Adaptive wavefront correction at high power laser systems

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Alexander Soloviev, December 1 (2020)

The 2nd China-Russia Frontier Seminar on Ultra Intense Laser Technology and Intense Field Physics

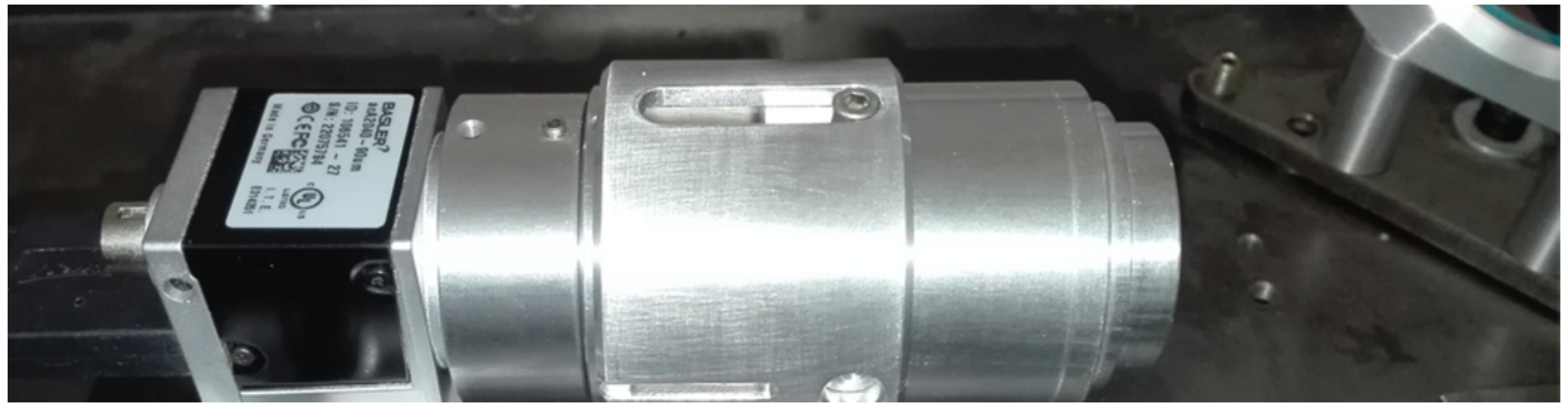
Motivation:
Focal spot peak intensity increase

An ideal focusing system converges the laser pulse with the ideal wavefront down to diffraction limit.

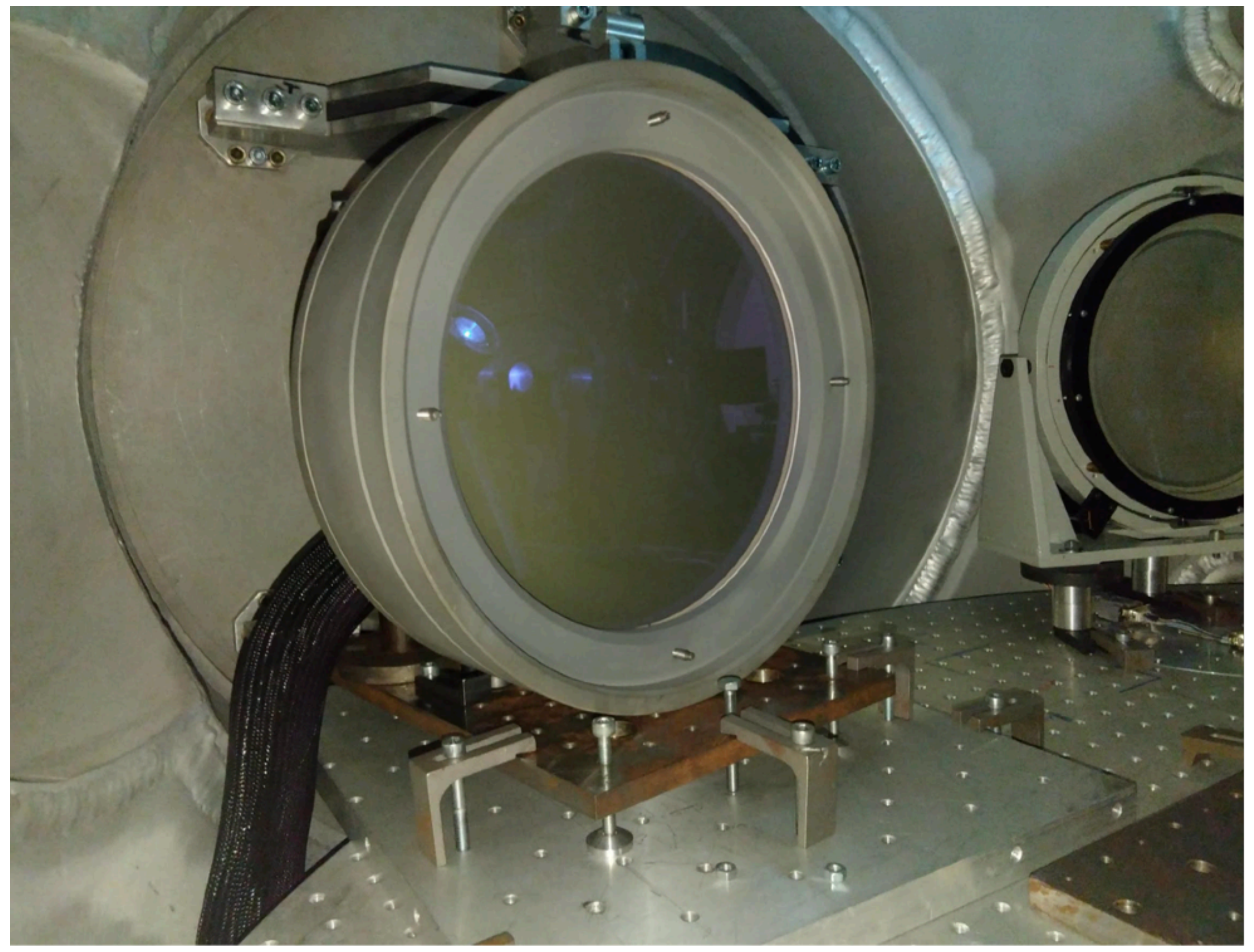
Assumptions:
1) spatial coherence,
2) spatial homogeneity of the spectrum (amplitude & phase)
3) absence of the angular chirp
4) λ - central wavelength

For the geometrical aberrations correction, a mirror with the controllable surface shape may be used

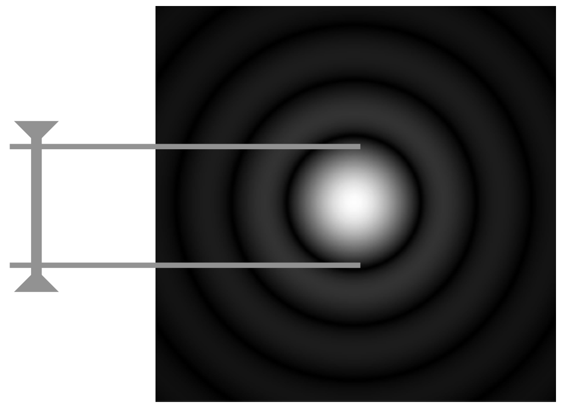
The wavefront measurements can be done by Shack-Hartmann sensor



Bimorth mirror in the interior:



$$2{,}44 \times \frac{\lambda}{D} f$$



Wavefront sensor (working principle):

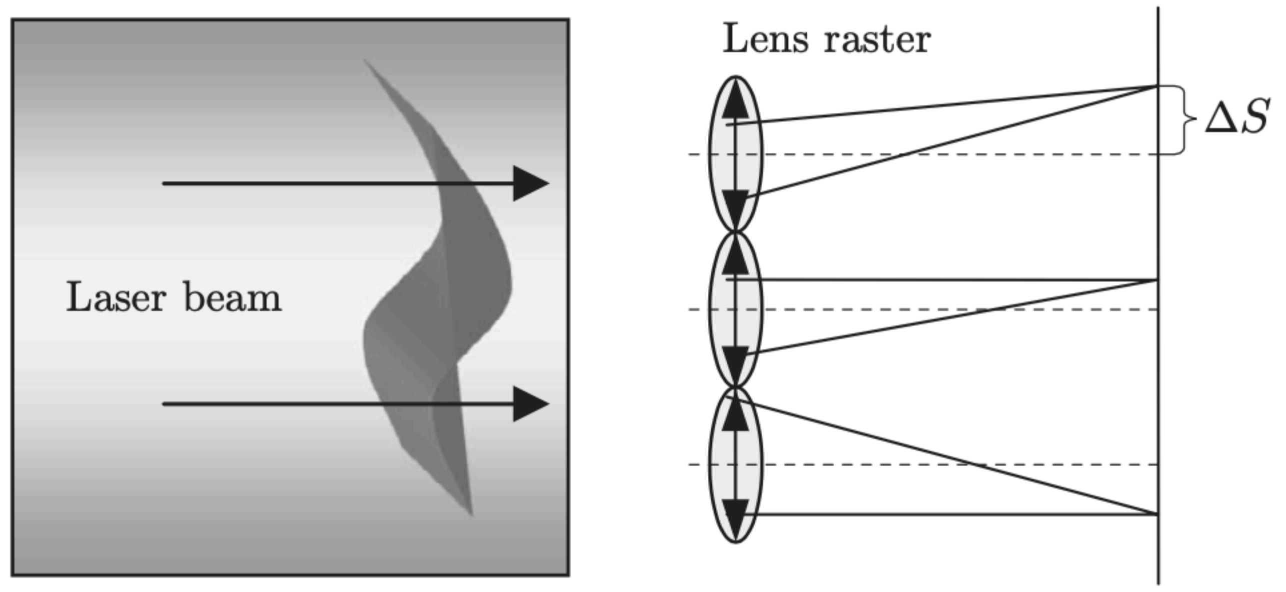
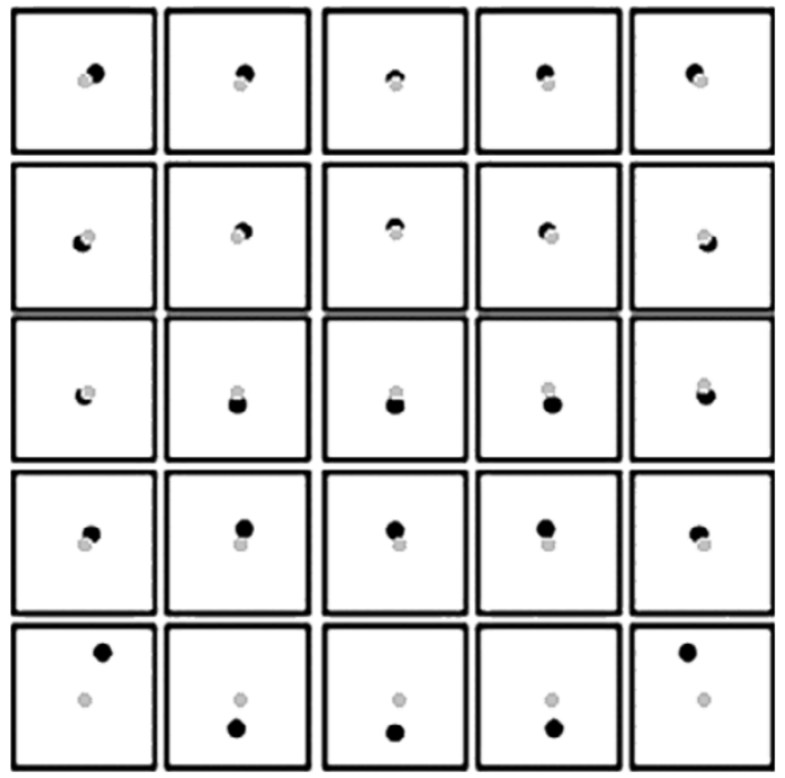


Fig. 4.



