Flexible Optical B.V.

Adaptive Optics • Optical Microsystems • Wavefront Sensors

Breadboard adaptive optical system based on 19-channel MMDM: technical passport

OKO Technologies,

OKO Technologies is the trade name of Flexible Optical BV

1 Installation of FrontSurfer software (Windows 2000/XP/Vista/7/8)

1. Start “setup.exe” from “fsurfer” directory of the installation CD to install FrontSurfer to your computer. Follow further installation instructions.
2. Start “Install.exe” from “keylok” directory of the installation CD to install drivers for the protection dongle. Select the option “USB dongle”. Please note that the installation should be completed BEFORE the dongle is connected.
3. Attach the FrontSurfer dongle to a free USB port. The system will recognize the device. Choose for automatic installation of the driver.
4. Under Windows Vista, 7 and 8, FrontSurfer should be started in compatibility mode under administrator access rights. To enable them, right-click on “FrontSurfer” shortcut and locate “Compatibility” property sheet. Enable the options “Run this program in compatibility mode for Windows XP (Service Pack 3)” (optional, maybe omitted on the most recent systems) and “Run this program as an administrator” and press OK to confirm.
5. Now you may start “FrontSurfer” from the Start menu.

2 Wavefront sensor

Please read the FrontSurfer manual [1] for general information on the wavefront soft- and hardware.

2.1 Specifications

Parameter	Value
Serial Number	FS3370-O300-F18.6_15_08
Camera model	uEye UI-3370CP-M-GL
Camera type	digital CMOS
Camera interface	USB 3.0
Array geometry	orthogonal
Array pitch	300 um
Array focal distance	18.6 mm
Clear aperture	≤9.0 mm
Subapertures	≤ 900
Maximum tilt, fast mode	0.007rad
Maximum tilt, slow mode	N/A
Repeatability, RMS	$\lambda^*/300$
Repeatability, PV	$\lambda^*/60$
Acquisition rate	≥80 fps
Processing rate, fast mode	∼38 fps**
Processing rate, subsampling x2 mode	∼102 fps**
Recommended Zernike terms	≤300
Wavelength	400. . . 900 nm (also sensitive at near IR)

* For $\lambda = 633$ nm.

** For low-order aberration analysis on a PC with Intel i7 1.73 GHz processor and 8 GB RAM.

The repeatability figures can be further improved by averaging over multiple frames. To enable averaging, go to menu "Options ⇒ Camera", press button "Properties" and correct the field "Average over . . . frames".

2.2 Using of the absolute and reference measurement modes

- To switch to the absolute measurement mode, go to the menu "Options ⇒ Parameters" and change the "Reference grid" setting to "square". Press "OK".
- To switch to the reference mode, go to the menu "Options ⇒ Parameters" and change the "Reference grid" setting to "get from picture". Press "OK" to complete.

2.3 Interfacing instructions

1. Install uEye camera drivers from "uEye" directory of the installation CD.
2. Connect the wavefront sensor to the USB3 port of computer (USB2 port also can be used, but this will limit the overall speed). The system will recognize the device. Choose for automatic installation of the driver.
3. Start "uEye Cockpit" program and make sure that you can see image from the camera.
4. Configure frame grabber type in FrontSurfer. For this purpose go to the menu "Options

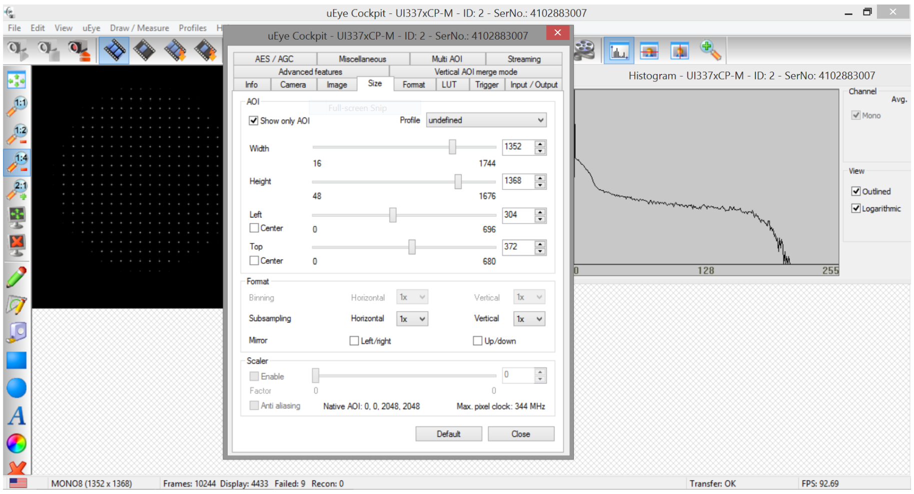

Figure 1: *Reading the AOI values set by the Crop tool of uEye Cockpit.*

⇒ Camera". In the dialog box "Camera interface" check "Plugin" option. After that, load plugin for the uEye camera by pressing "Load" button and selecting "uEye.dll" file in the FrontSurfer installation directory. Press "OK".

5. Load the wavefront sensor calibration data. For this purpose go to the menu "Options ⇒ Parameters". In the dialog box "Sensor parameters" press "Load" button and load the calibration file "calibration.txt" from the "fsurfer" directory of the CD. Press "OK" to complete.

6. To increase the processing speed, the sensor can be used with a smaller area of interest (AOI) and/or subsampling mode. To change AOI and subsampling mode, go to menu "Options ⇒ Parameters". In the dialog box "Camera interface" press "Properties" button. In "Area of interest" section, unselect the option "maximize" and adjust the fields "Left", "Width", "Top" and "Height" to set the desired AOI. You need to reduce dark space at the periphery of the frame, keeping the whole pattern of spots visible. A convenient way to set these parameters is to use the Crop tool of uEye Cockpit (see Fig. 1) to chose the desired AOI, jot down the AOI size and coordinates, and insert their values in the FrontSurfer. In "Sampling mode" drop-down menu, chose the desired sampling mode ("Normal", "Subsampling x2", or "Subsampling x4") (see Fig. 6). Load the proper calibration file for the chosen sampling mode.

The sensor has a microlens array with orthogonal arrangement of microlenses, and is aperture is mostly limited by the image sensor size. Sometimes, it is more convenient to use sensor in this configuration in reference mode with manually defined circular aperture. To define the aperture (area of interest), load the reference pattern first, then click on the reference picture and draw the aperture by dragging the cursor. It will be displayed as a red circle. For more information, refer to section 3.6.3 of the FrontSurfer manual.

3 Deformable mirror

3.1 Specifications

Please refer to the technical passport of the deformable mirror for its specifications.

3.2 Interfacing instructions

The mirror is supplied with matching high-voltage amplifier, USBDAC40 control unit with USB 2.0 interface and a set of cables. Installation procedure is briefly described below.

1. Connect DAC40USB unit to a USB port of your computer.

   (Optionally; not required for Windows 7 and 8: install the drivers; drivers for this unit can be found in "DAC40USB/Driver" directory of the installation CD.)

   Start "DAC40USB/Program_win2000/TEST_DAC40.exe" to make sure that the unit is recognized by the system.

2. Load configuration of channels for the deformable mirror. With this purpose go to the menu command "Mirror ⇒ Configuration", then press "Configure". In the dialog box "Deformable mirror configuration" press the "Load" button and load the file "mmdm 15.18 usb.txt" from the CD "fsurfer" directory. Press "OK" twice to complete configuration.

3. Disconnect DAC40USB control unit from your computer.

4. Connect the amplifier units to DAC40USB units using two 20 pins-to-26 pins cables.

5. Connect the mirror to the amplifier unit using two 20 pins-to-20 pins cables. Fix the cables to the optical table.

6. Connect DAC40USB to the computer using a USB cable.

4 Adaptive optics setup

The scheme of the adaptive optics breadboard is shown in Figure 3 and photo of its external features can be seen in Figure 2. A beam from fiber-pigtailed laser diode LD operating at 650 nm wavelength is collimated with lens L1. Polarization filter PF is used to adjust the intensity of the beam. Iris diaphragm ID limits the light cone to provide beam width of 20 mm corresponding working aperture of the deformable mirror. The telescope consisting of lenses L2 and L3 conjugates the entrance pupil (aberration source should be placed there) to the deformable mirror DM with 1x scaling, and the telescope consisting of lenses L4 and L5 provides conjugation between DM and wavefront sensor (WFS). Imaging camera IC (not included), which is placed after beam splitter BS, allows obtaining an image of the focal spot.

