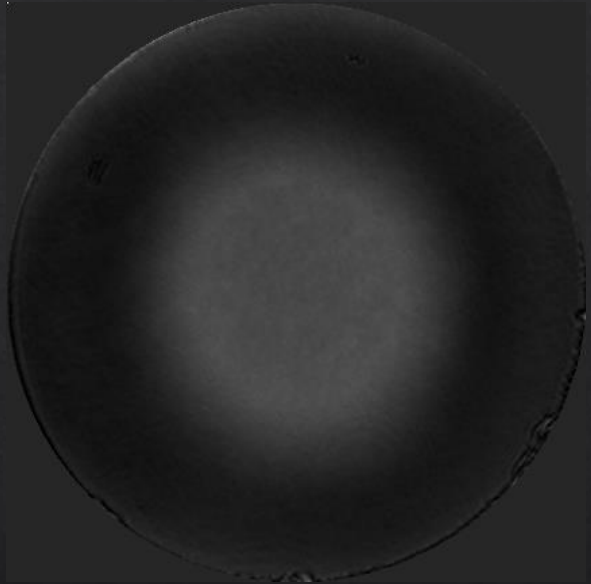


OPD to be sent to the SLM

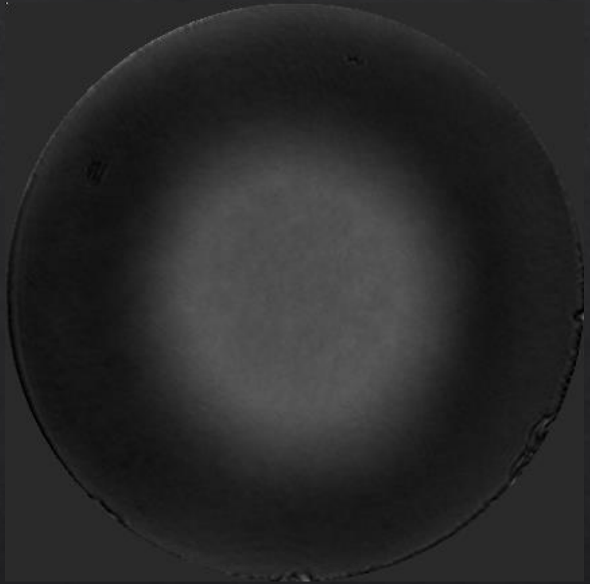
Apodised filtering



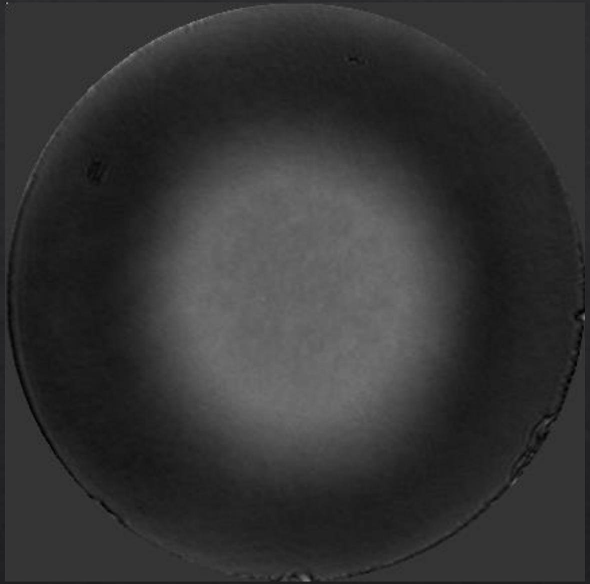
Without filtering



Filter value : 250