Adaptive system basic algorithm:

Phase conjugation:

1) Measurement of the respond functions for all the actuators

while true:

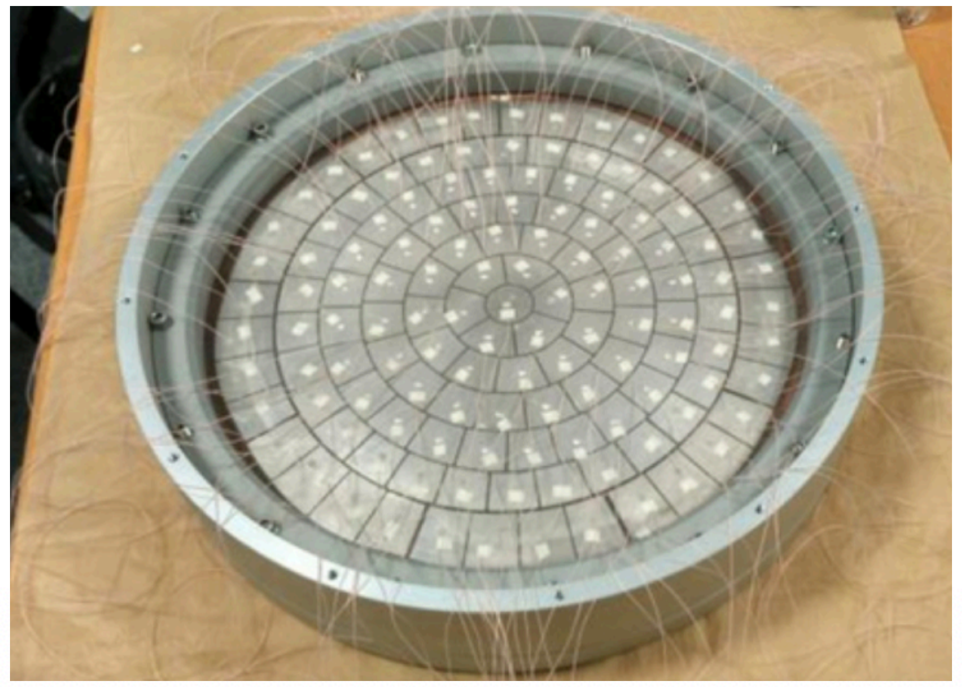
I) Phase distortions measurement, in the conjugated plane

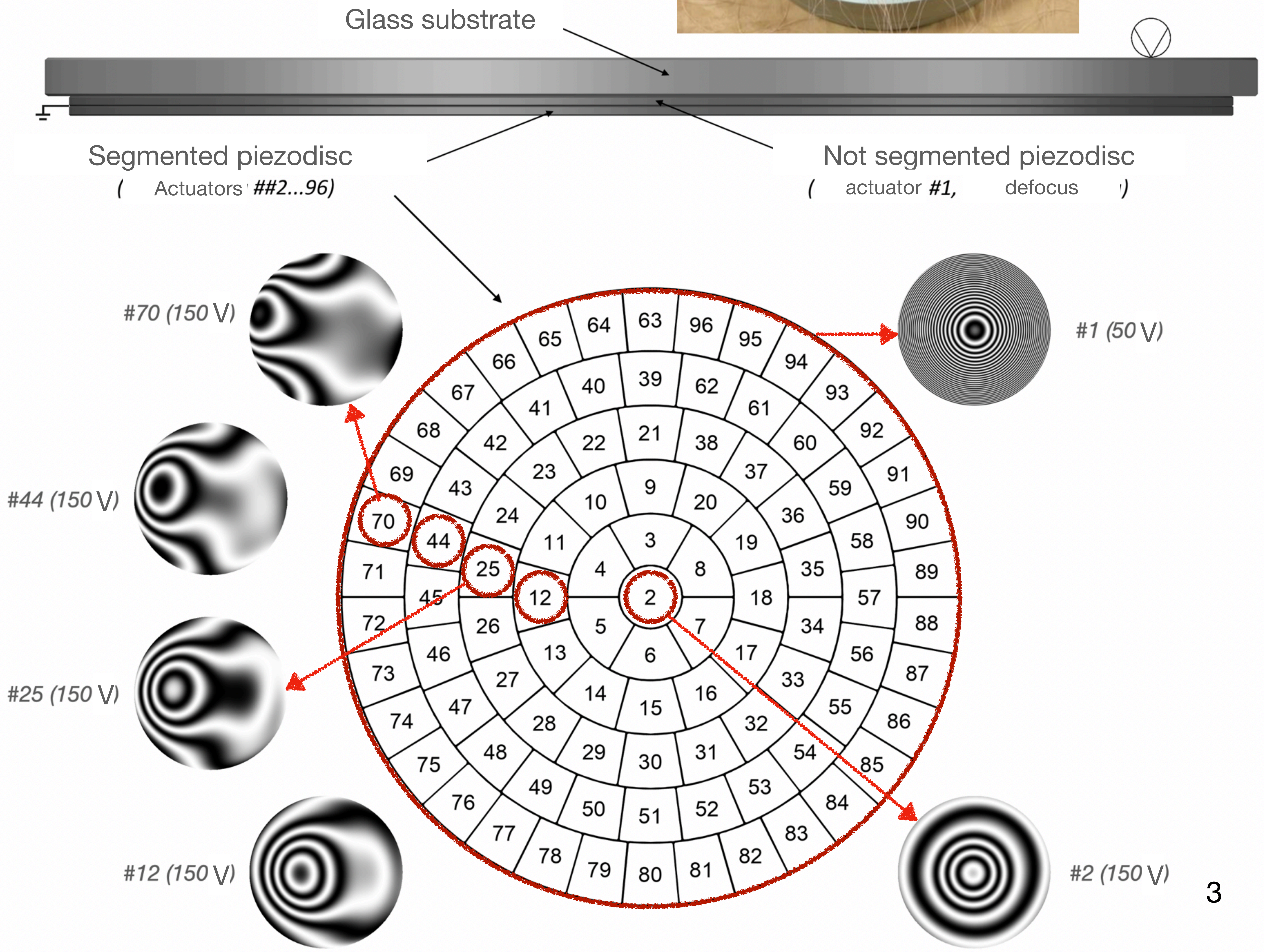
II) decomposition of the distortions into a series of respond functions. (The coefficients in the decomposition are the voltages)

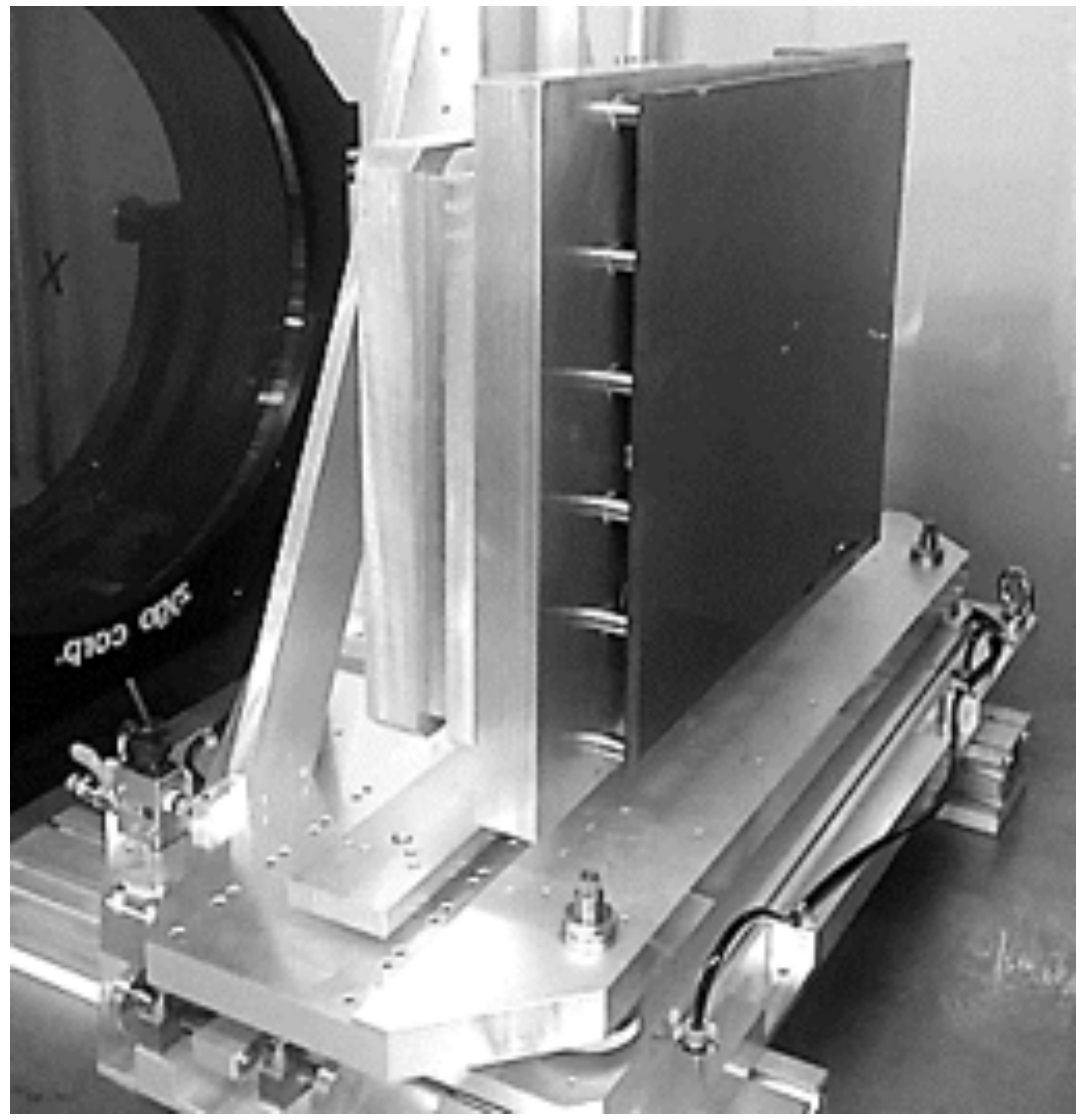
III) The voltages application to the actuators