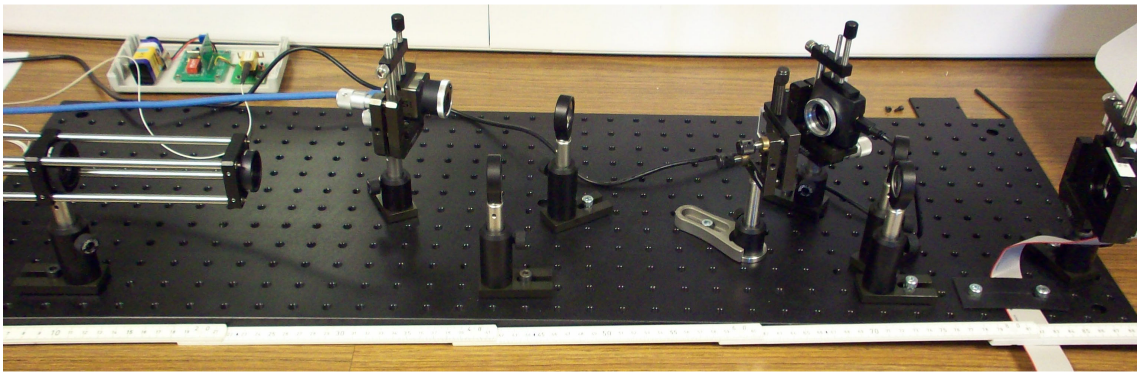

Figure 2: *Optical setup view*

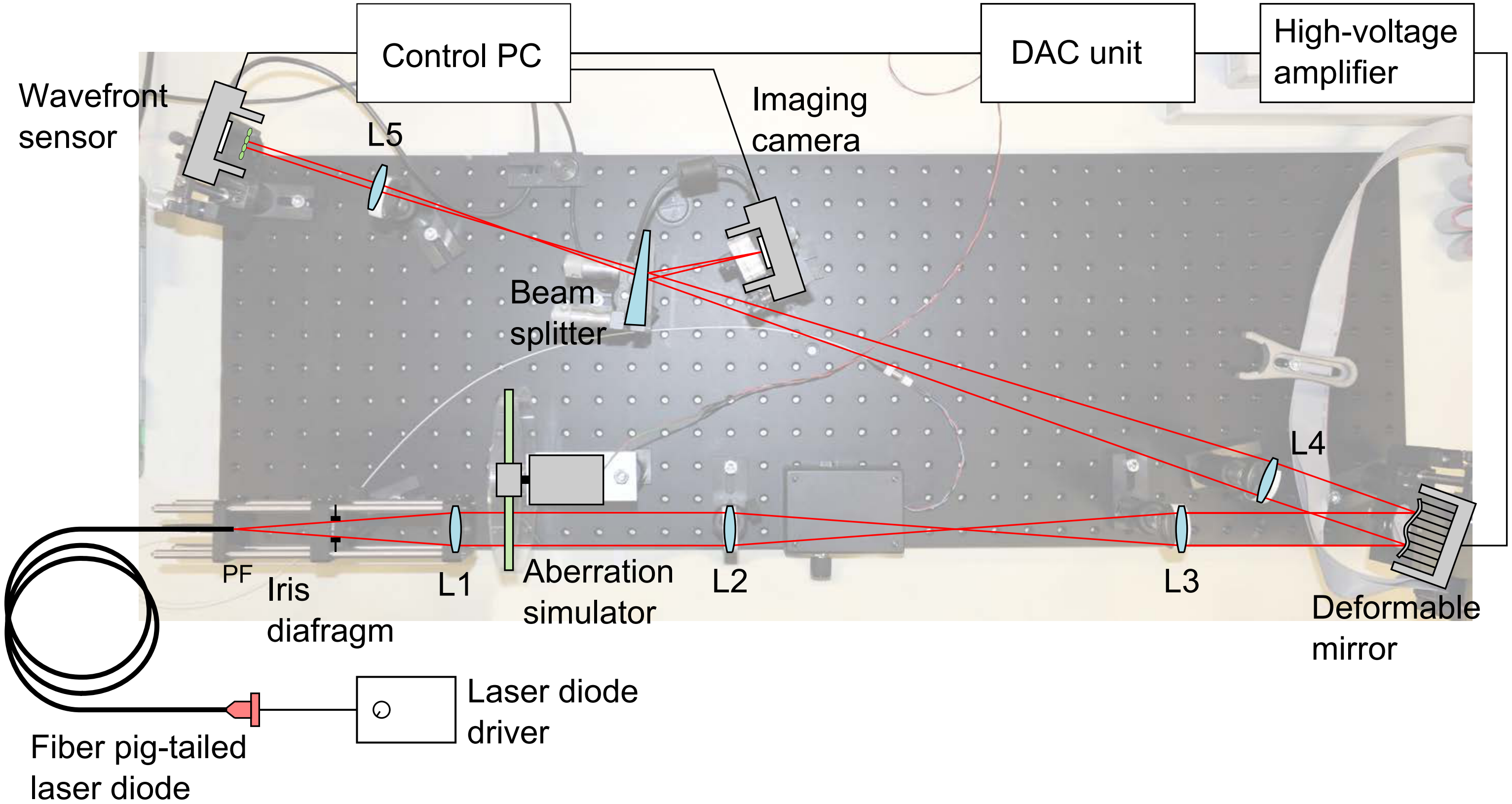

Figure 3: *Optical setup diagram overlapped with photo of external features. Component details are shown schematically and not to scale. L1 is a plano-convex spherical lens with focal length $f_1 = 250$ mm, L2-L5 are achromatic doublets with focal distances $f_2 = f_3 = f_4 = 150$ mm, and $f_5 = 100$ mm. Fiber mount, polarization filter, iris diaphragm and collimator lens L1 are combined in cage system. L2 and L3 form 1:1 telescopic system. L4 and L5 form 3:2 telescope. Imaging camera (uEye UI-1540) and aberration simulator (plastic plate attached to a geared DC micro-motor spindle) are not included in the standard set; they can be included and purchased by request.*

For proper functioning, the adaptive optics setup should satisfy the following conditions.

1. The optics should re-image the plane of the mirror to the plane of the Hartmann mask (or microlens array).
2. The scheme should scale the beam in such a way that the working aperture of the mirror ($\approx$ 20 mm) should be re-imaged to the working area of the Hartmann mask/microlens array ($\approx$ 4 mm).
3. The optics should allow for calibration. In the general case, it consists of separate measurement of the complete setup aberration with ideal object or a source of ideal wavefront, replacing the one to be tested.

4.1 Laser diode

The fiber pigtailed laser diode (LD) serves as a light source. The end of the fiber has SMA connector which attaches to the mount of the collimator. LD is powered by dedicated driver implementing stabilized output. Knob on the upper panel of the unit allows to switch on/off the laser and adjust its power. The device is powered by PP3 9V battery.

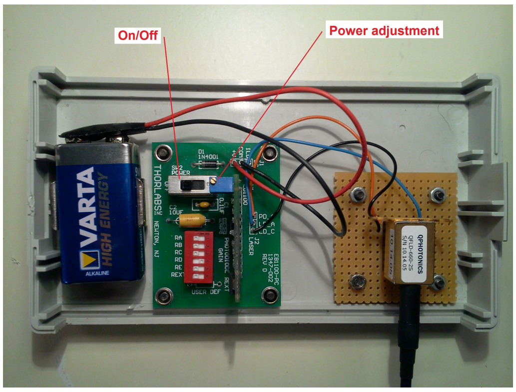

Figure 4: *Laser diode driver.*

Important! The fiber-coupled laser diode (650 nm wavelength, 2 mW maximum output power) is an extremely fragile and static sensitive device. It should be handled with care. Flexible Optical BV is not liable in case of mechanical damage to the fiber or electrostatic damage to the diode. In case you need to replace the diode, please use an antistatic wrist band.

To start using the laser

1. Check that the LD driver is switched off (rotate potentiometer knob counter-clockwise till click).
2. Install the battery if it is not already installed: open battery compartment cover on the bottom of the unit, connect a PP3-style 9V battery observing polarity, insert the battery to the compartment, close the cover.
3. Carefully insert laser diode terminals into TO-92 socket of LD driver unit observing correct alignment of the triangular footprint of the LD and the socket.
4. Connect the laser diode fiber to the system (LD mount);
5. Switch on the laser diode and adjust the power to see the beam. Normally for the purpose of alignments it should be set to maximum (clockwise till stop), but during normal operation of the system output power could be reduced to minimum.

6. For longer battery life and conserving laser diode resource please keep the driver switched off when not in use.

4.2 Polarization filter

A linear polarizing filter is included in the system to regulate the light source intensity if needed. It can be mounted inside the cage system using the tread in the LD mount.

4.3 Assembling and alignment

The system was assembled, adjusted and tested in our lab after that it was disassembled and packed. To make the reassembling easier, the positions (footprints) of mounts are marked by permanent marker on the breadboard. To minimize aberrations introduced by the lenses it is important to observe their front/back orientation in respect to the optical axis. Each lens is marked with its number and direction of the beam (arrow). During the assembling, the components should be added and adjusted one by one.

Several points should be taken into account.

1. The laser beam should be centered with respect to the apertures of all components.
2. The beam should be collimated after L1, on the surface of the deformable mirror DM and at the wavefront sensor WFS. Its width should be 20 mm in DM plane and 4 mm in WFS plane.
3. Check conjugation of the components by observing the images of entrance pupil in DM and WFS planes; it should have sharp edges.
4. Part of the system behind the deformable mirror (lens L4 and further) should be aligned with the DM turned on and all values set to 0.
5. In order to minimize the astigmatism, all lenses should be placed perpendicularly to the beam.
6. In order to minimize the spherical aberration, orientation of achromatic lenses L1-L5 with respect to the beam should be observed. Generally, the lenses should be oriented with their highest curvature surface in direction of a collimated beam.
7. Close the iris diaphragm to get a narrow beam for alignment in the pupil plane; open the diaphragm to align with a focal spot in the image plane.
8. After all components are placed and aligned, fine tune the position of the deformable mirror and the wavefront sensor in such a way that the first actuator is imaged in the middle of the reconstruction aperture (see Fig. 5 for illustration).
9. To ensure the correct position of the wavefront sensor, check that the number of spots in the Hartmann pattern remains constant for any shape of the deformable mirror. A good way to check it is to use “defocus.exe” command-line program supplied on the CD.

4.4 Running the adaptive optics loop

1. Switch on the laser diode.
2. Connect the wavefront sensor and deformable mirror; turn on the power supplies.
3. Start FrontSurfer. Go to menu “Mirror → Set values” and set value 0 to all actuators. It corresponds to the bias voltage, which produces slightly concave shape on the mirror.

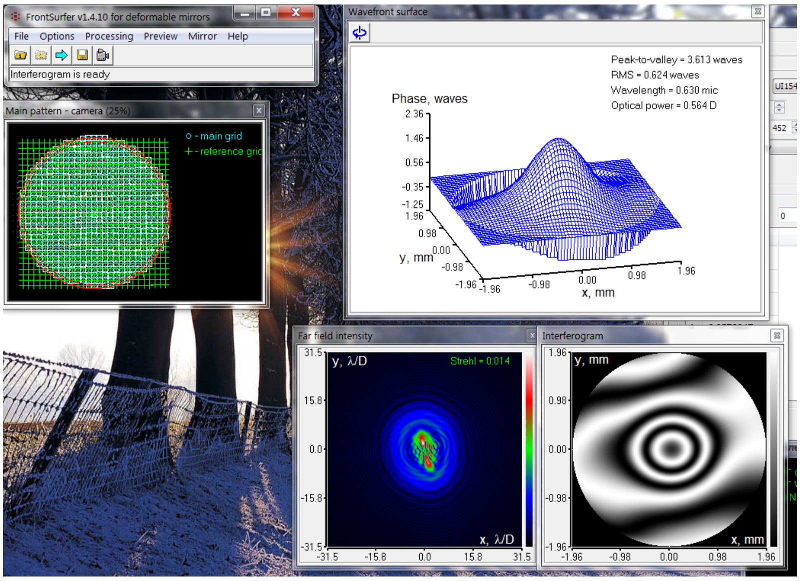

Figure 5: *Reconstructed response function of the first actuator. In a well aligned system, the response is centered with respect to the wavefront sensor aperture.*

4. Make sure that the beam is centered on the deformable mirror, wavefront sensor and other components.
5. Turn on the preview mode in FrontSurfer and check an image from the Hartmann sensor. Adjust the wavefront sensor position for centering.
6. Adjust the beam brightness with laser diode power potentiometer and/or polarization filter and the wavefront sensor exposure (use menu "Options ⇒ Camera" and then "Properties" button; see Figure 6) to make the spots good visible, avoiding the saturation.
7. Switch on the imaging camera and adjust the exposure to see the focal spot. If needed, adjust the camera position to achieve the best focus.
8. In menu "Mirror ⇒ Feedback parameters", set the parameters according to Figure 7. We recommend setting "Delay" to 100 ms for calibration; it can be reduced to 1 ms for the closed-loop operation.
9. If used in a reference mode, take a reference pattern (use menu "File ⇒ Open Reference" or use a shortcut button "2").
10. Go to menu "Mirror ⇒ Calibrate mirror" to calibrate the system. The calibration data can be saved for further use from menu "Mirror ⇒ Save calibration".
11. Check the eigen modes of the system (use menu "Mirror ⇒ Singular values" and double-click on a singular value marker to see the corresponding mode). They should look similar to the modes shown in Fig. 9. Noisy or low-contrast modes indicate an alignment/calibration problem.
12. Now you may start closed-loop correction from menu "Mirror ⇒ Start feedback". During the correction loop, you may compensate for residual static aberration of the system by manually adjusting Zernike terms, in particular, defocus (C[2,0]) and astigmatism (C[2,2] and C[2,-2]). Spot sharpness should be improved.

Please refer to FrontSurfer manual for further information about the feedback loop operation mode.