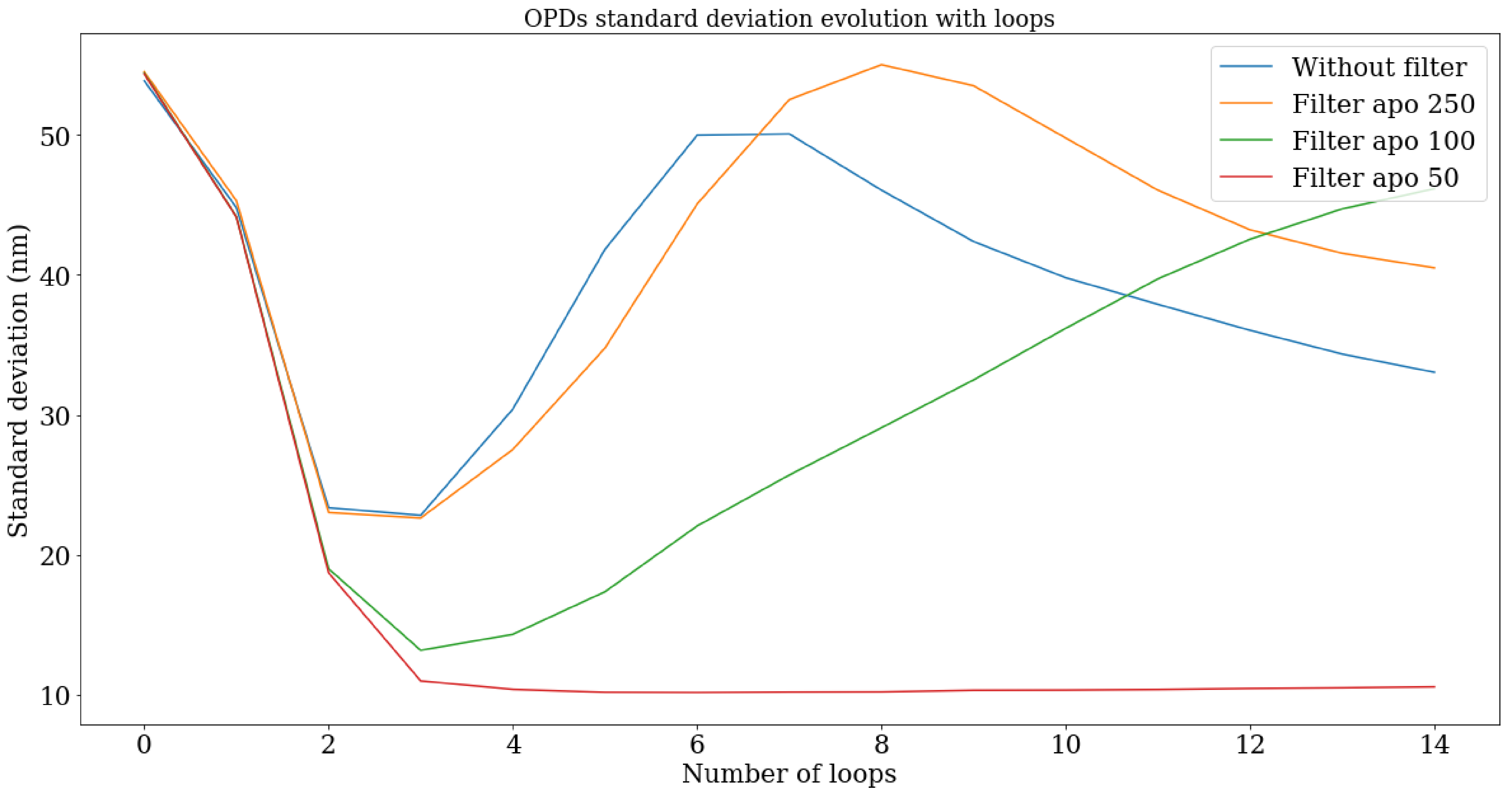


Filter value : 100



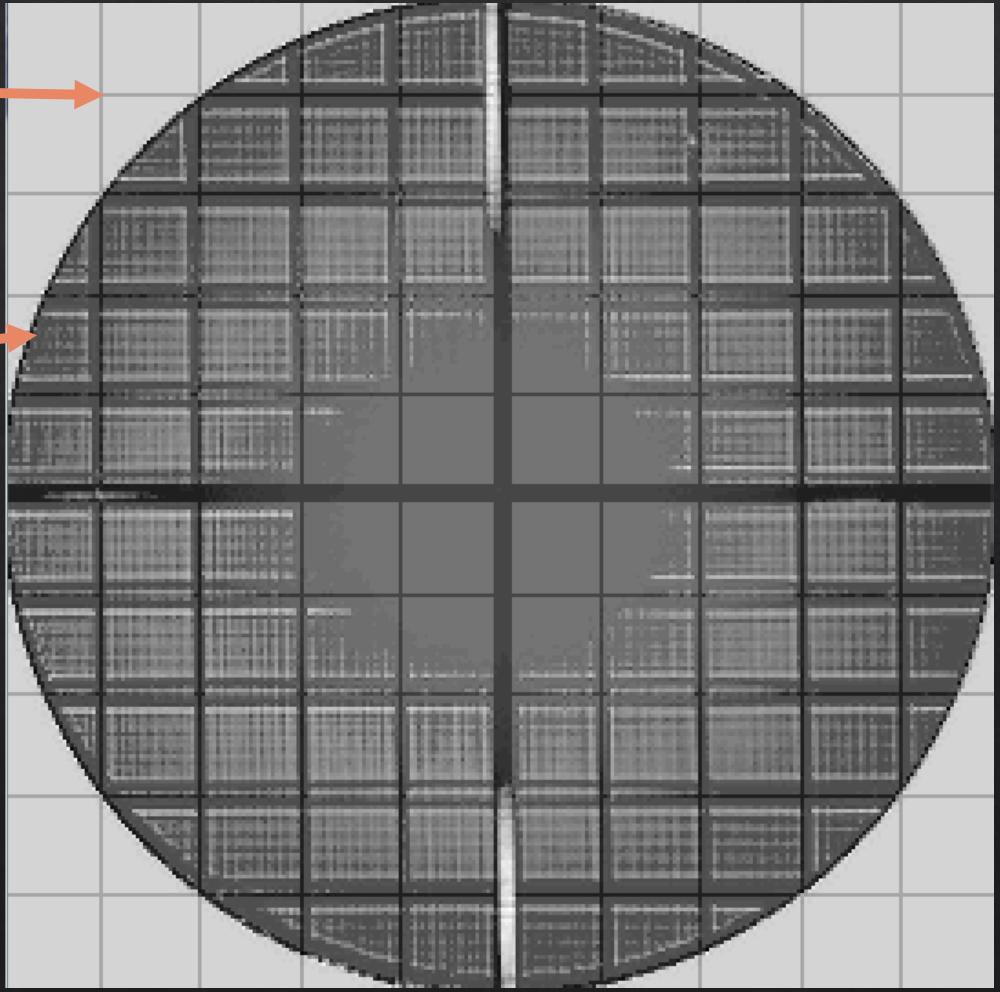
Filter value : 50

Apodised filtering



Detection of deformation

- Placing a grid on the SLM
- Analyzing the image (Zeldagram) of the grid