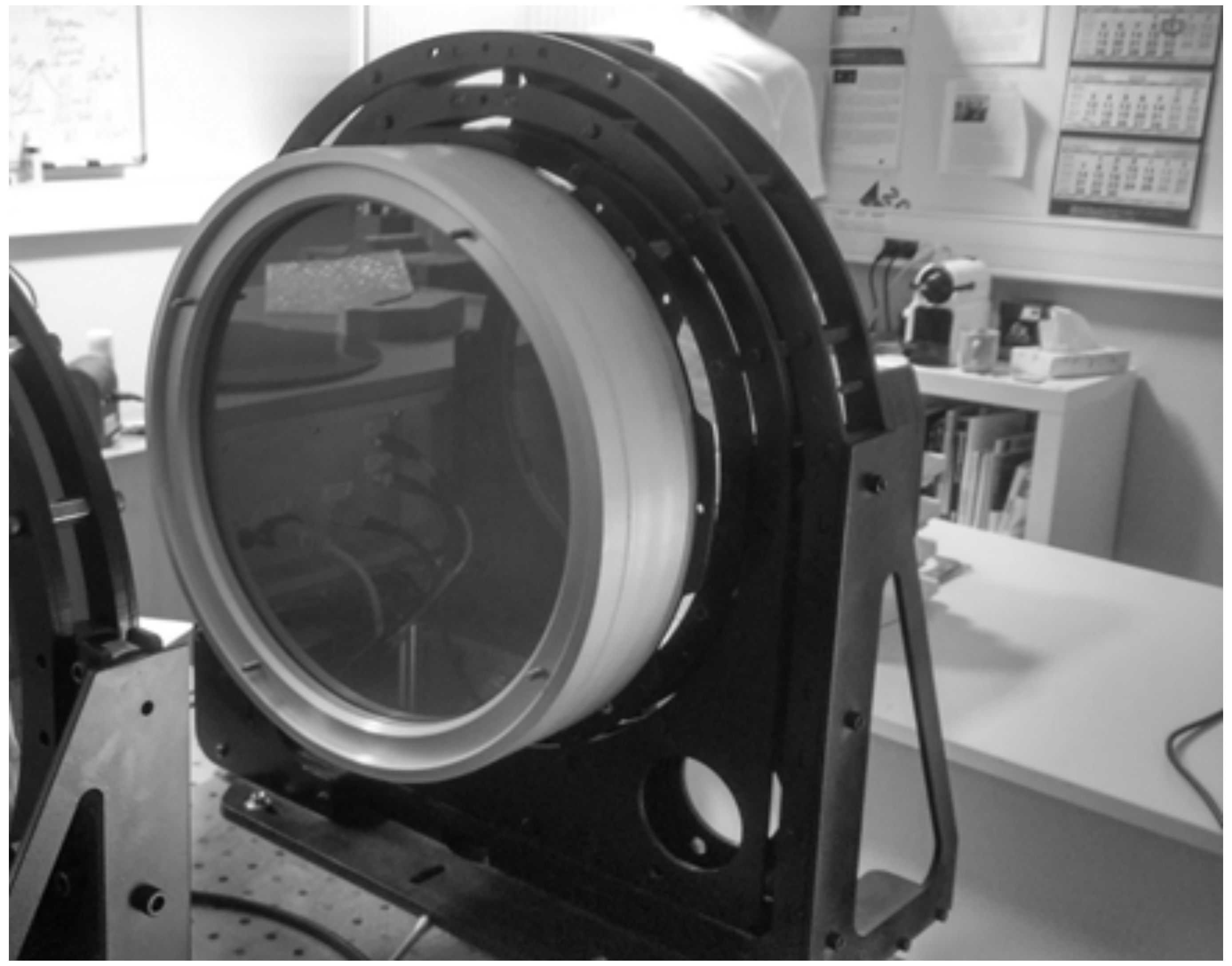
Why the focal spot may be not perfect:

1) Differential distortions (the key-point of the work)
2) Approximation error
3) Dynamic aberrations
4) Nonlinear phase distoritons



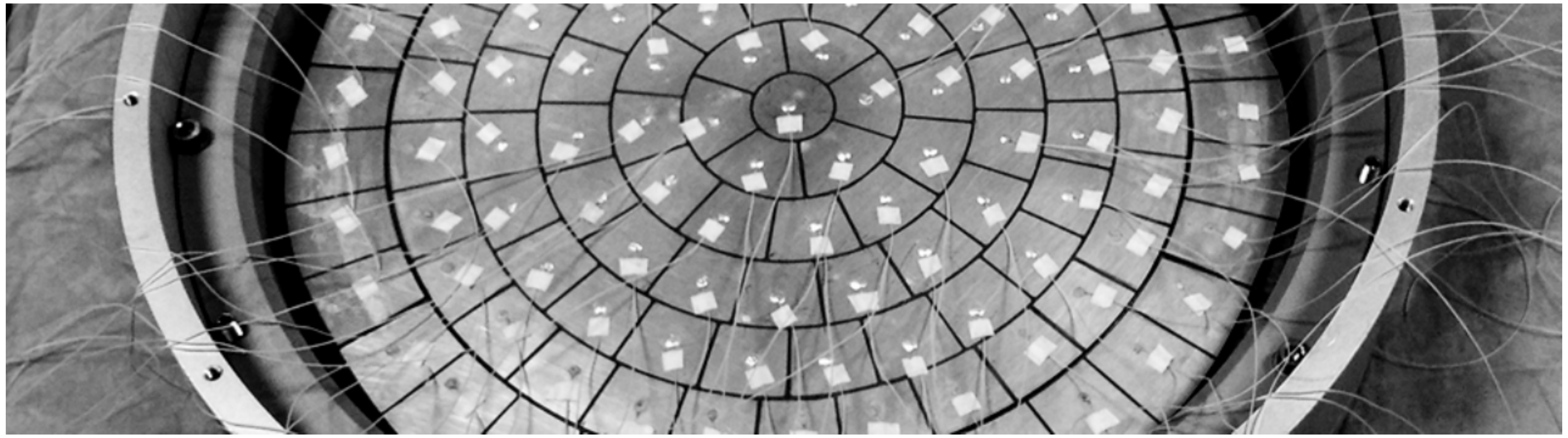






SPECIFICATIONS

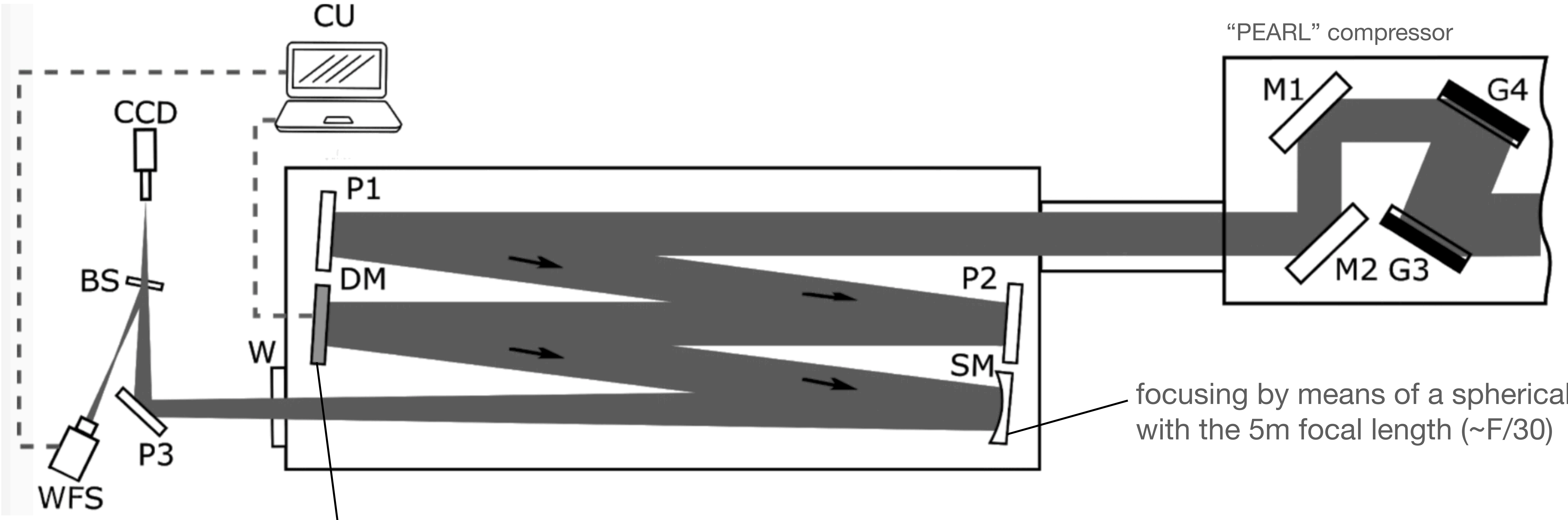
- **CLEAR APERTURE: 450 mm AND LARGER**
- **VOLTAGE RANGE: -500 … +600 V**
- **NUMBER OF CONTROL CHANNELS: UP TO 127**



AKA Optics akaoptics.com

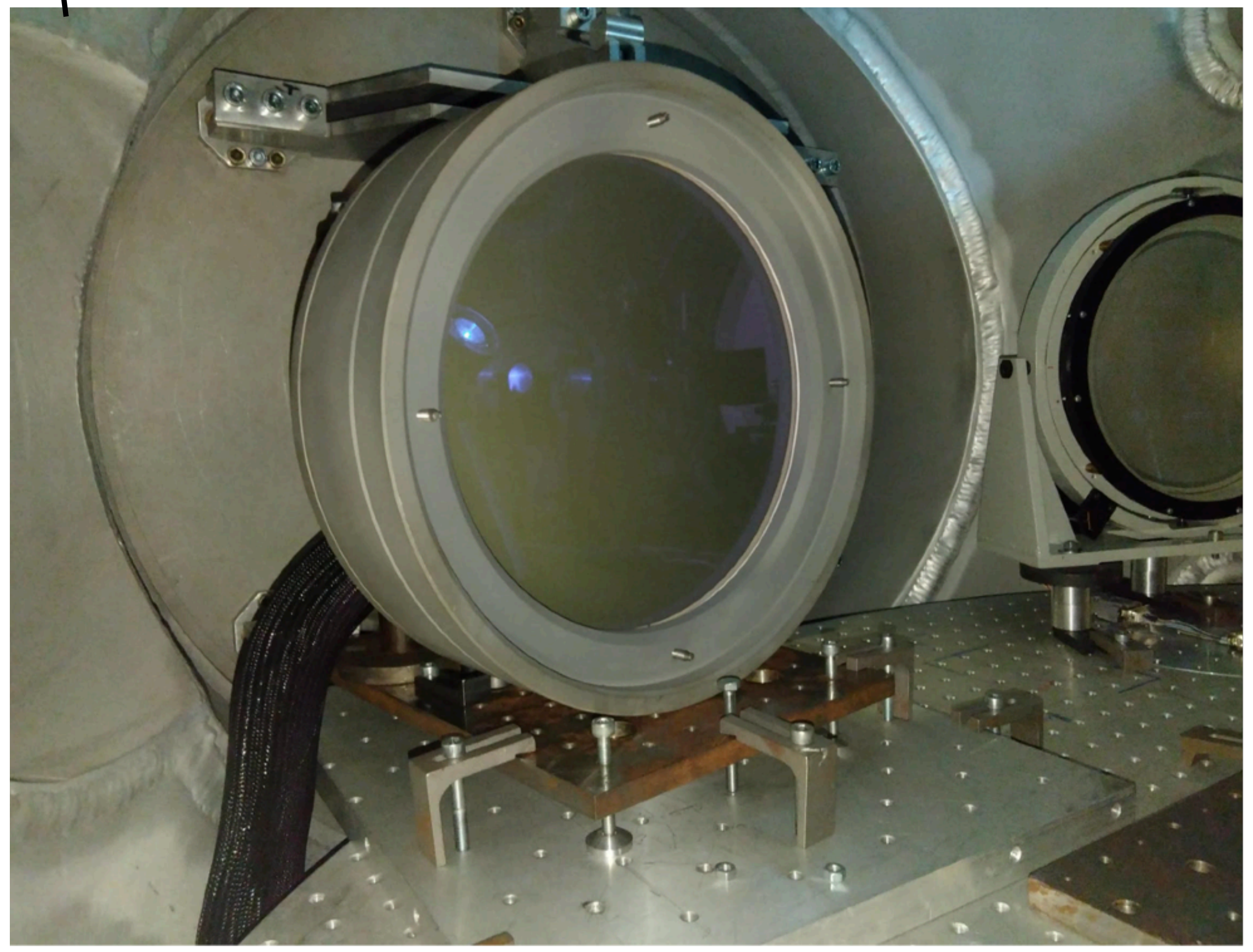
Active Optics NightN activeoptics.ru

Principle scheme of the experiment:



focusing by means of a spherical mirror with the 5m focal length (~F/30)