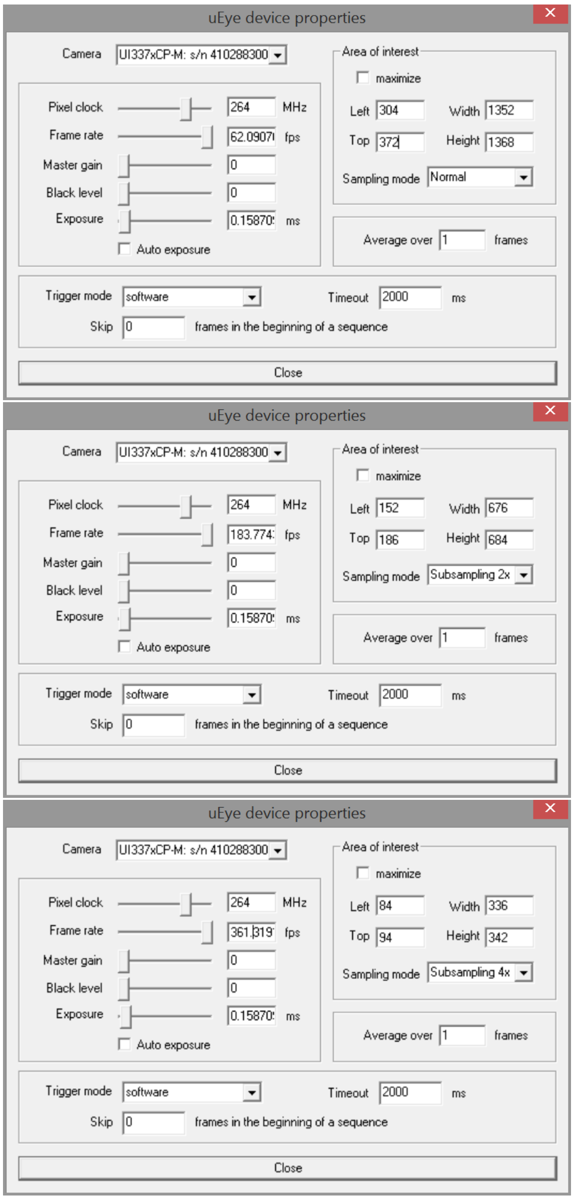

Figure 6: *"uEye" plugin properties; settings for "Normal", "Subsampling x2" and "Subsampling x4" modes (top to bottom).*

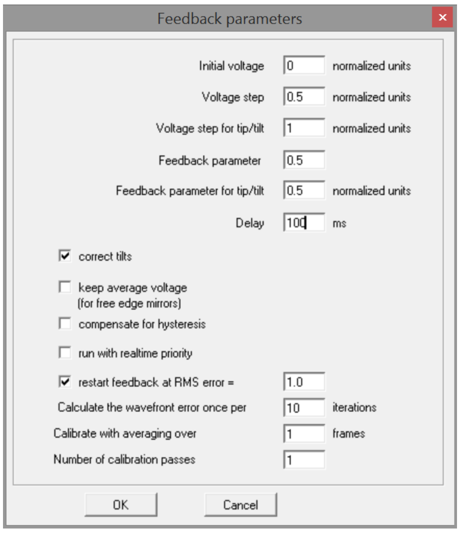

Figure 7: *Feedback parameters for calibration of MMDM*

5 Closed-loop test

FrontSurfer perform wavefront correction in a series of iterations. If the residual aberration ϕ_n at the n-th iteration corresponds to the set of actuator signals $\mathbf{X}_n$ then the actuator signals at the next step $\mathbf{X}_{n+1}$ will be determined by expression

$$\mathbf{X}_{n+1} = \mathbf{X}_n - g\mathbf{A}^{-1}\phi_n,$$

where g is the feedback coefficient with value in the range (0..1], $\mathbf{A}$ is the influence matrix of the mirror, $\mathbf{A}^{-1}$ is its pseudo-inverse given by

$$\mathbf{A}^{-1}=\mathbf{V}\mathbf{S}^{-1}\mathbf{U}^T,$$

$\mathbf{U}$, $\mathbf{S}$ and $\mathbf{V}$ are the singular value decomposition (SVD) of $\mathbf{A}$ which is $\mathbf{A}=\mathbf{U}\mathbf{S}\mathbf{V}^T$ [2]. The columns of the matrix $\mathbf{U}$ make up orthonormal set of the mirror deformations (modes), and the values of the diagonal matrix $\mathbf{S}$ represent the gains of these modes. Discarding those modes having small singular values may improve controllability of the system.

Experimental singular values for the deformable mirror are given in Figure 8; some of the SVD modes are shown in Figure 9.

5.1 Closed loop in reference measurement mode

The results of closed-loop testing of the system in the reference measurement mode are shown in Figures 13-25. We have used a Hartmann pattern obtained from optimized by BeamTuner software [3] as a reference. The system has been calibrated with the parameters shown in Fig. 7; for the closed loop, we have used the parameters as shown in Fig. 39. After closing the feedback loop and generation of one of the aberrations (Fig. 10), a main pattern was captured and processed by FrontSurfer (Fig. 11) and compared with the actual focal spot image. For imaging, we used 1/2" CMOS camera (UI-1540LE).

NB! *The ability of the system to reproduce the results below depends strongly on the alignment quality!*

Optimization started from the initial state produced by setting all mirror values to zero; it is shown in Figure 12. In the first test we have corrected the aberration; the result is shown in Figure 13.

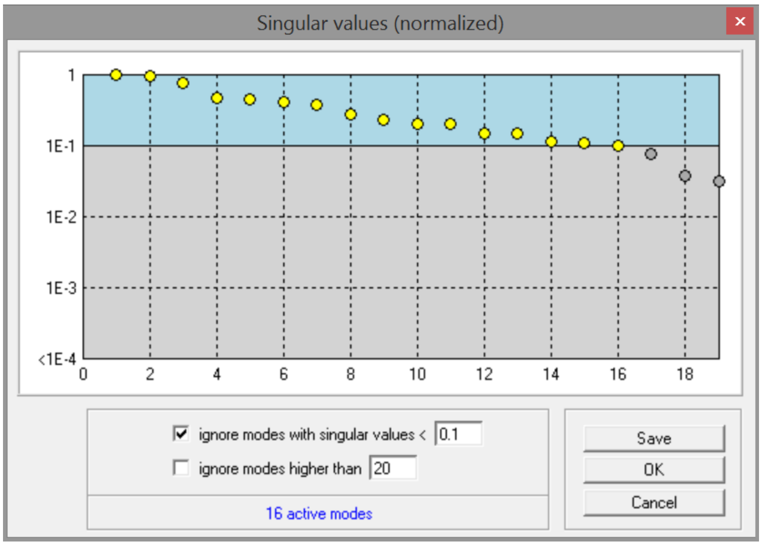

Figure 8: *Singular values of the 19-channel mirror.*

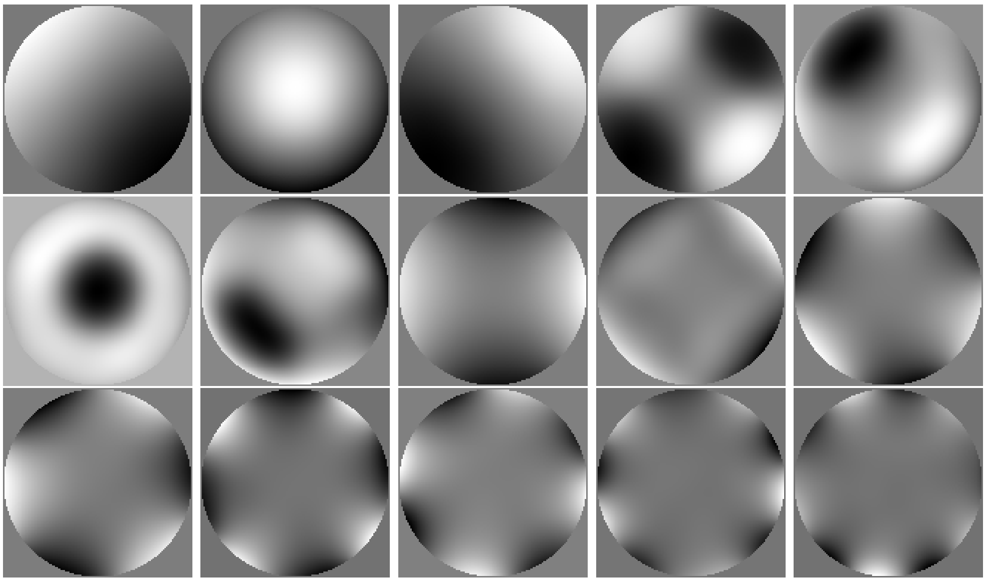

Figure 9: *Modes 1–15 of the 17-channel mirror.*

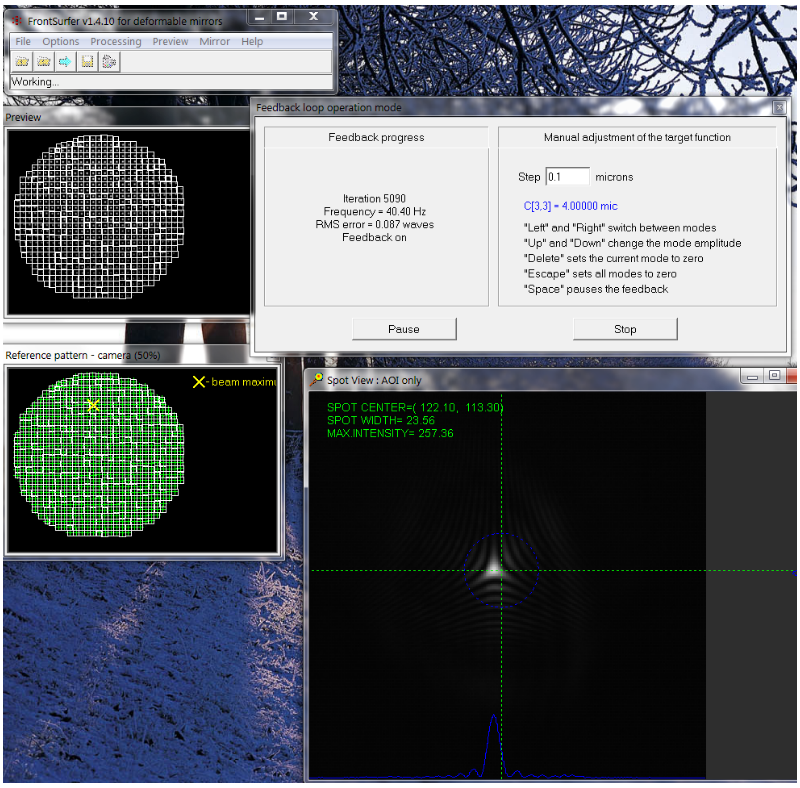

Figure 10: *Aberration generation with the AO system in closed feedback loop (general screen shot obtained with another system)*

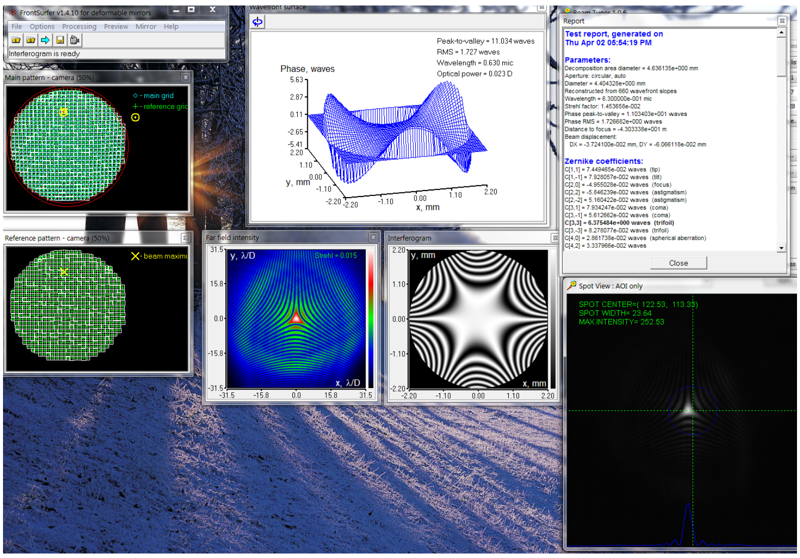

Figure 11: *Processing of the generated aberration with FrontSurfer (general screen shot obtained with another system)*