- Non-uniform deformation => distortion



Analysis of deformation

Gaussian dots on the SLM

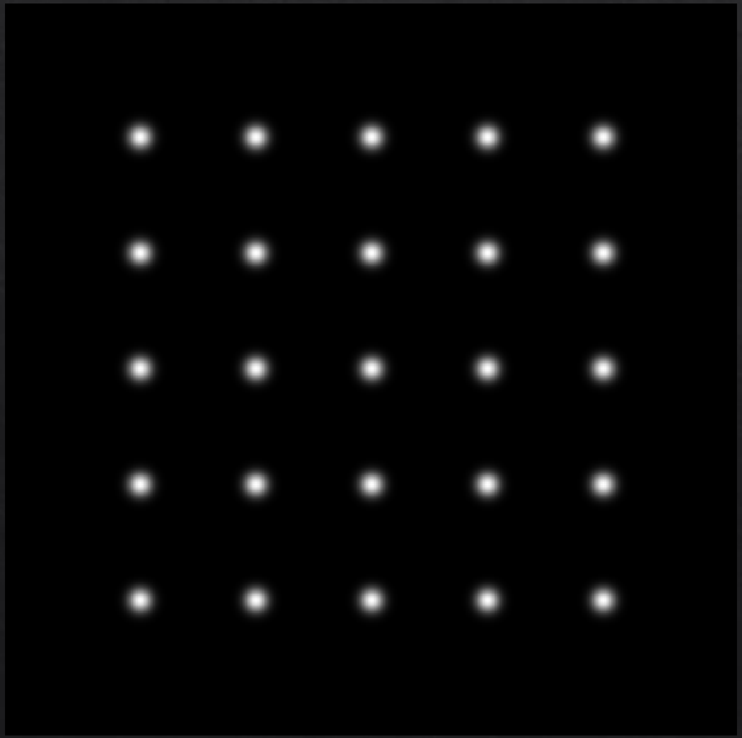
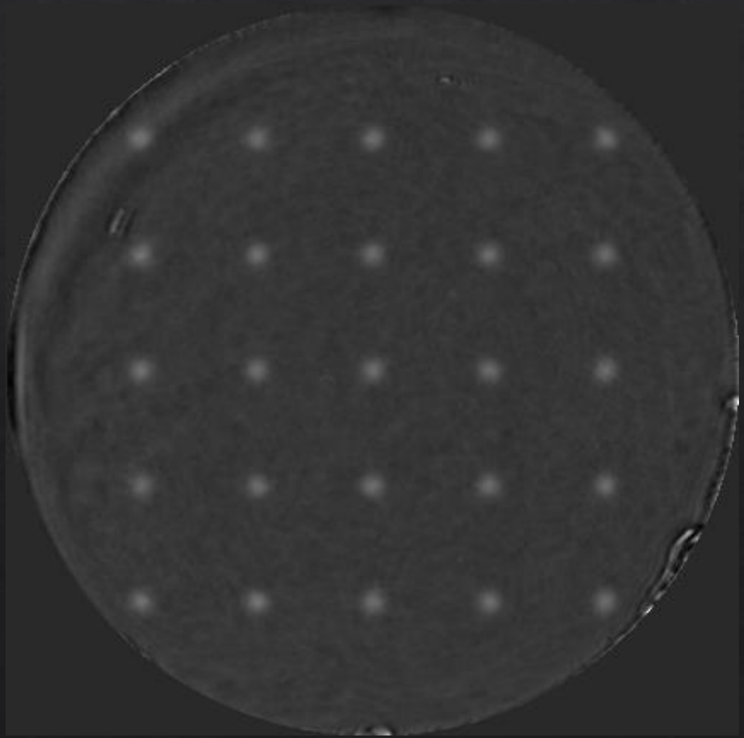
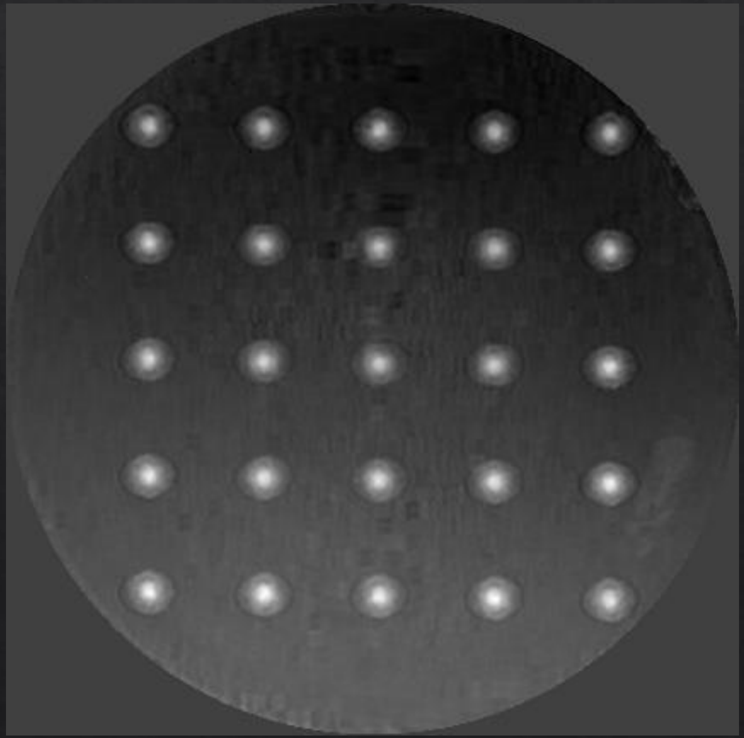