Deformable mirror in the interior:



Laser regimes:

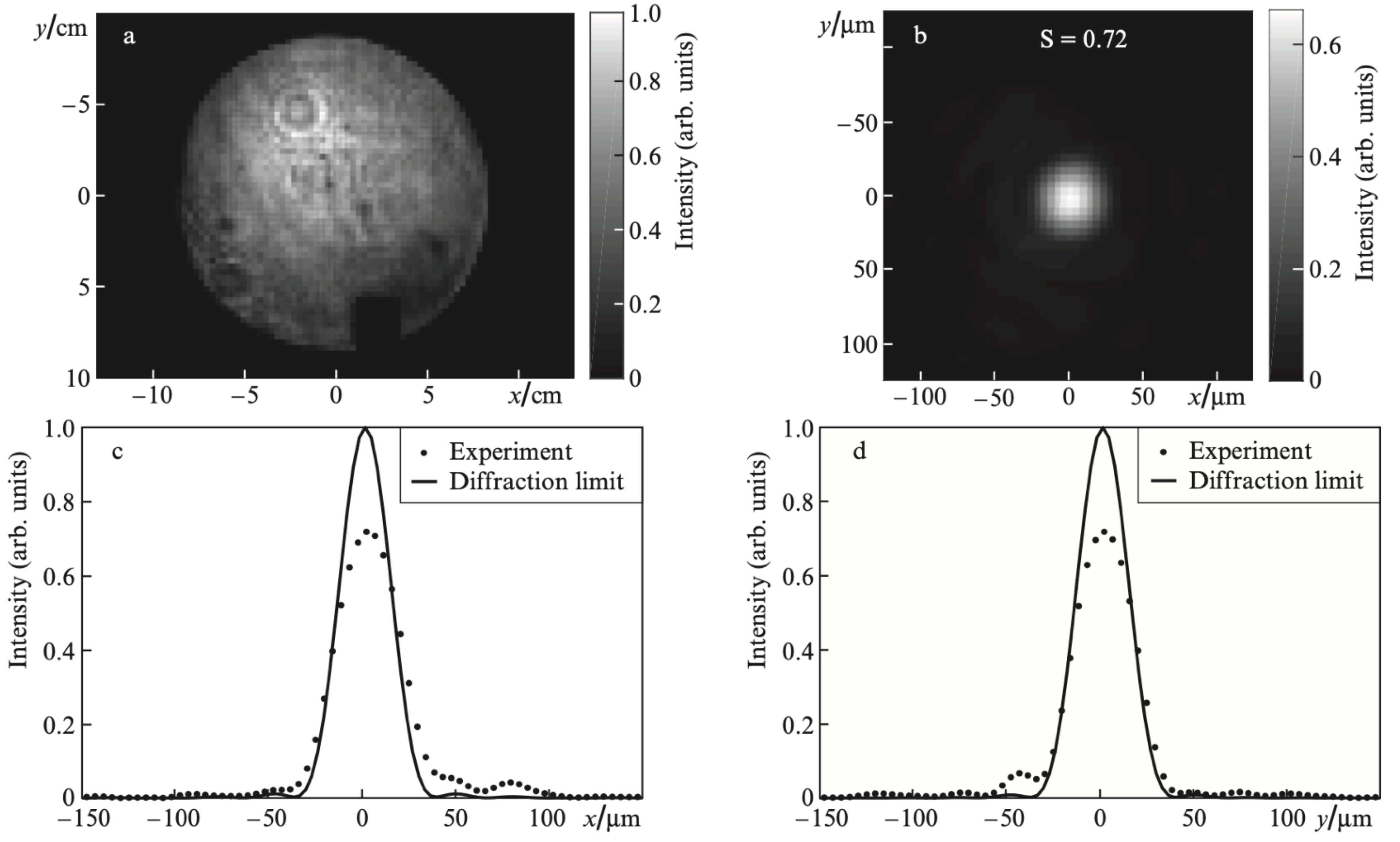
1) Quasi-CW (70 MHz, ~500 pJ)
2) Pulsed alignment (1Hz, ~10 mJ)
3) Single-shot (10^{-3} Hz, ~20 J)

B-integral<1/10

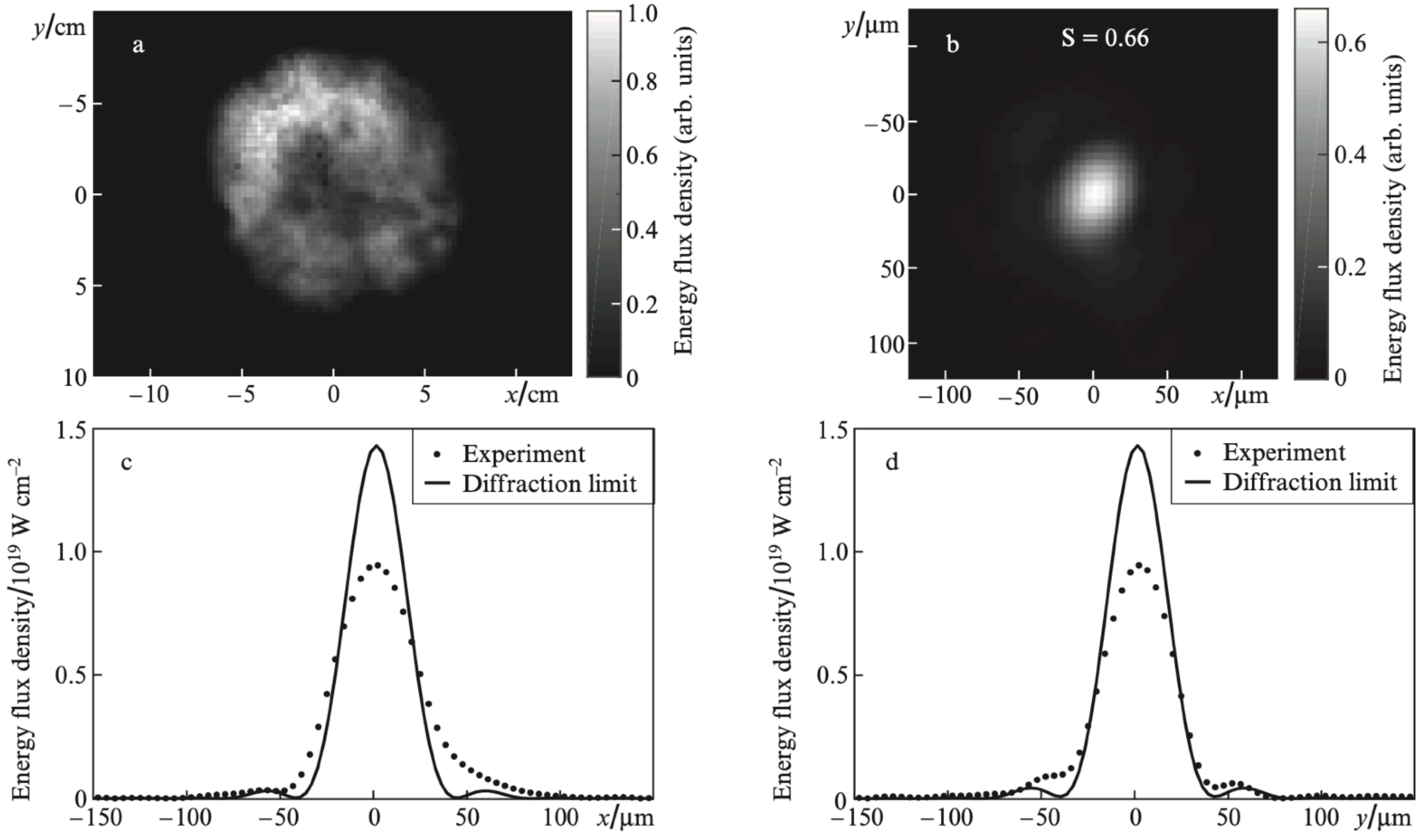
For all the regimes: 910nm+-20nm, ~50fs

Experimental results for wavefront correction:

Quasi-CW regime:



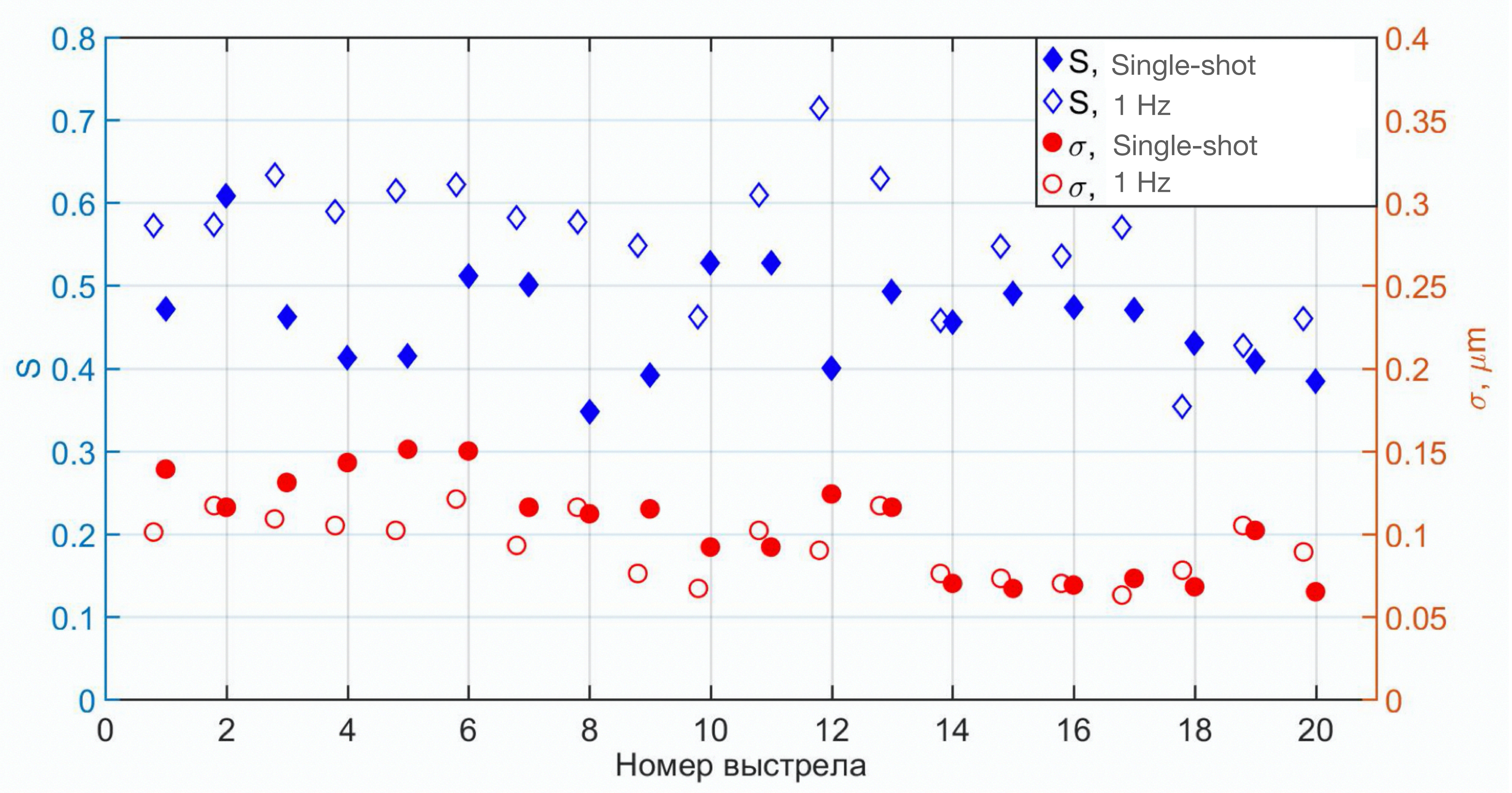
Single-shot regime (7 J, 50 fs):