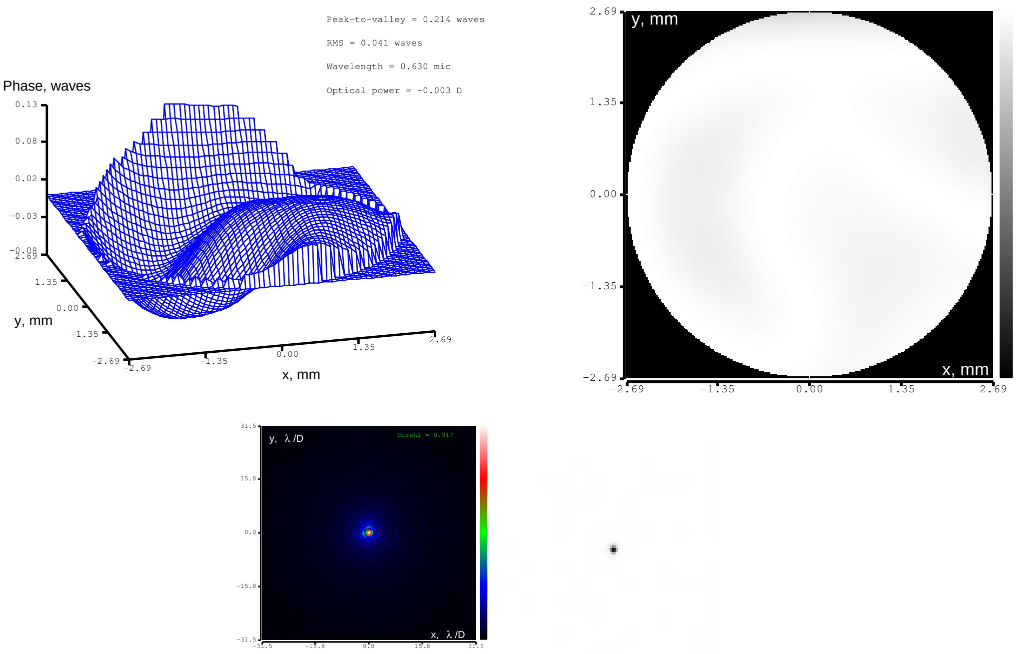

Figure 12: *Initial aberration of the system. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

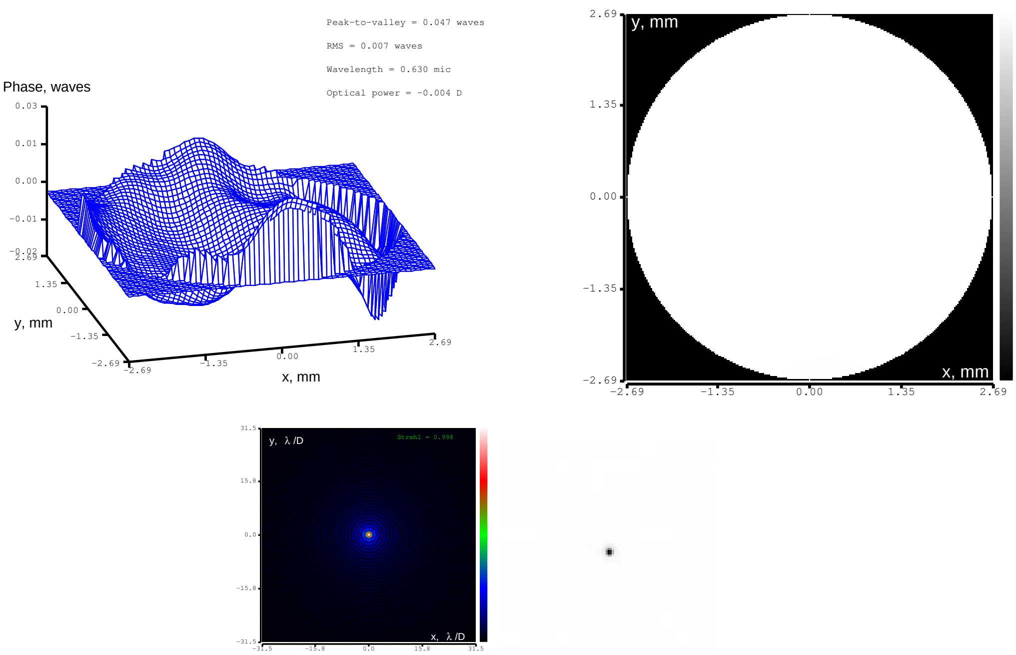

Figure 13: *Aberrations in the system after correction. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

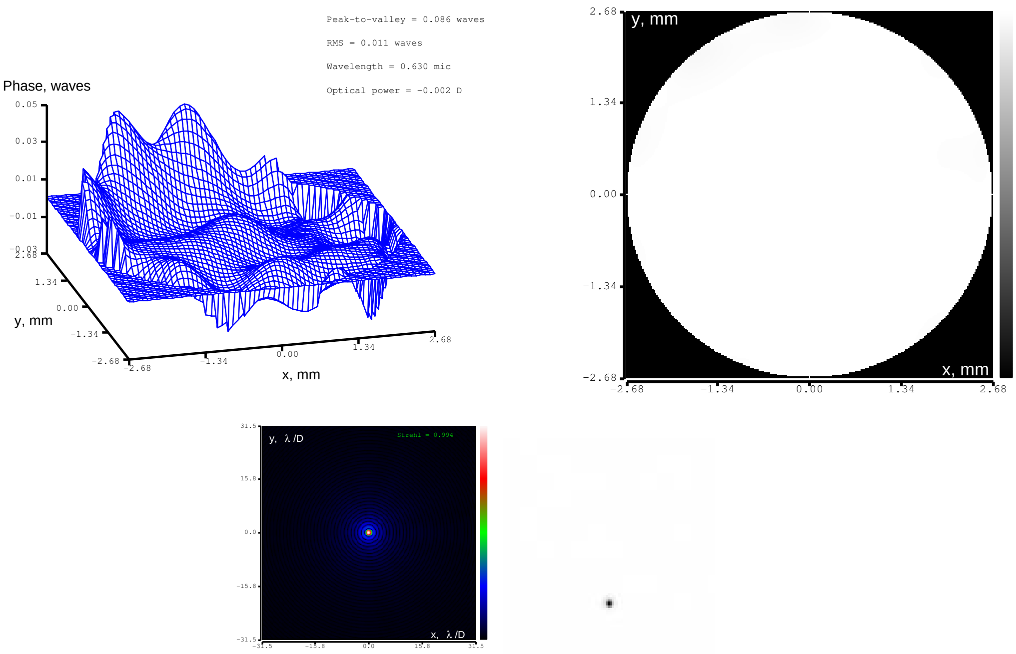

Figure 14: *Tip (Zernike term Z[1,-1]) of amplitude 4μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

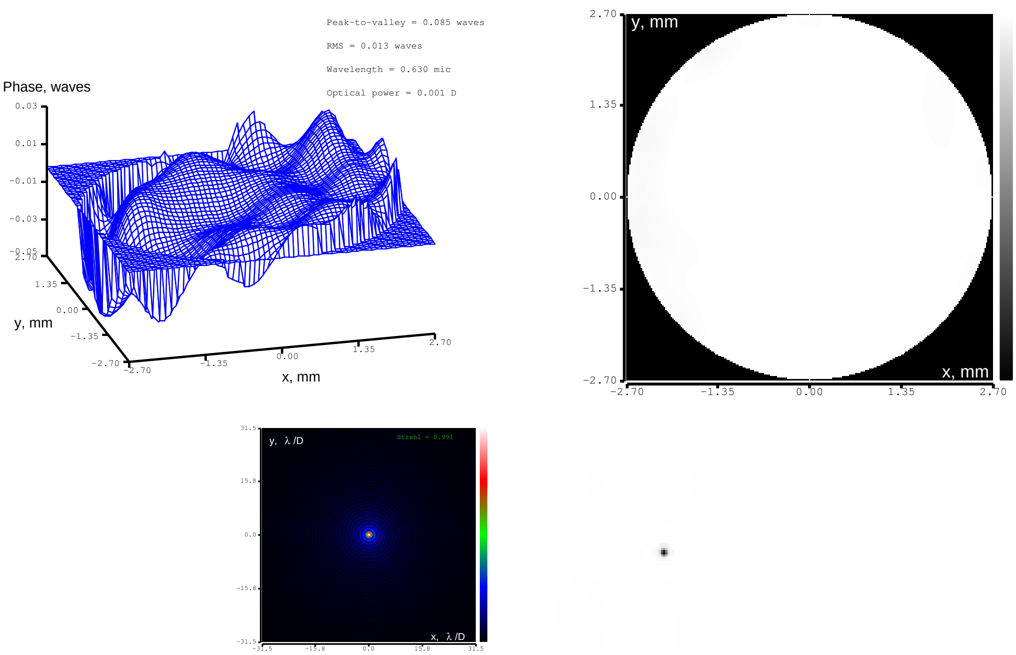

Figure 15: *Tilt (Zernike term Z[1,-1]) of amplitude 4.1μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

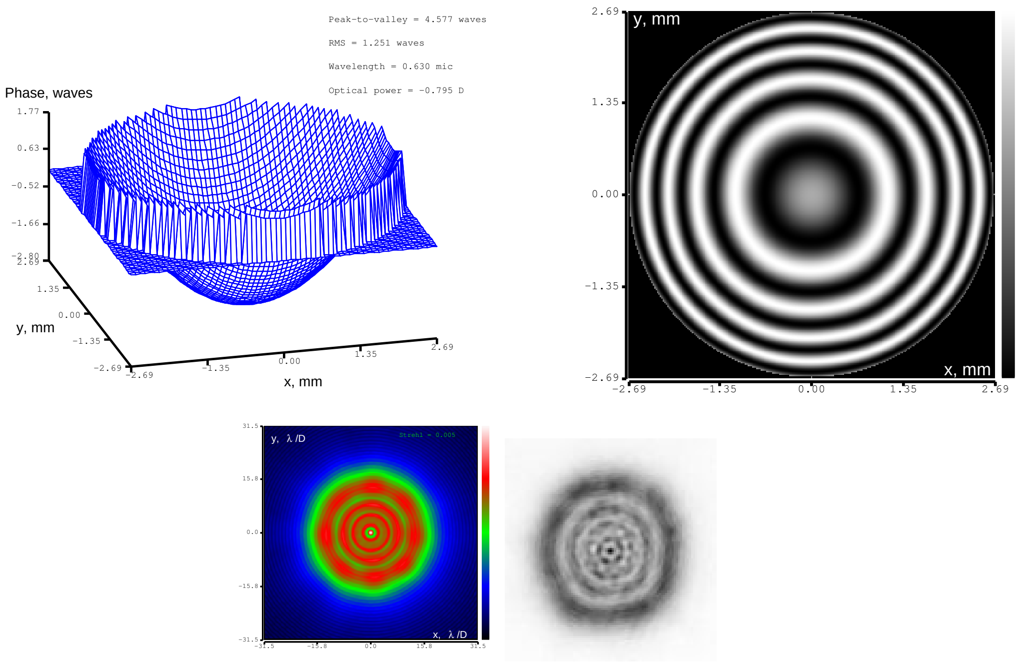

Figure 16: *Defocus (Zernike term Z[2,0]) of amplitude* $1.8\mu m$ *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