Image of the dots



Deduced OPD



Caculation of deformation

U : Values sent to the SLM

U' : Values from Zelda

Transformation f computed :

$f: U' \rightarrow U$

$f(U') = MU + C$

With M a 2*2 matrix and C a 2*1 vector

Results from computation

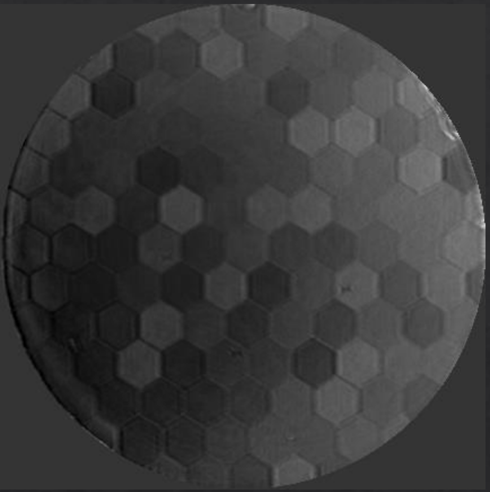
- $M = \begin{pmatrix} 1{,}00513 & -0{,}00084 \\ 0{,}01583 & 0{,}99277 \end{pmatrix}$

- $C = \begin{pmatrix} -3.34632 \\ -5.83732 \end{pmatrix}$

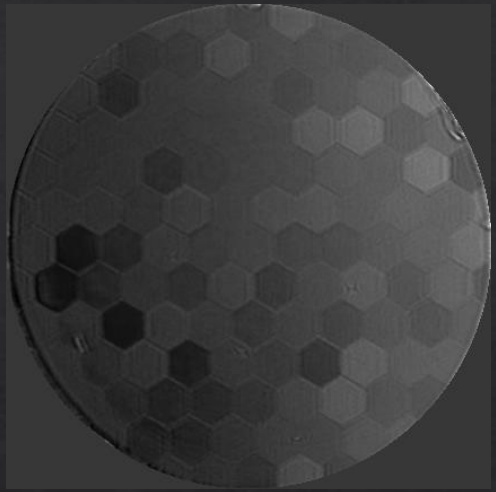
- Max residual error: 0.55 pix
- Mean error: 0.19 pix
- Error standard deviation: 0.13 pix