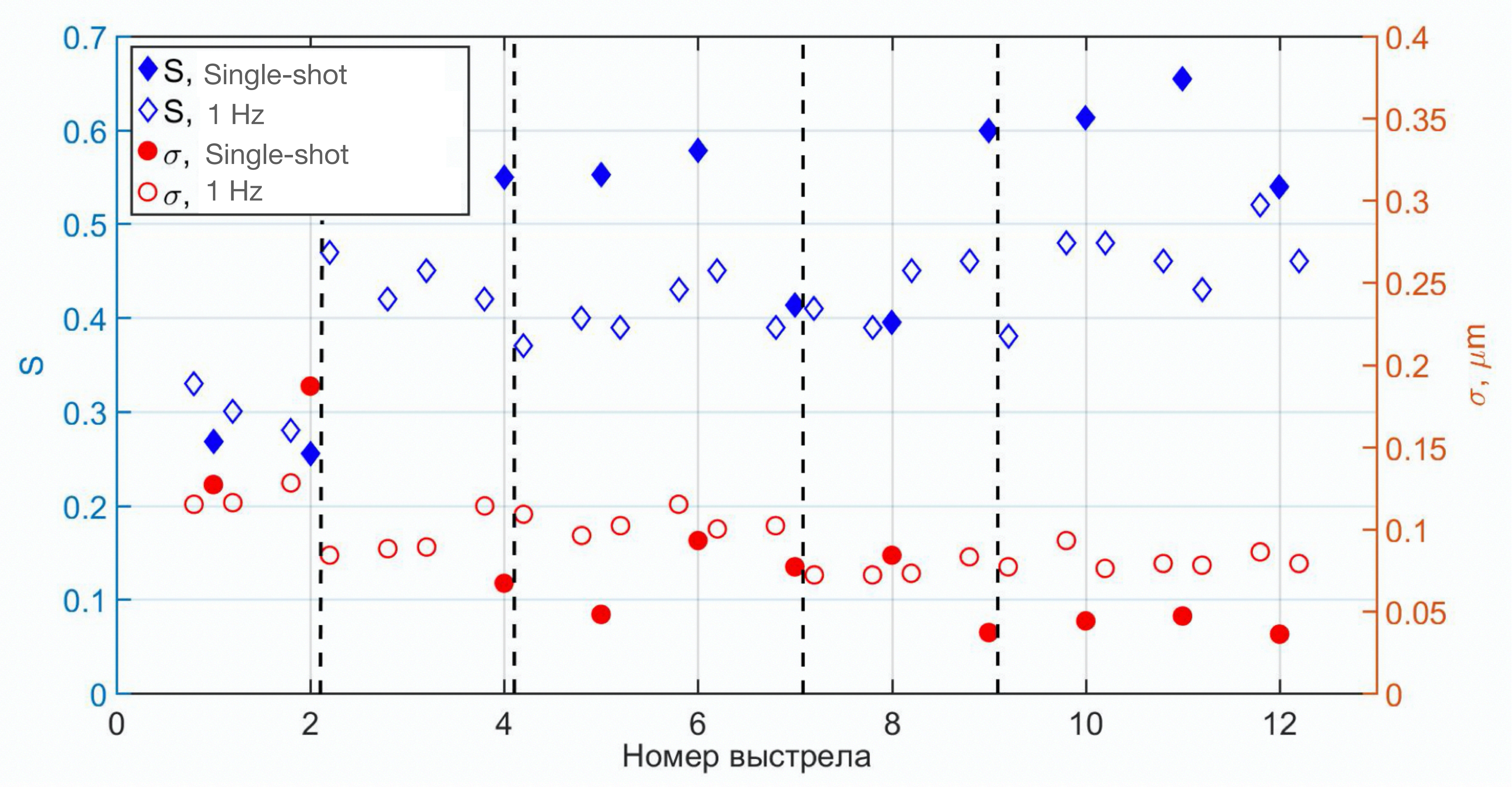
Notes:
1) When the Strehl ratio S is measured, the near field distribution is taken into account
2) The S measurement accuracy is improved by means of original modification of the Fourier-filtration algorithm

Statistics:

Phase conjugation with respect to 1Hz alignment regime



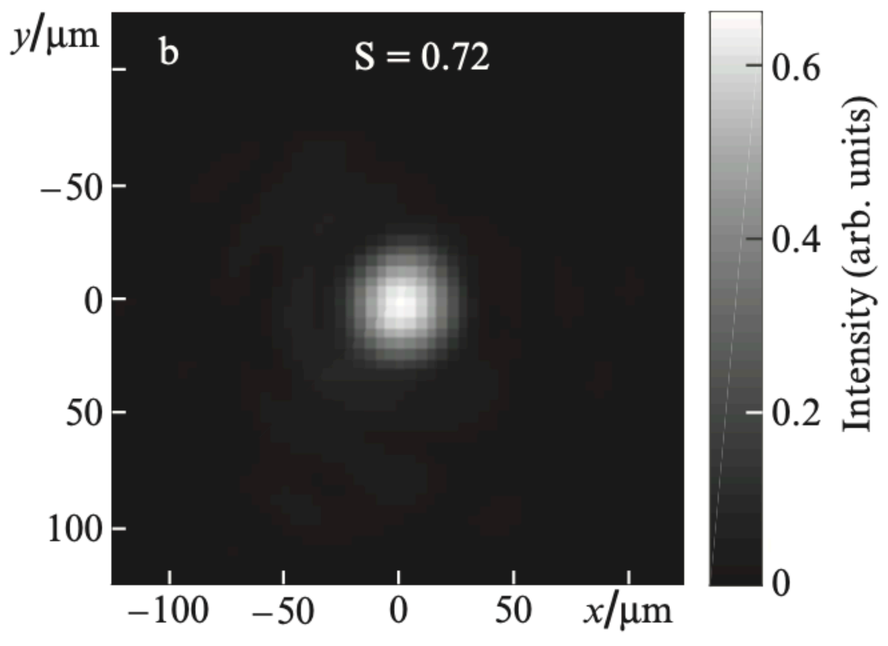
Phase conjugation with respect to single-shot regime



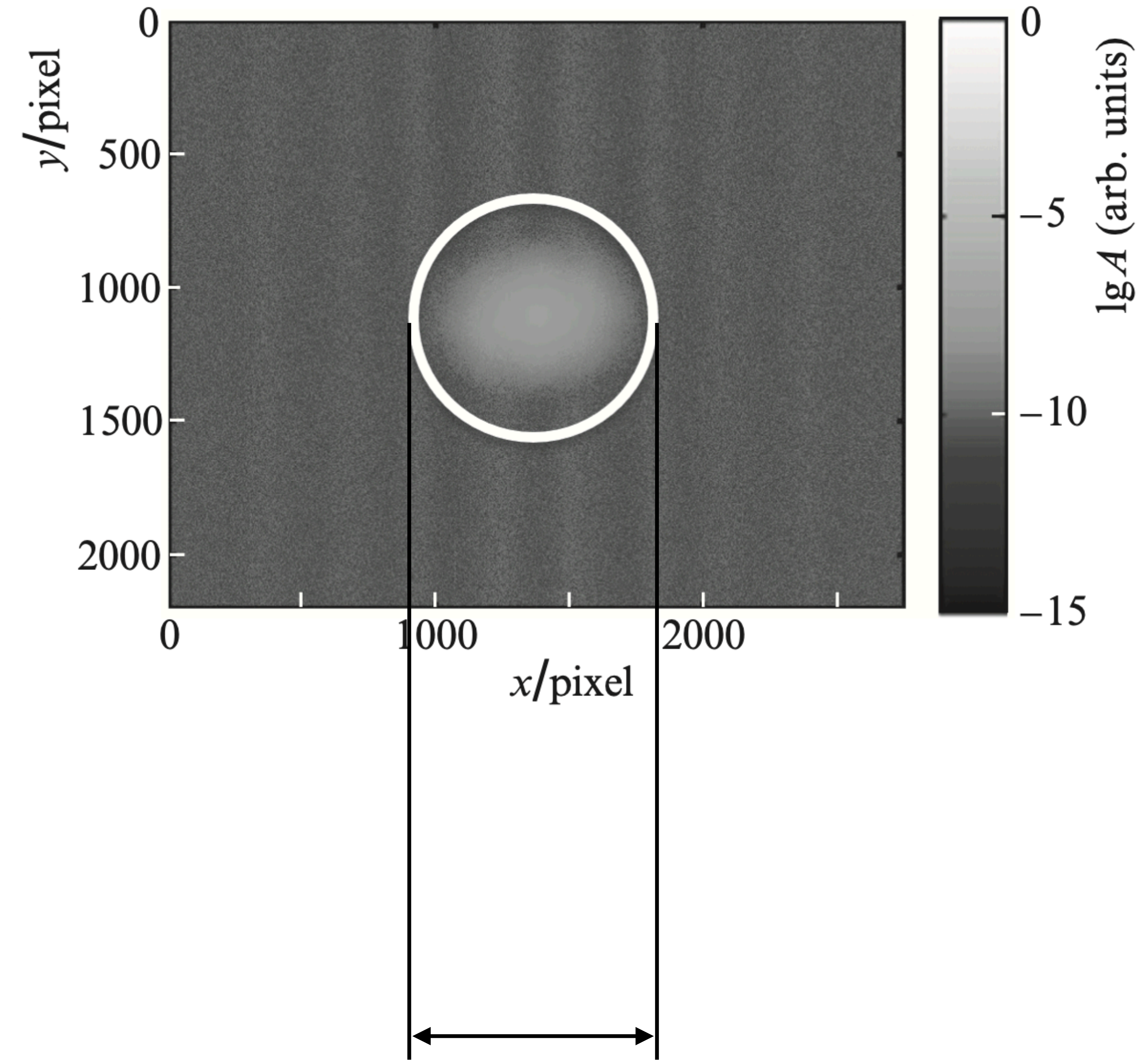
Conclusions on the plots:
The higher (approx. 20%) Strehl ratio S is always corresponds to the regime under which the phase conjugation has been applied. Thus, it is shown, what wavefront deviations from shot to shot in the single-shot regime are smaller than the difference between the single-shot and the 1Hz alignment regime.