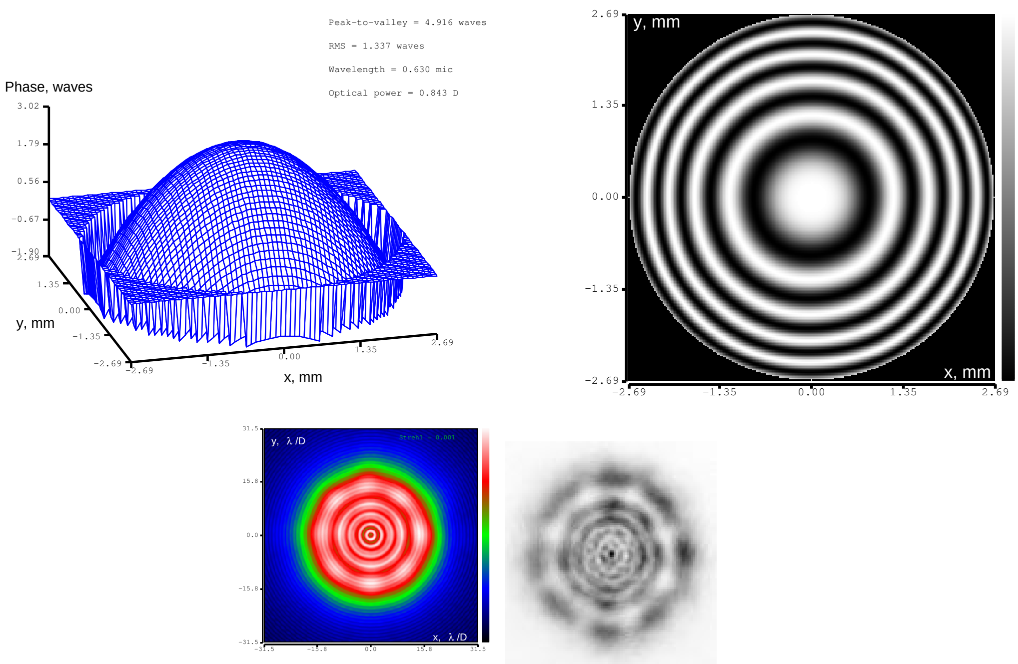

Figure 17: *Defocus (Zernike term Z[2,0]) of amplitude* $-1.9\mu m$ *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

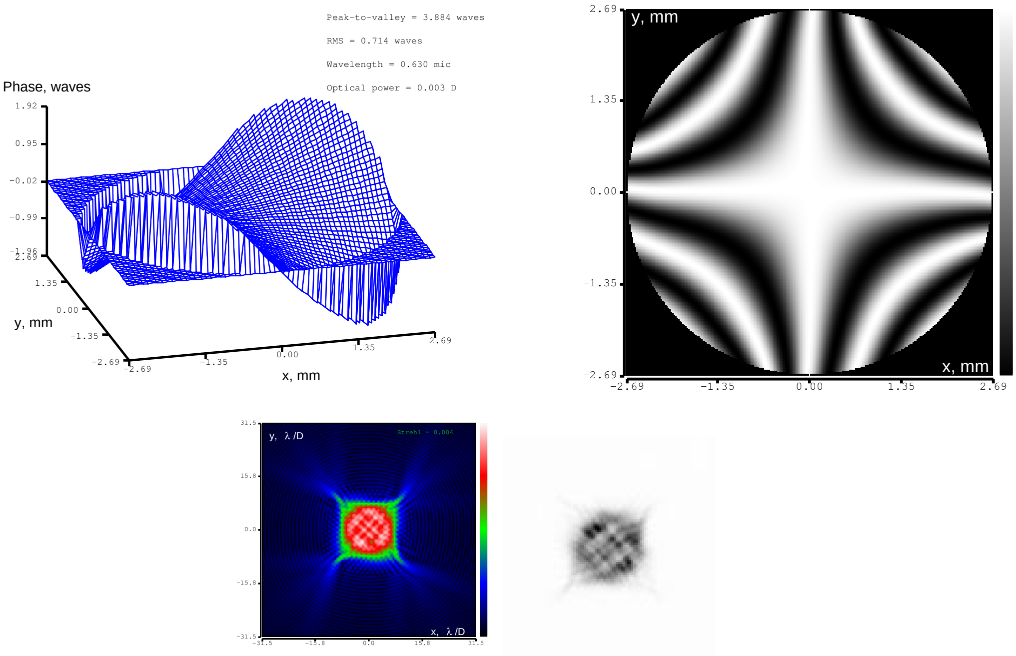

Figure 18: *Astigmatism (Zernike term Z[2,2]) of amplitude 2.2μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

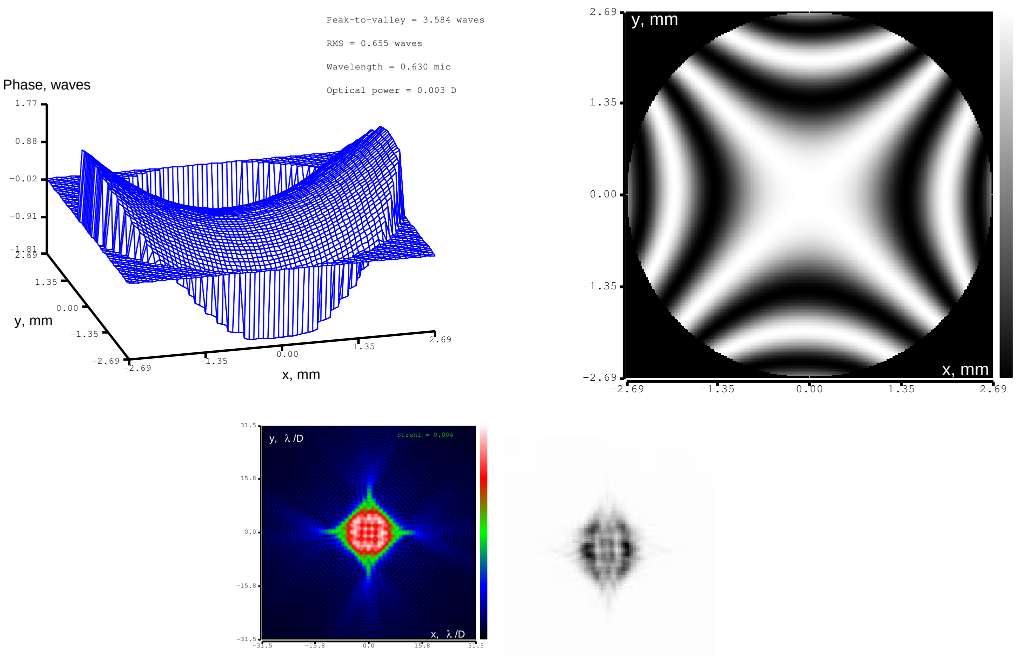

Figure 19: *Astigmatism (Zernike term Z[2,-2]) of amplitude 1.6μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

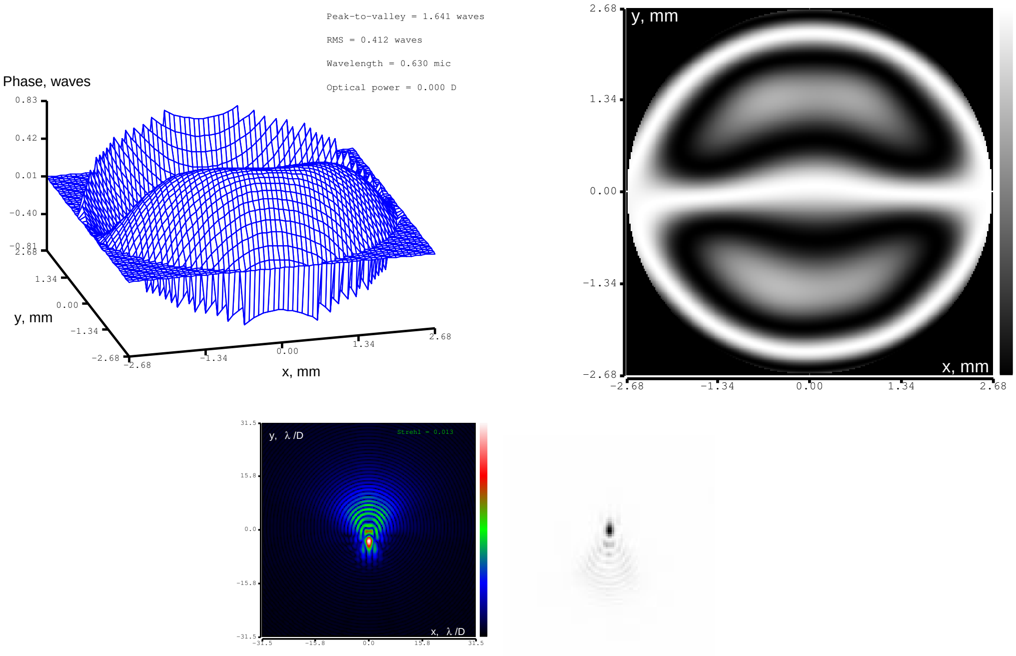

Figure 20: *Coma (Zernike term Z[3,1]) of amplitude 1μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

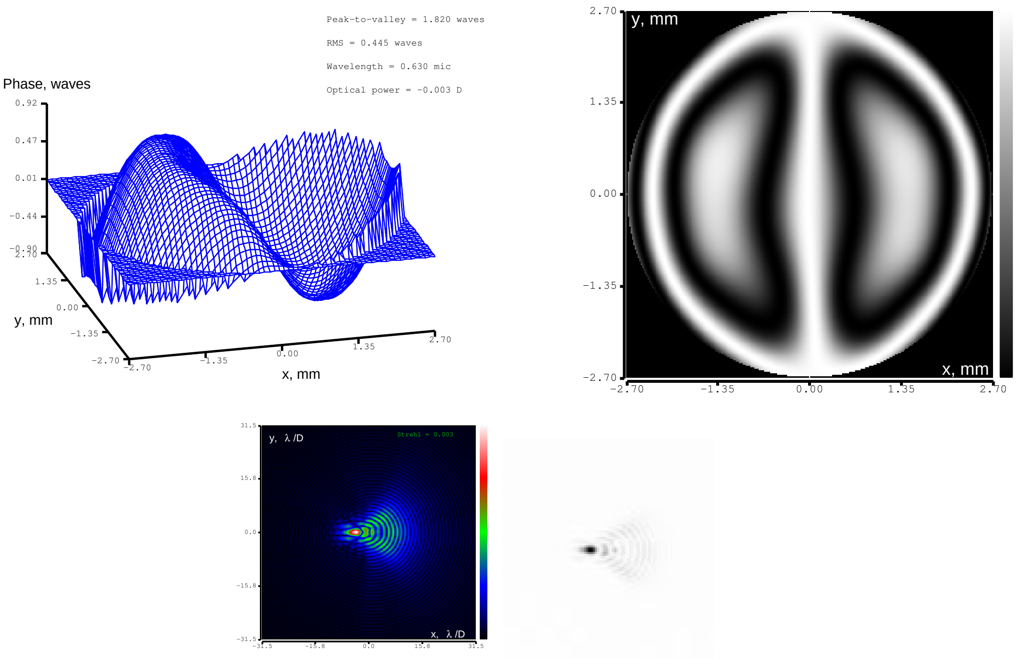

Figure 21: *Coma (Zernike term Z[3,-1]) of amplitude 1.1μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