Results with a segmented pupil

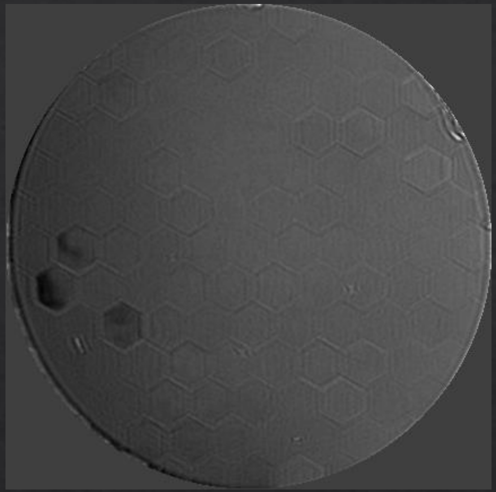
Initial pupil



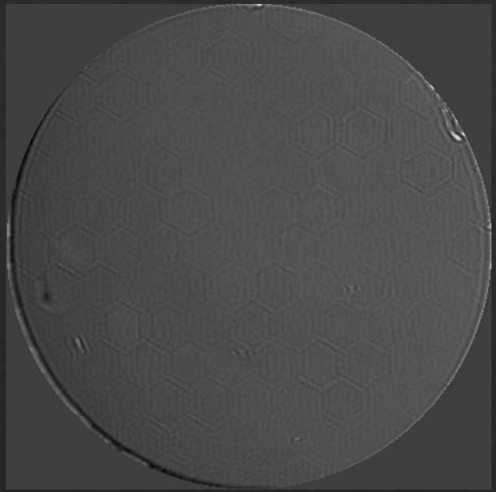
After 1 loop



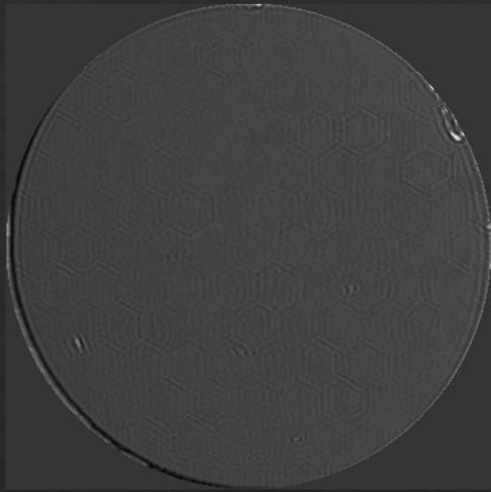
After 2 loops

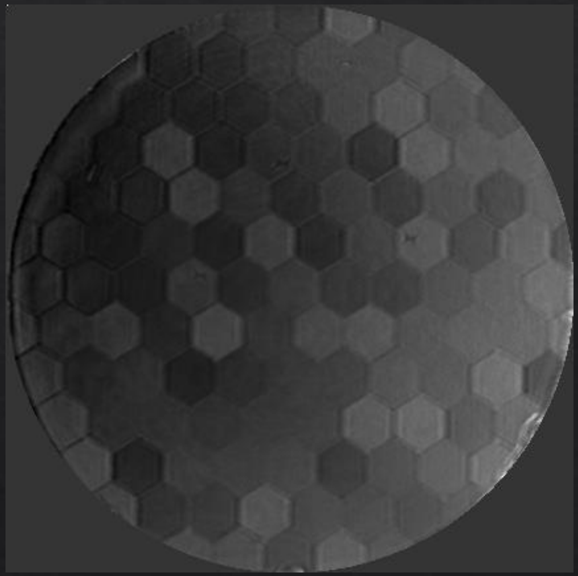


After 3 loops



After 4 loops