Fourier-filtration:

<4% of the peak pixel value

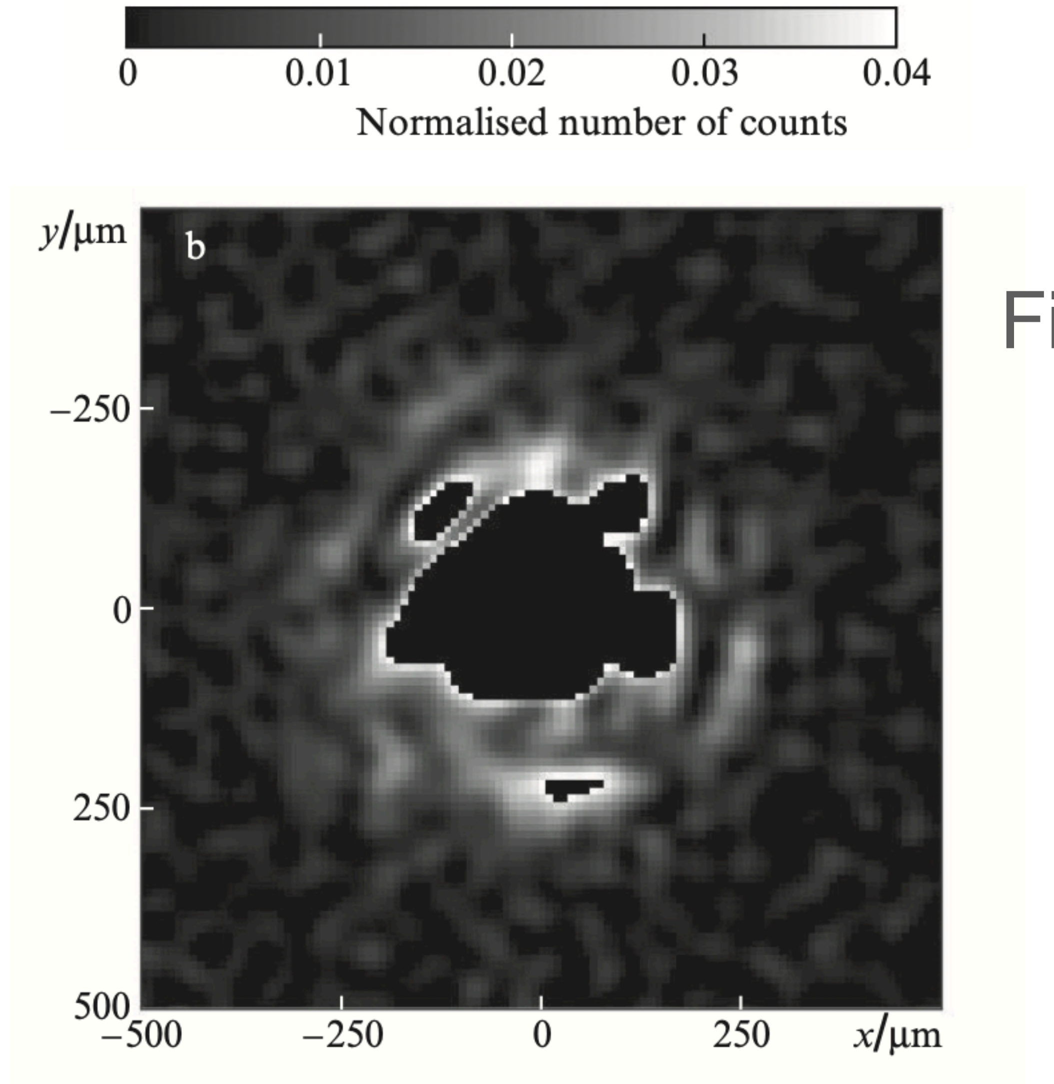


FFT

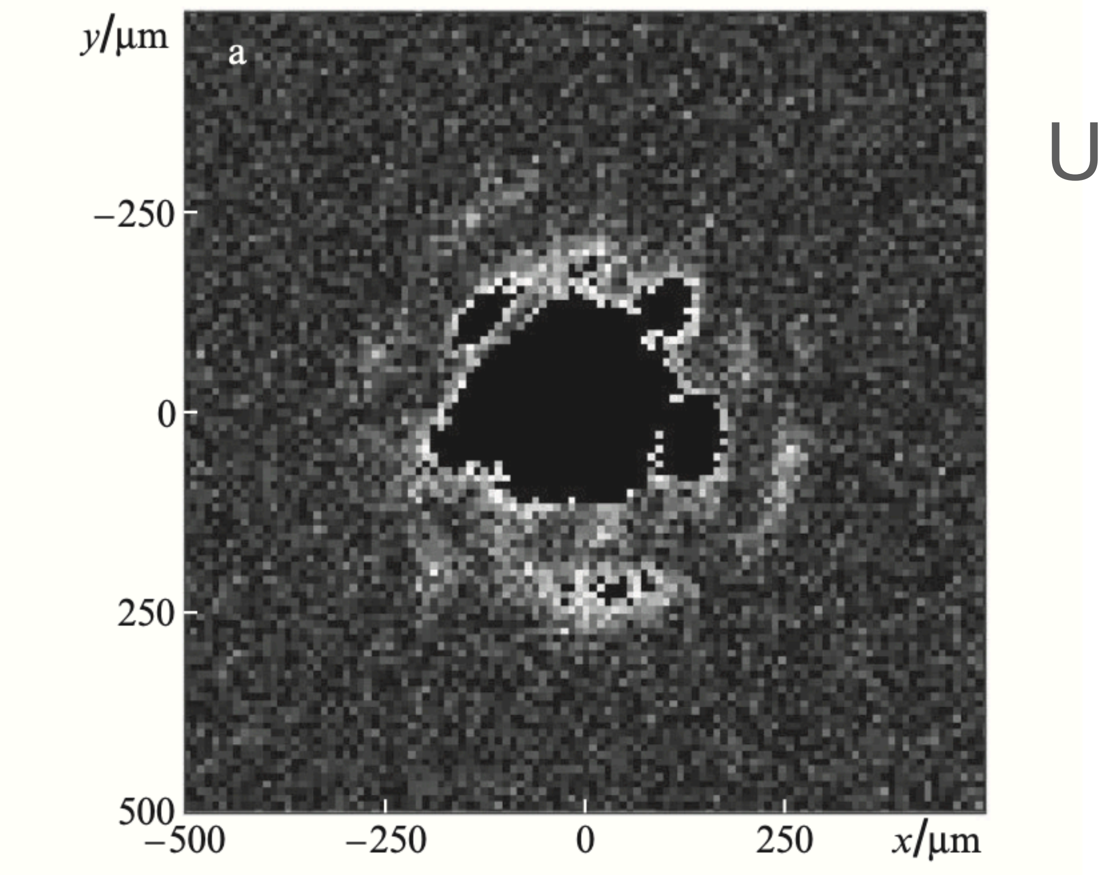


D ~ diffraction divergence

IFFT



Filtered

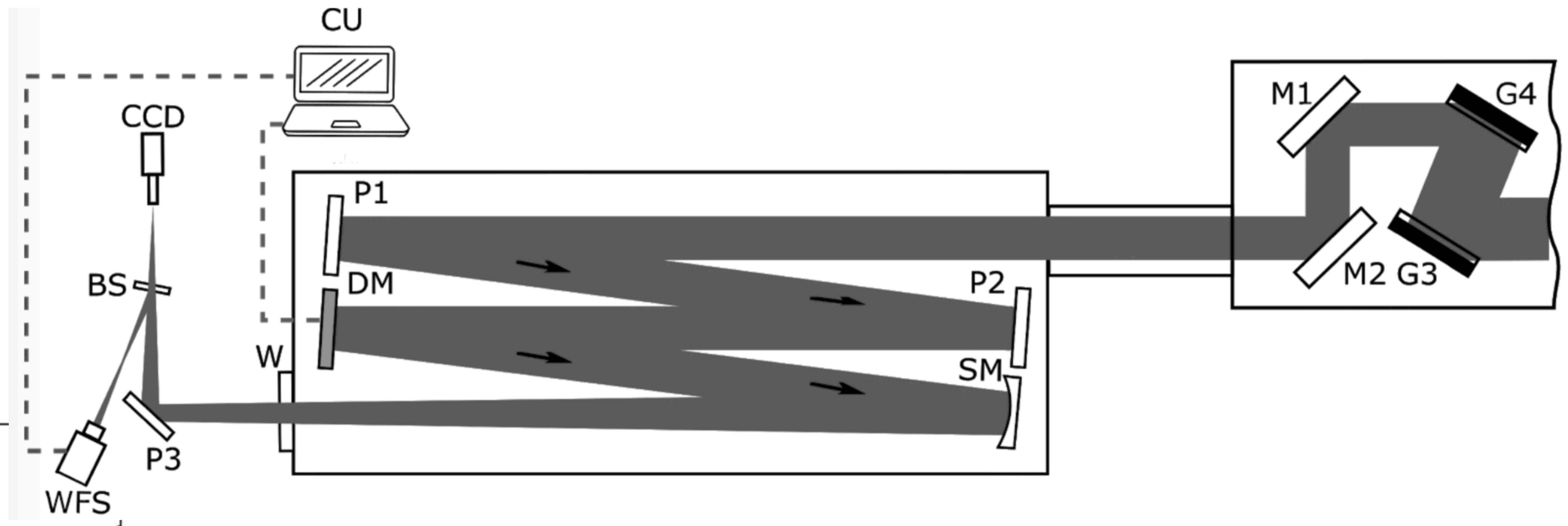


Unfiltered

The main problem is to find the “zero level”.

FFT allows to suppress the noise energy approx. in 10 times. Thus the error of Strehl ratio calculation decreases in factor of 10

Differential abberation treatment:



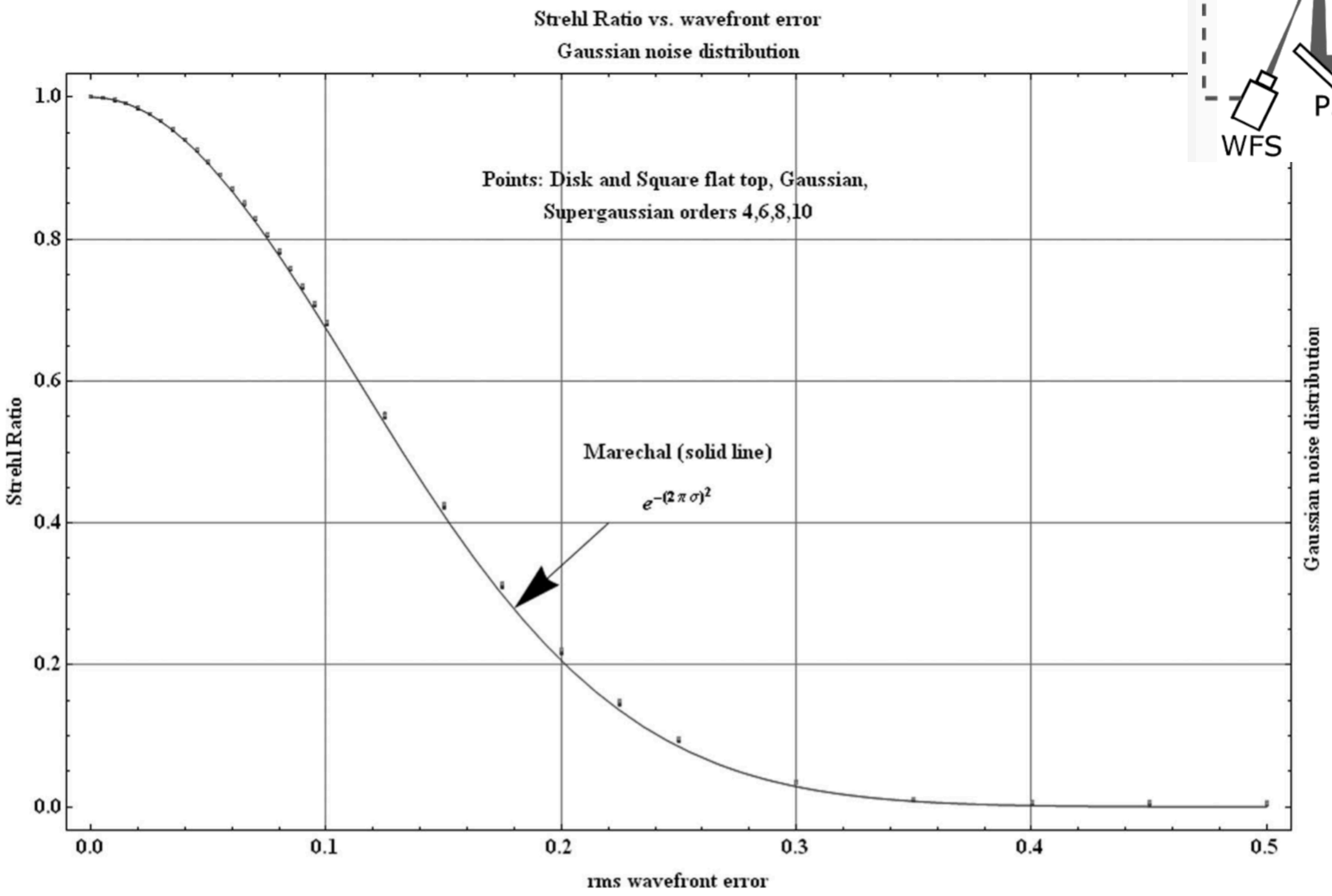
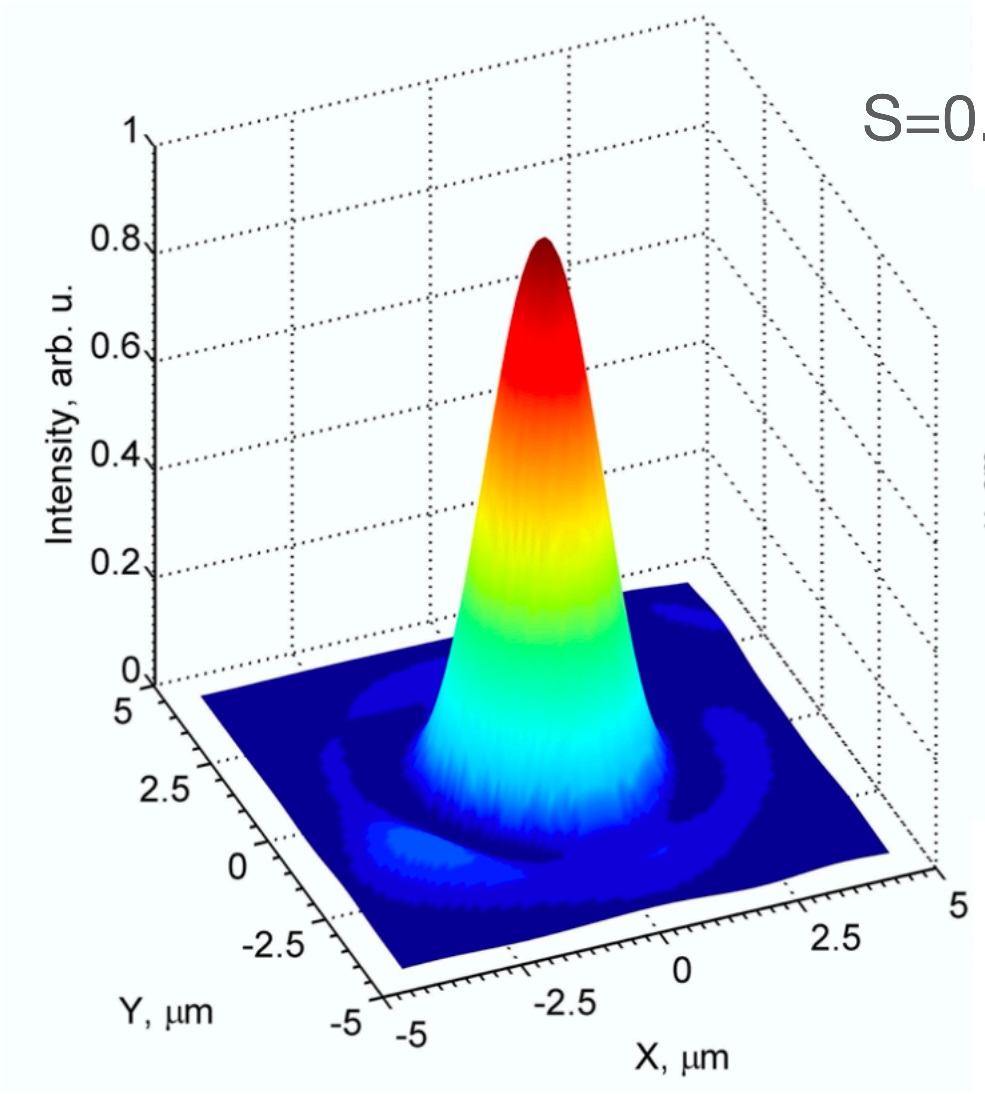


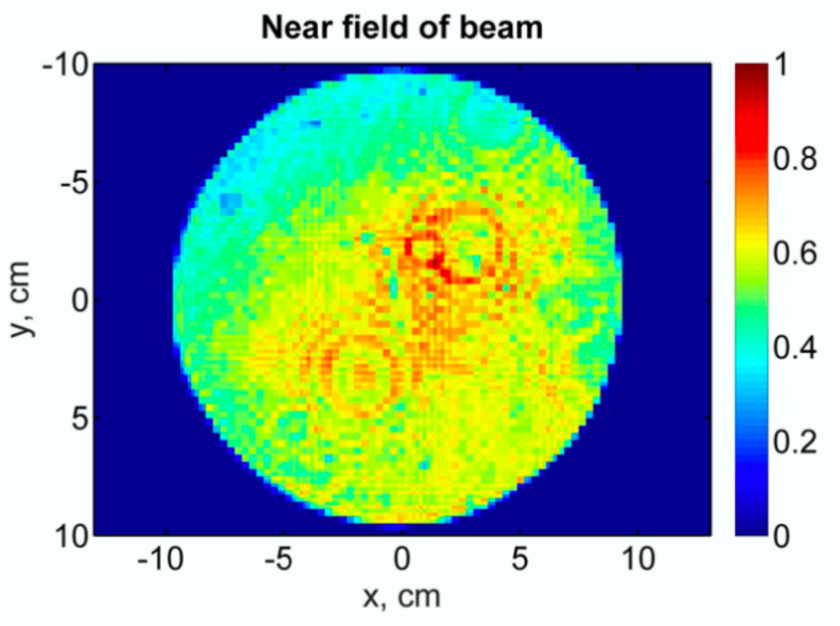
Fig. 1. Strehl ratio for a Gaussian noise distribution.

Problems:

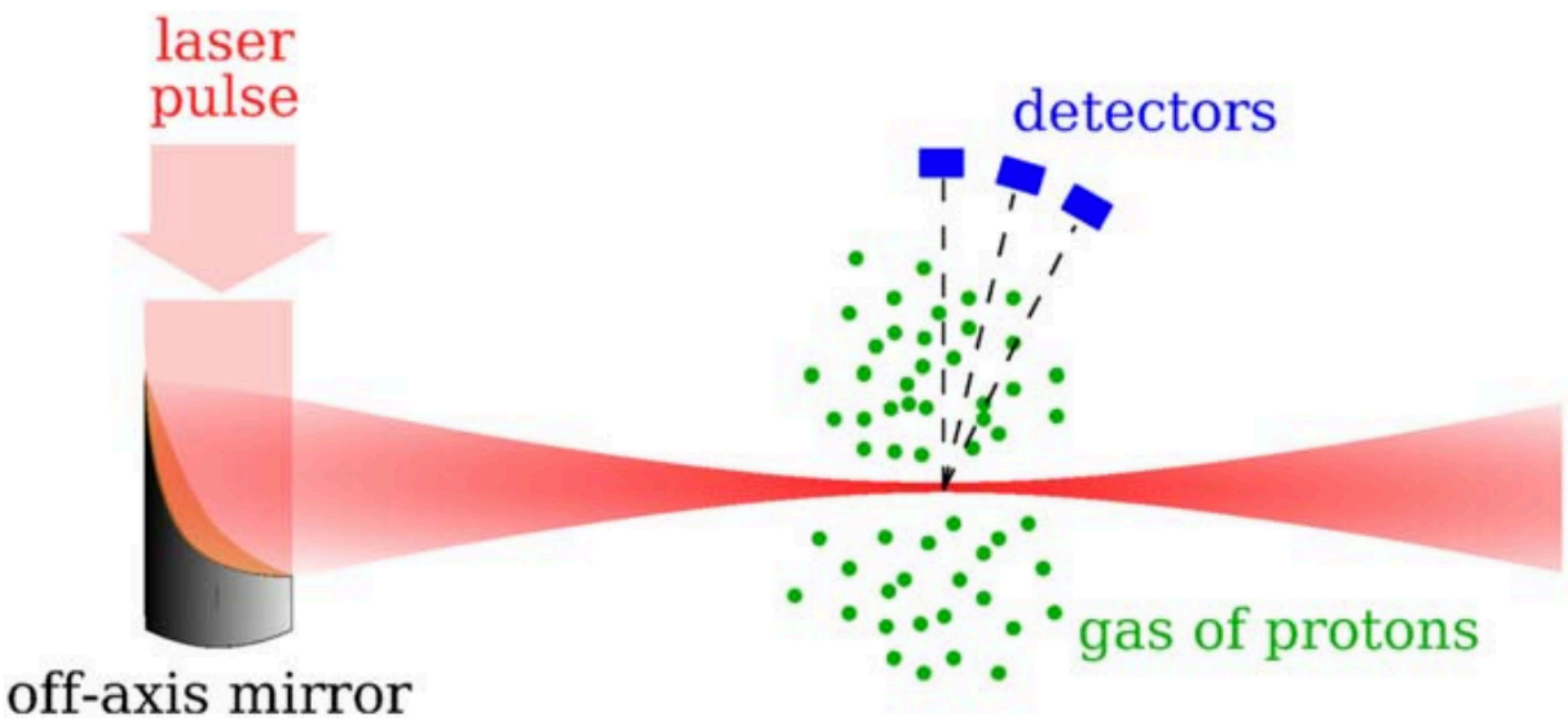
1. Focal spot optimisation without Phase Conjugation
2. Optical conjugation of the WFS and bimorth mirror under tight focusing