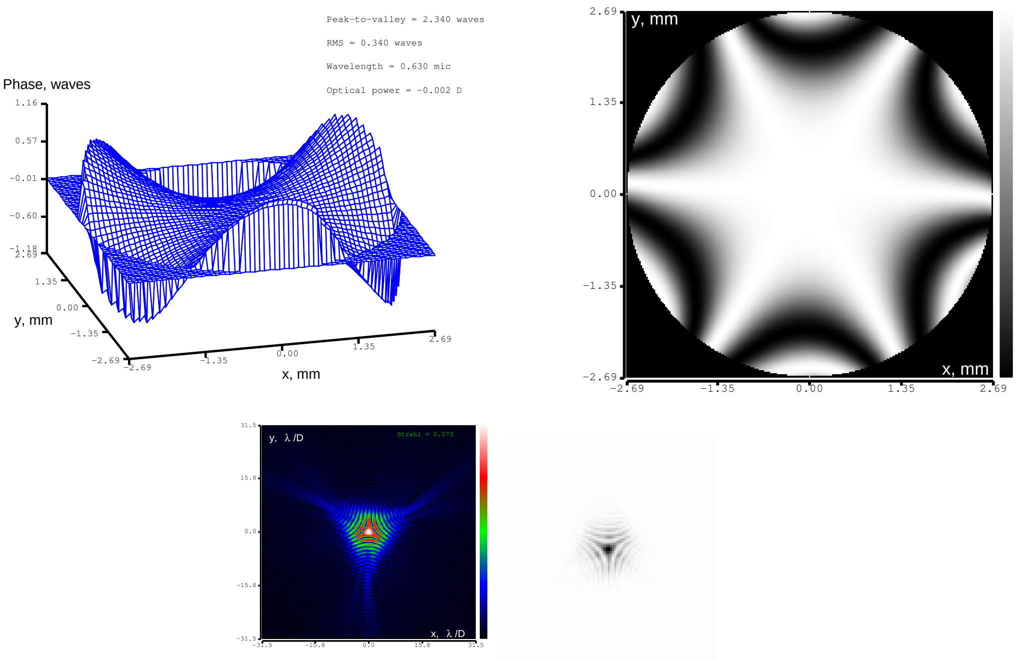

Figure 22: *Trefoil (Zernike term Z[3,3]) of amplitude* 1.1μm *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

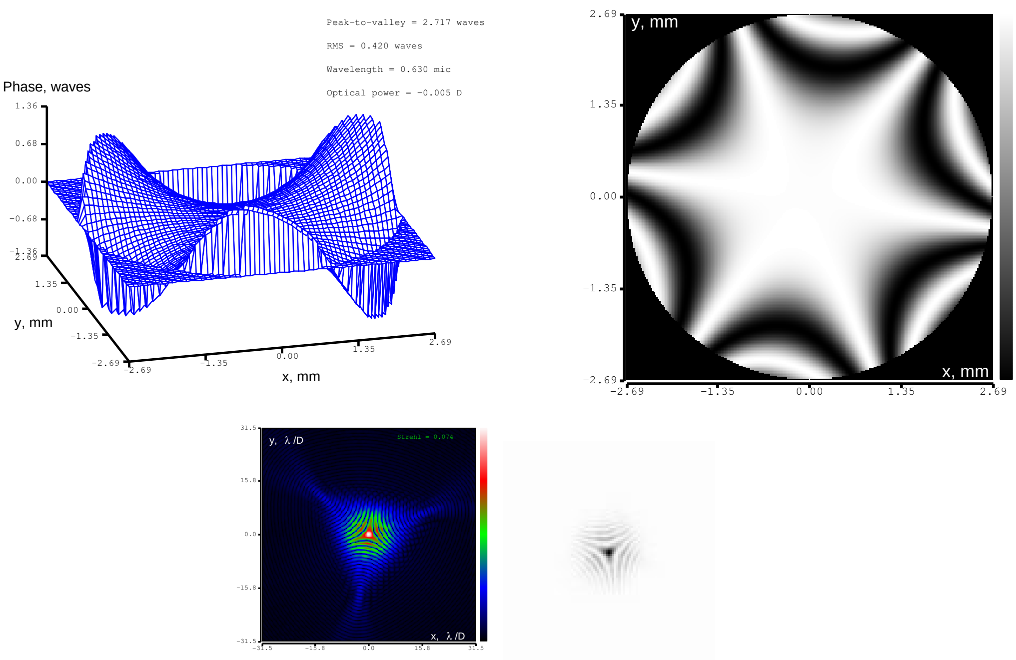

Figure 23: *Trefoil (Zernike term Z[3,-3]) of amplitude* 0.7μm *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

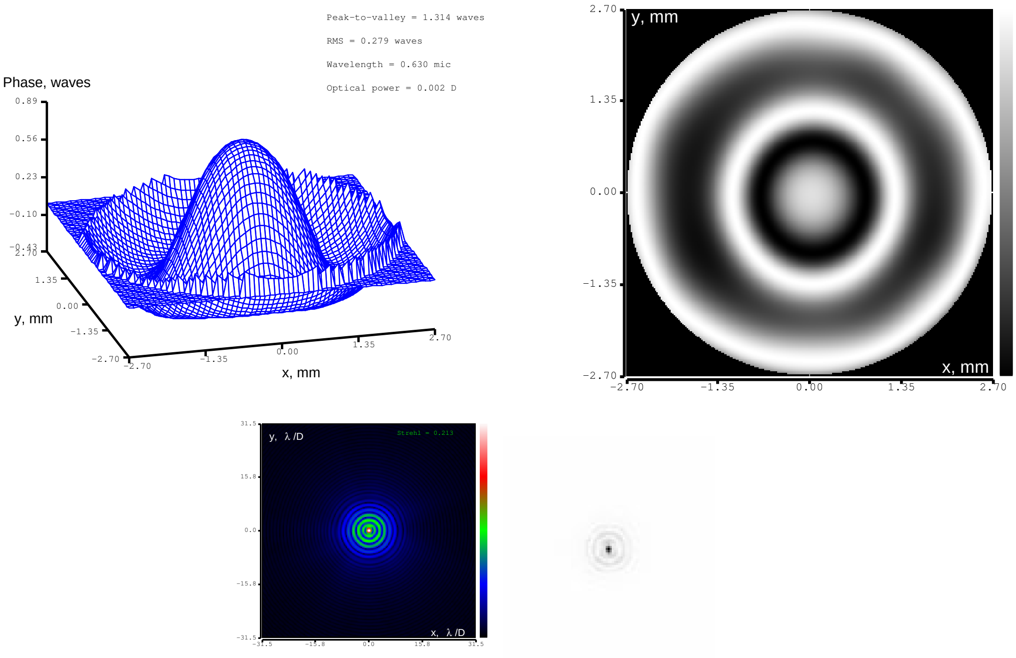

Figure 24: *Spherical aberration (Zernike term Z[4,0]) of amplitude* $0.5\mu m$ *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

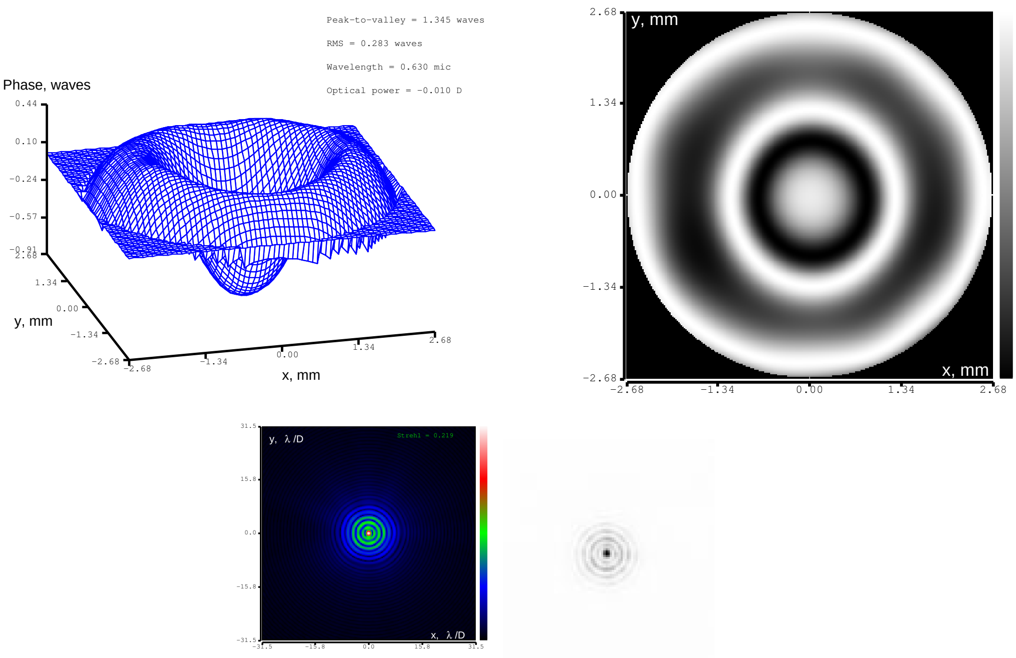

Figure 25: *Spherical aberration (Zernike term Z[4,0]) of amplitude* $-0.5\mu m$ *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

5.2 Closed loop in reference measurement mode, subsampling x2

The same sequence of tests has been repeated in subsampling x2 mode.

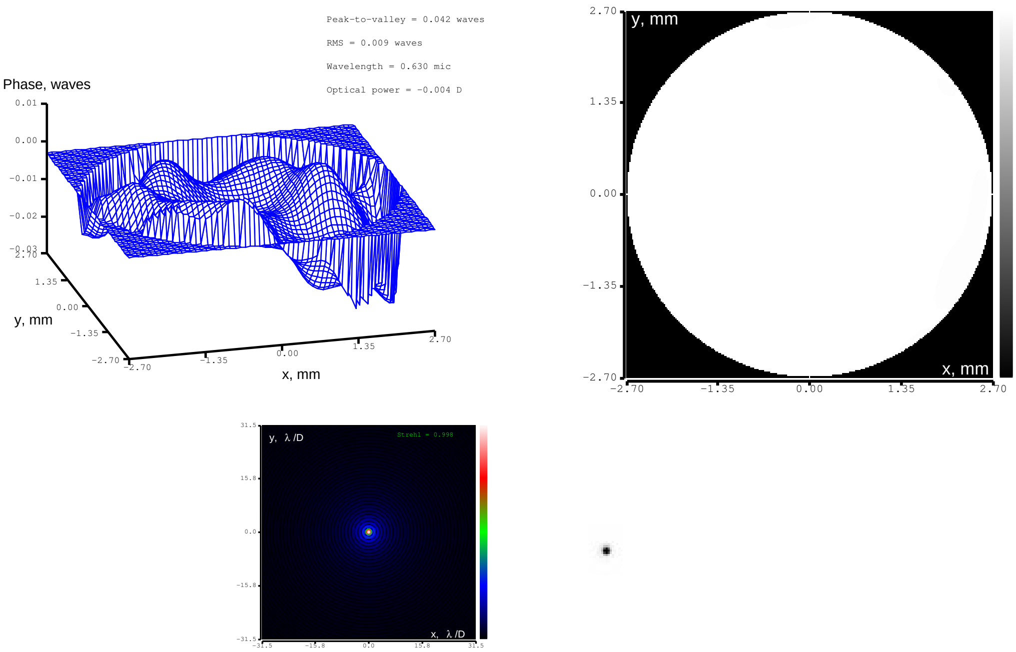

Figure 26: *Aberrations in the system after correction. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