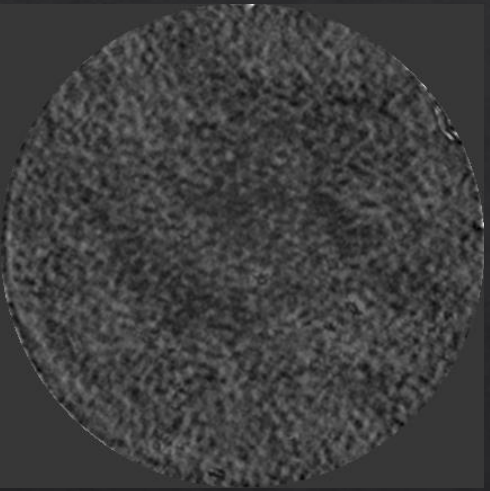




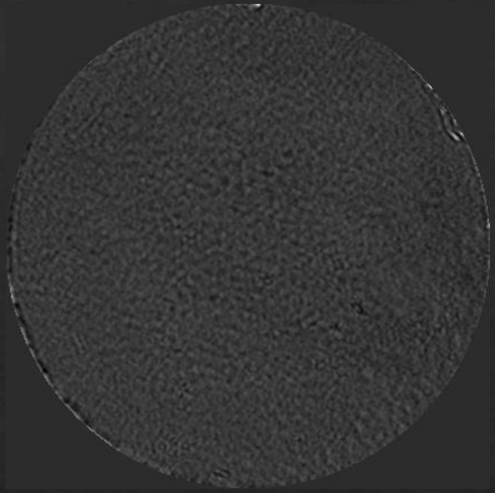
Residual RMS : 28 nm

Results with random turbulence

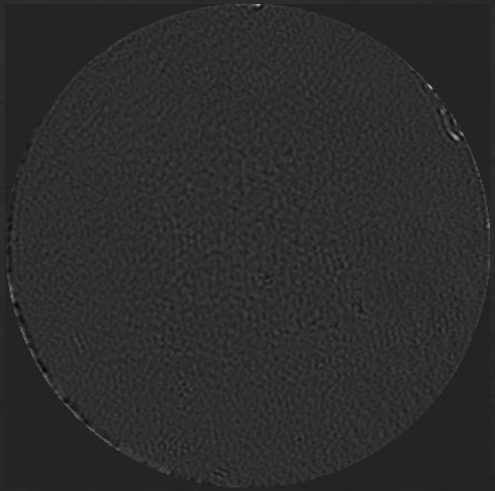
Initial pupil



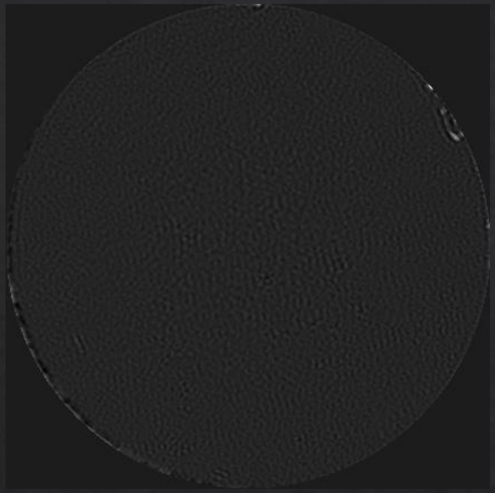
After 1 loop



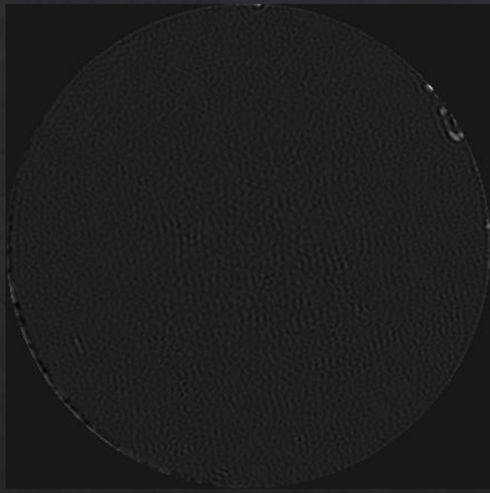