S=0.82

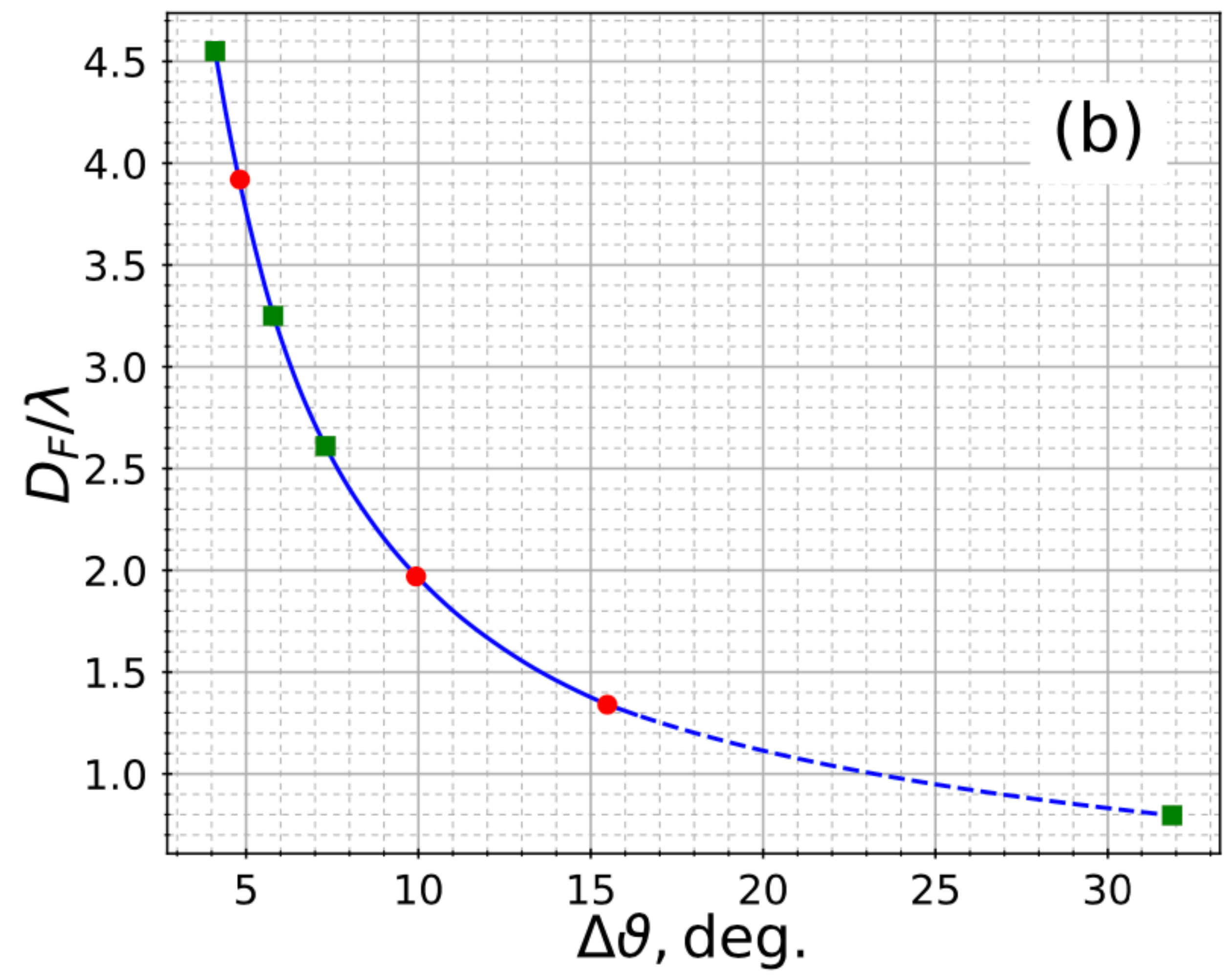


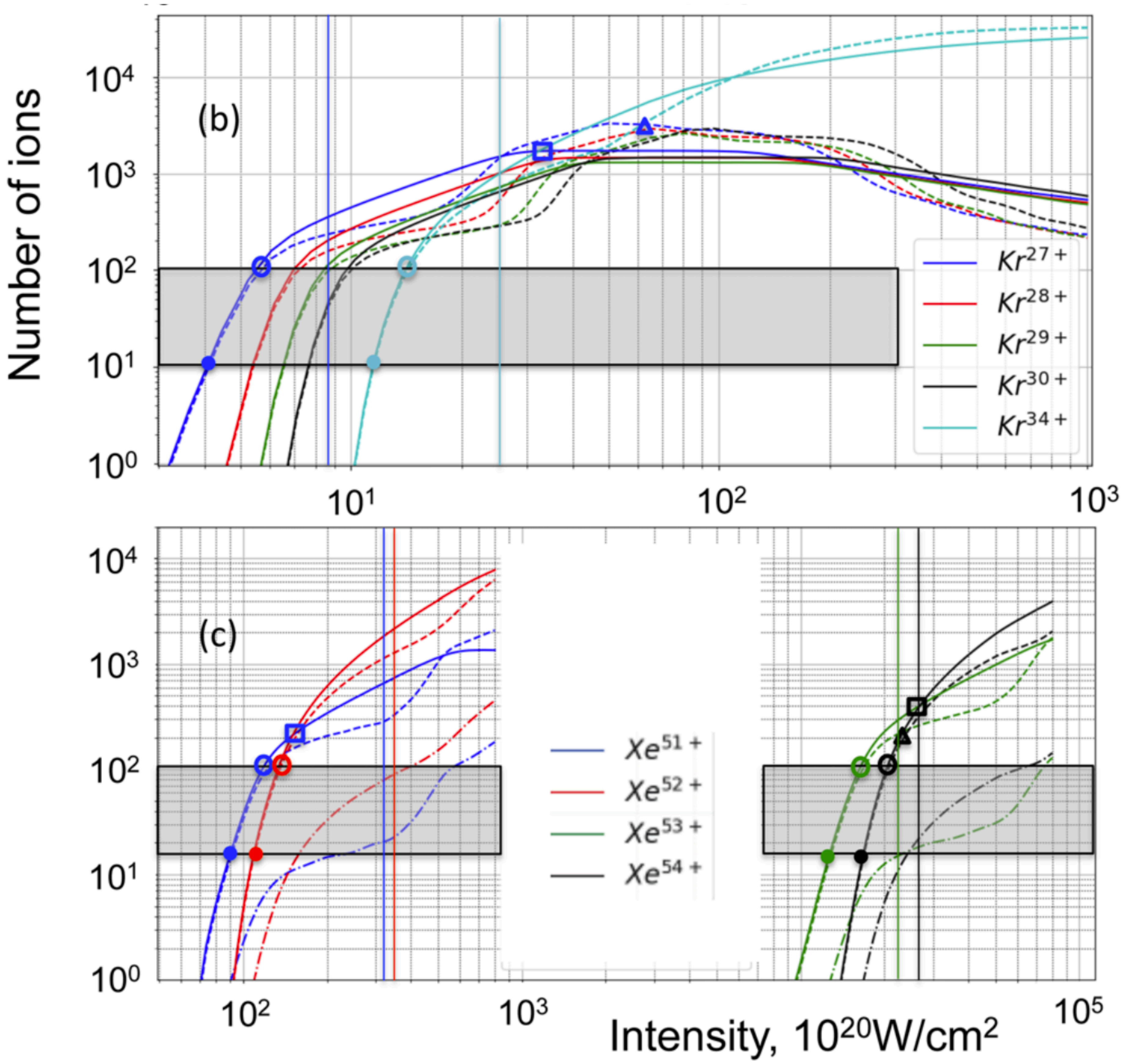
Direct intensity measurements:



Matter Radiat. Extremes **5,** 044401 (2020); doi: 10.1063/5.0005380

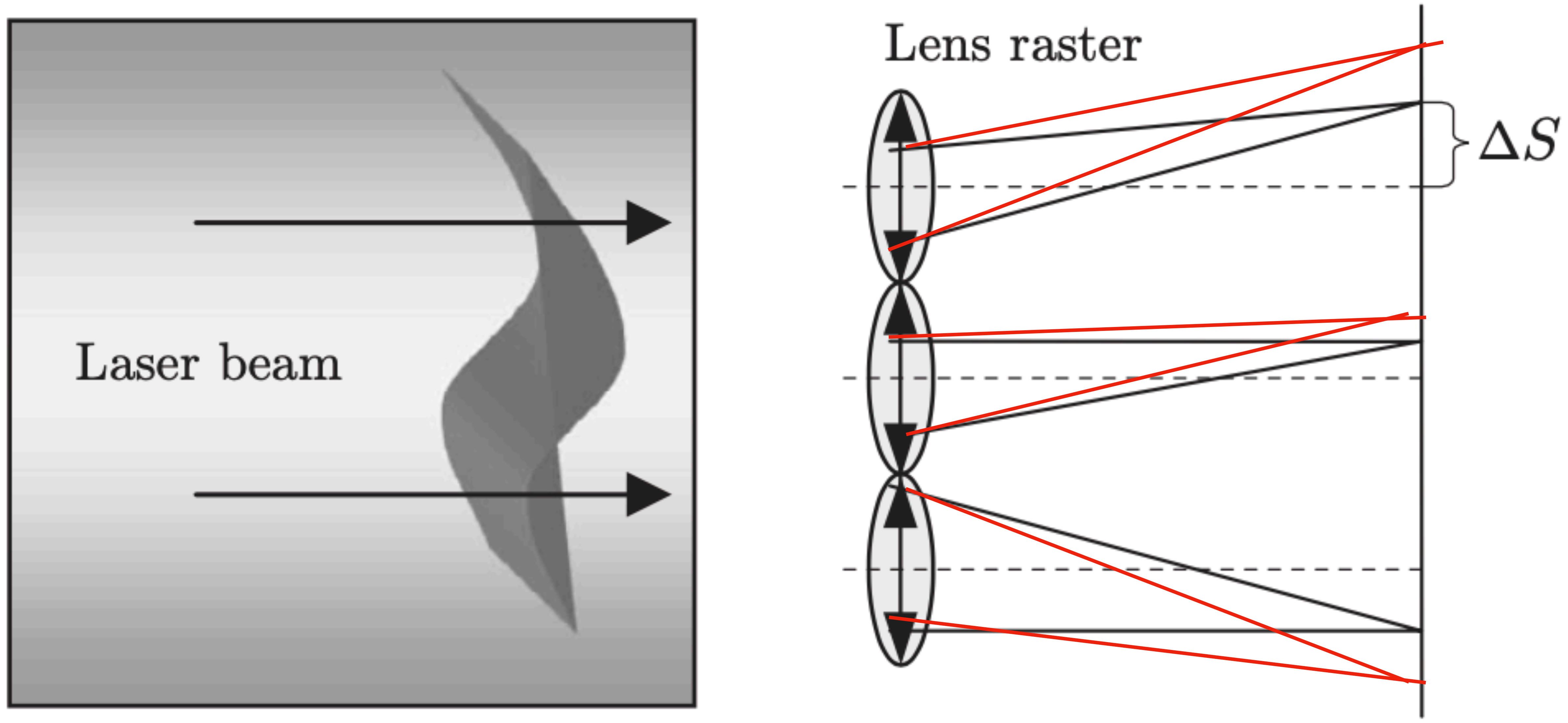
O. Vais et al.
New J. Phys. **22** (2020) 023003





Correction of nonlinear phase-front distortions :

WFS behaviour in case of nonlinear phase



$$1mm - \frac{50mJ}{1cm^2} for 50fs$$

$$5m - \frac{200mJ}{1cm^2} for 1ns$$

The main results:

For the PEARL facility, the use of adaptive wavefront correction system allow of increase of the Strehl ratio from 0.3 up to at least 0.6. It means that the peak intensity in the focal spot is doubled. For a PEARL laser, when the radiation is focused by a parabolic mirror with *f* = 32 cm (relative aperture *f*/2), pulse duration 50 fs, energy 20 J, and S = 0.6, the intensity at the focus will be $6*10^{21}$ W/cm–2.

The key point was the original procedure for differential distortions elimination.

Near perspectives:

1) Peak intensity direct measurements
2) Focal spot optimisation for the laser pulse after the nonlinear phase self-modulation (SHG, CafCA etc.)

Quantum Electronics **50** (12) 1115–1122 (2020)

LASERS

https://doi.org/10.1070/QEL00000

Adaptive system for wavefront correction of the PEARL laser facility

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