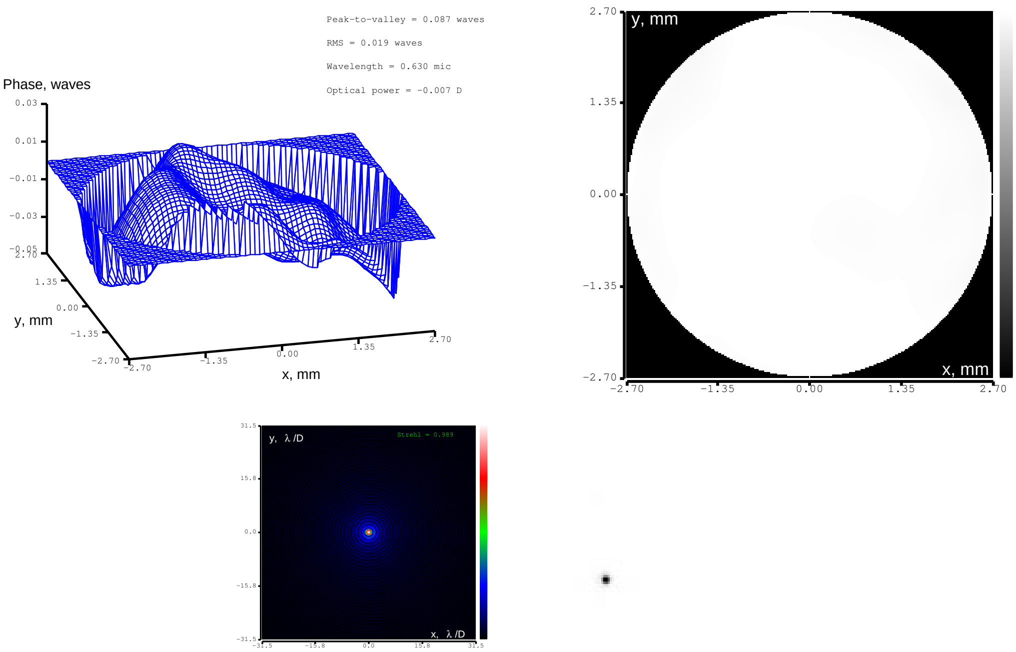

Figure 27: *Tip (Zernike term Z[1,-1]) of amplitude* 2.1μm *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

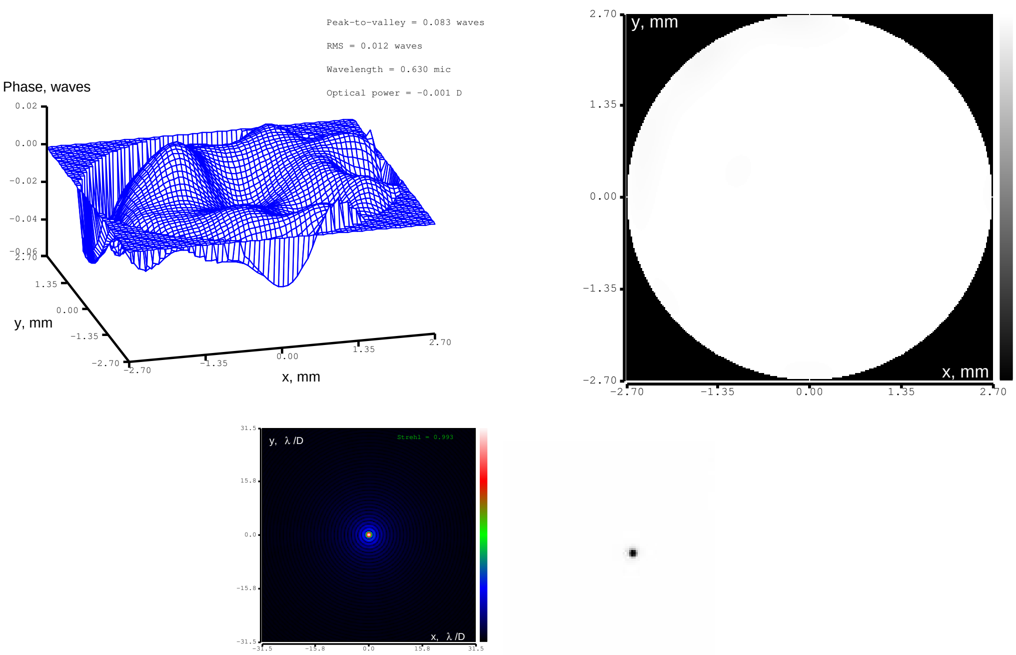

Figure 28: *Tilt (Zernike term Z[1,-1]) of amplitude* 2.0μm *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

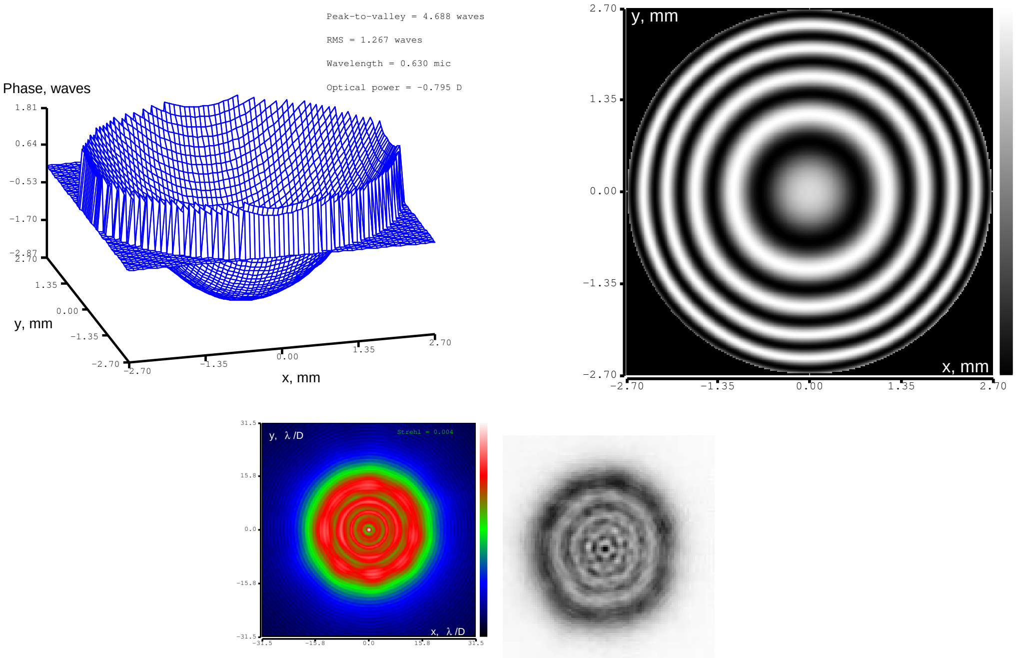

Figure 29: *Defocus (Zernike term Z[2,0]) of amplitude* 1.8μm *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

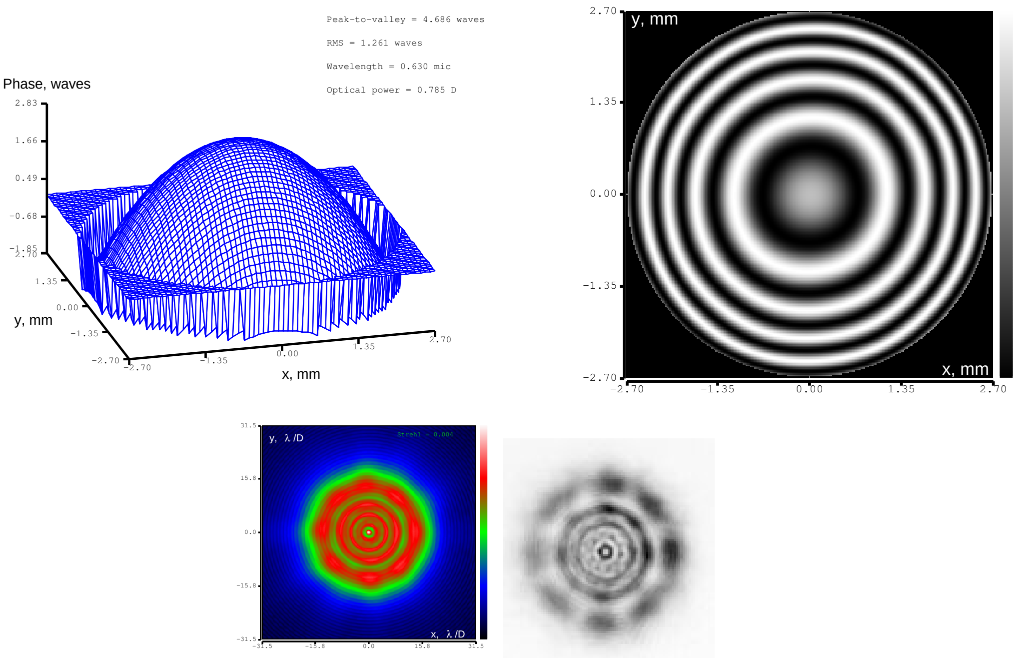

Figure 30: *Defocus (Zernike term Z[2,0]) of amplitude* $-1.8\mu m$ *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

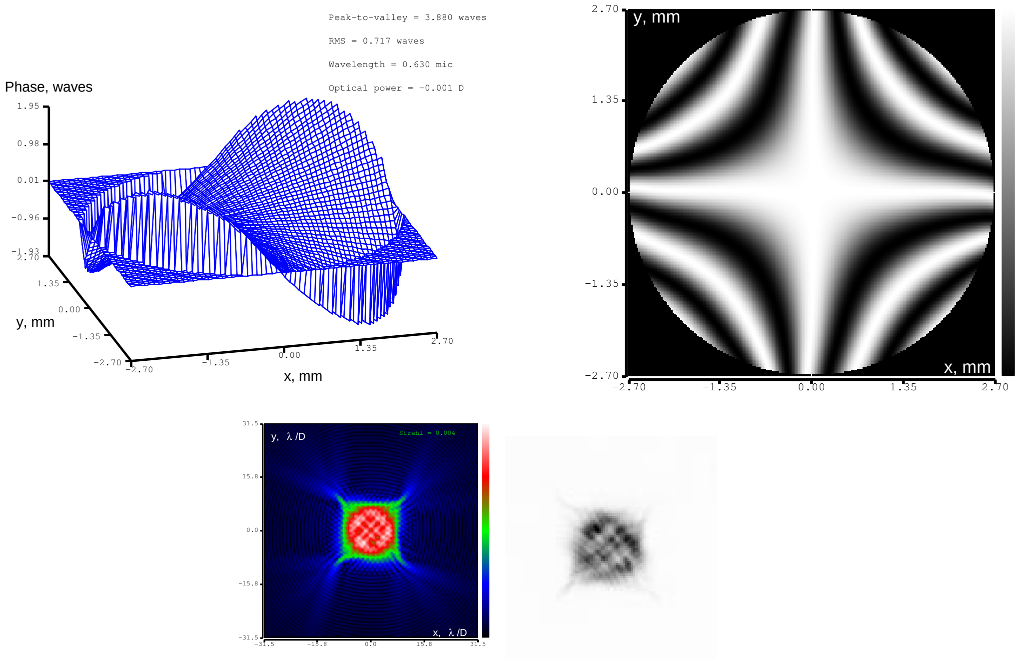

Figure 31: *Astigmatism (Zernike term Z[2,2]) of amplitude 2.2μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