After 2 loops

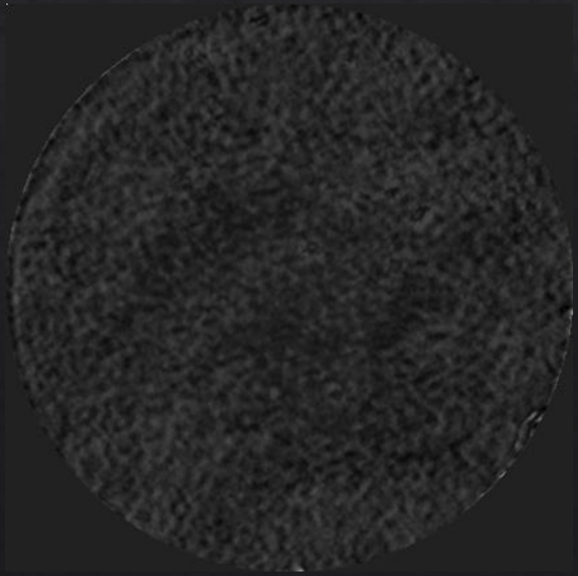


After 3 loops



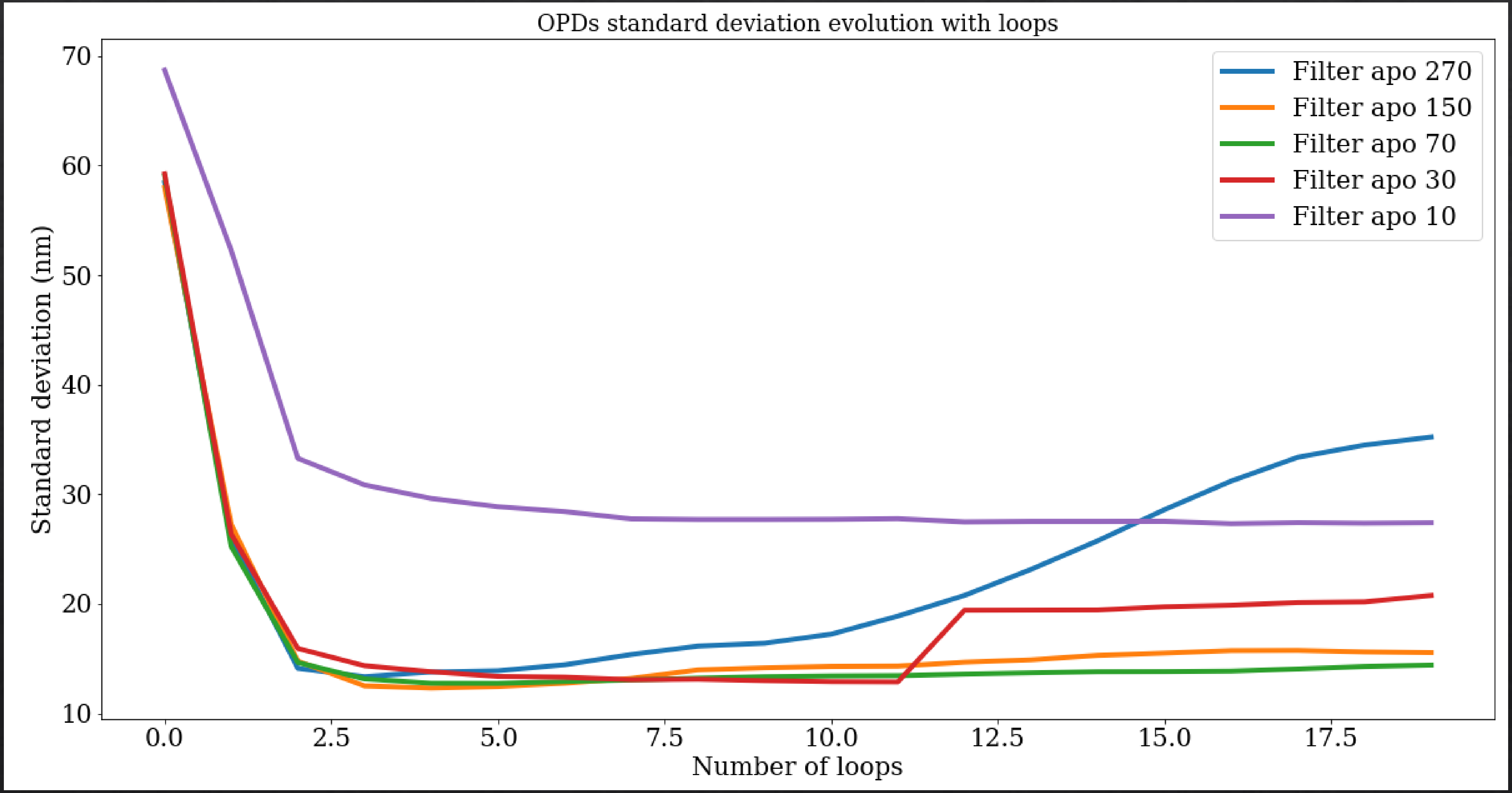
After 4 loops





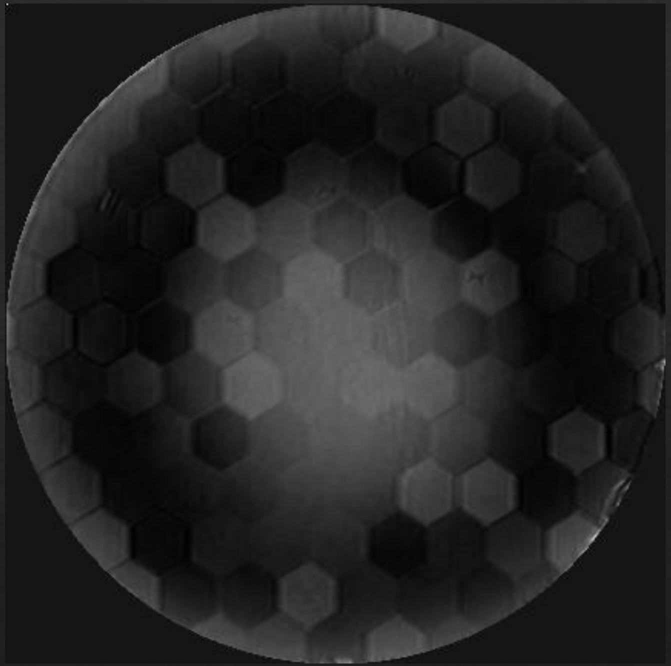
Residual RMS : 26 nm

Apodised filtering + correction of deformation (gain = 0.7)



Remaining issues

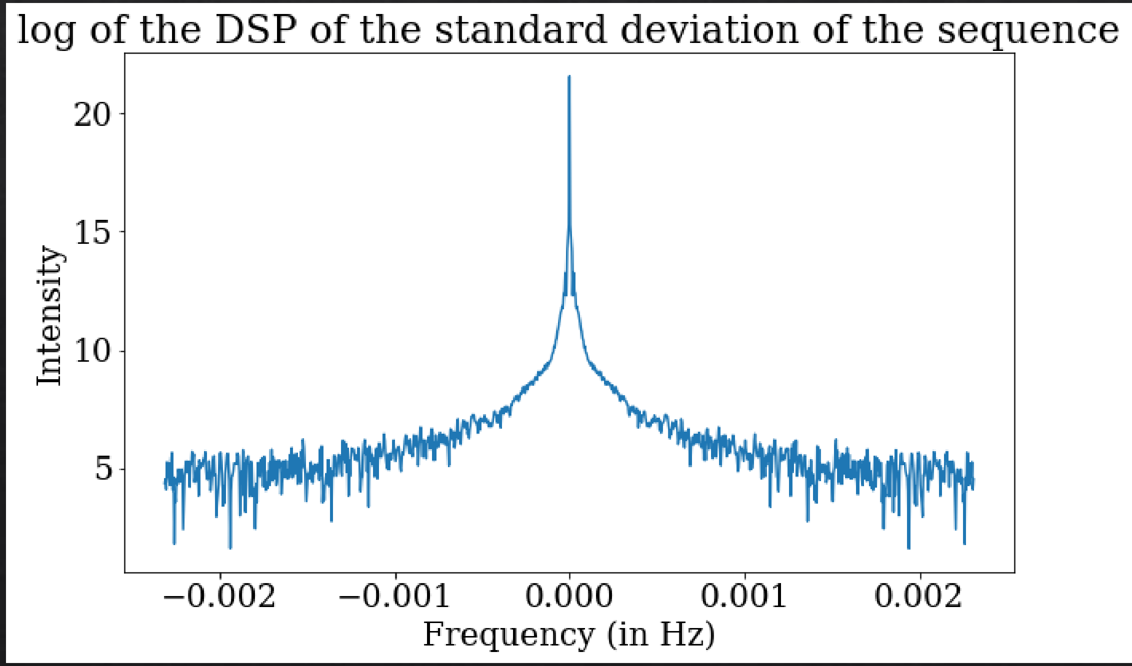
- Remaining (but smaller) wrinkles (even with anti-aliasing)
- Some astigmatism in the pupil conjugation
- Dust on sensible components

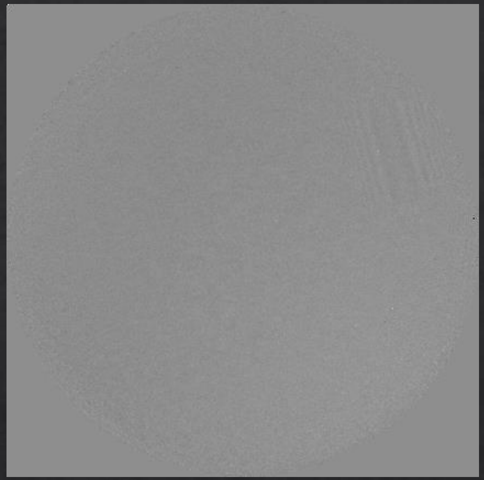


Time evolution analysis

- Some (but non-disturbing) high frequencies

- 0.0046 Hz (1000 images in ~60 hours)





1st phase substracted– 10 Hz

Perspectives for the bench

- Automatize the bench (in progress) for easier measurement (in a unique interface for all elements)
- Remotely operate the bench ?
- Calibration of the NCPA
- Real-time correction of perturbation
- Compute an interaction matrix for optimal correction
- Fully characterize the bench (how does the mask move with time) and heat

Acknowledgments

Kjetil DOHLEN, Arthur VIGAN,
Jean-François SAUVAGE, Amandine CAILLAT,
Thierry FUSCO, Mamadou N'DIAYE