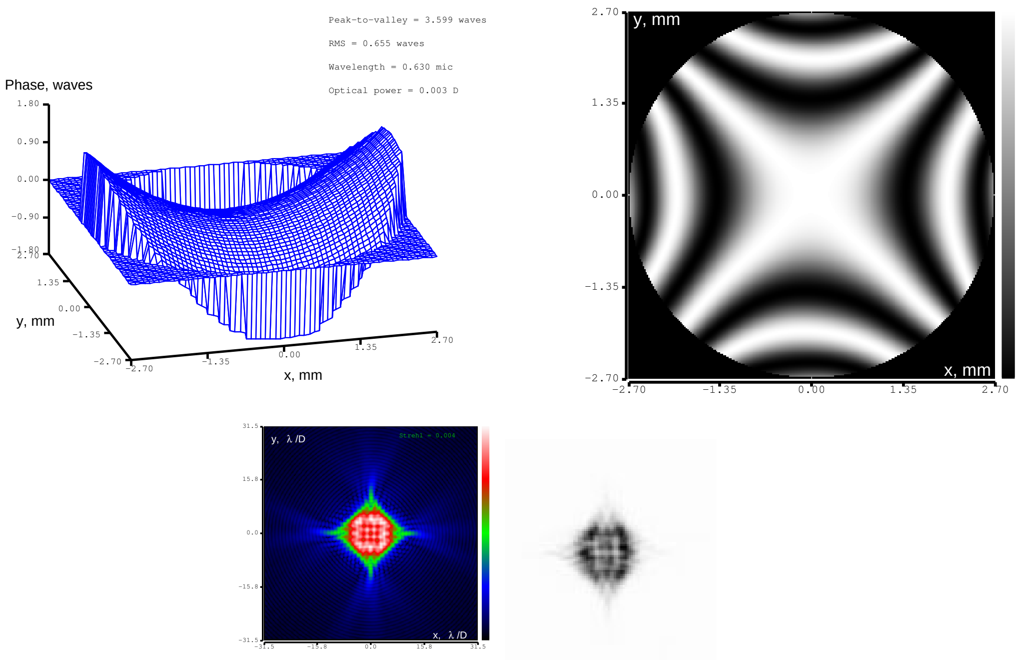

Figure 32: *Astigmatism (Zernike term Z[2,-2]) of amplitude 1.6μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

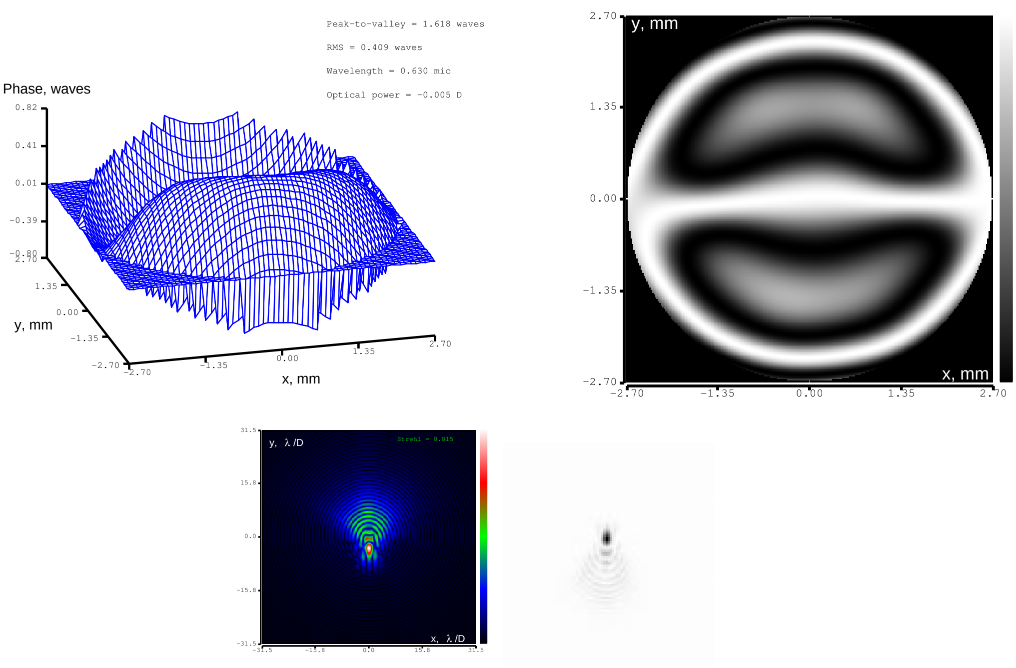

Figure 33: *Coma (Zernike term Z[3,1]) of amplitude 1μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

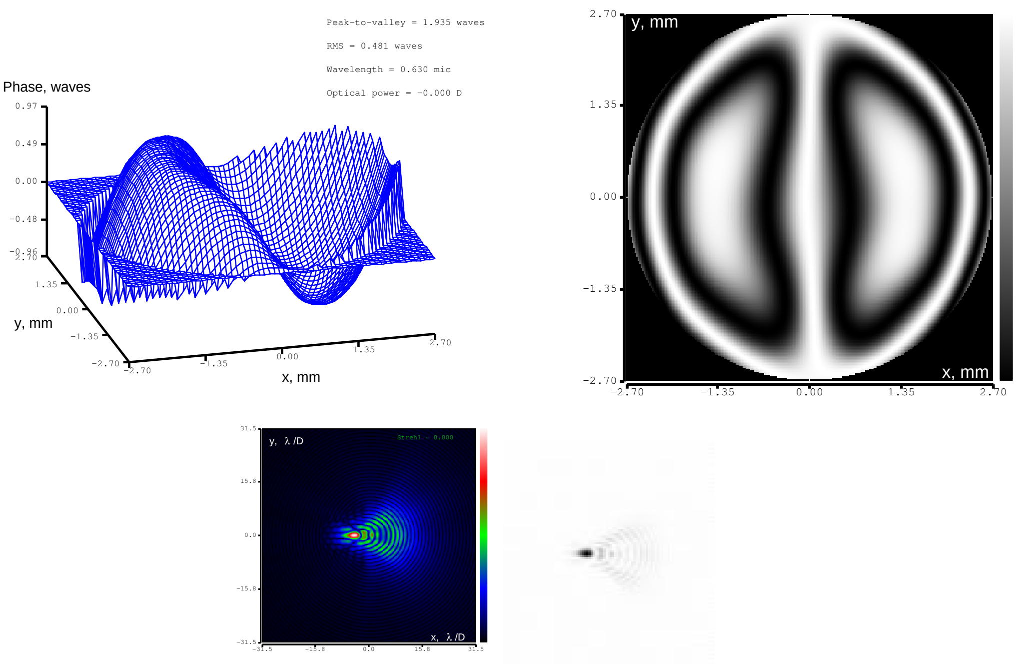

Figure 34: *Coma (Zernike term Z[3,-1]) of amplitude 1.2μm generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

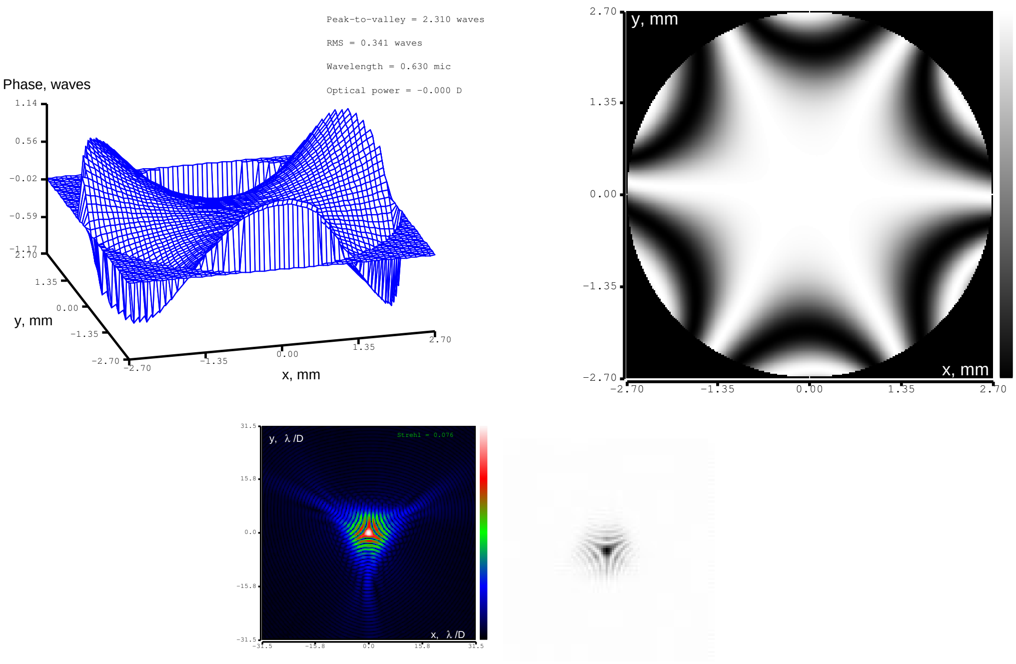

Figure 35: *Trefoil (Zernike term Z[3,3]) of amplitude* 1.1μm *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

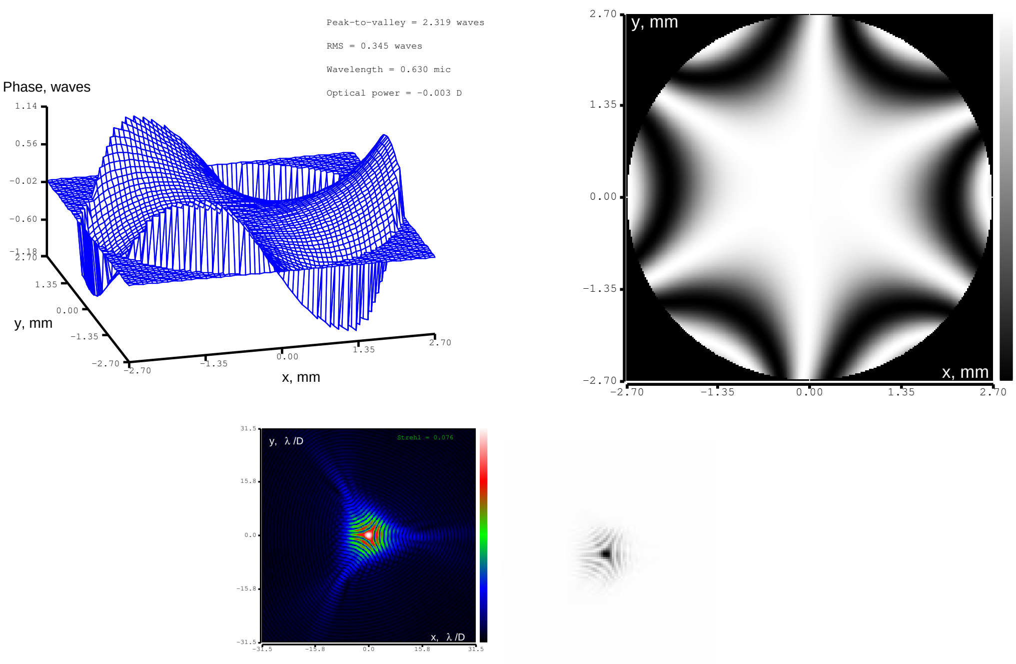

Figure 36: *Trefoil (Zernike term Z[3,-3]) of amplitude* 1.2μm *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

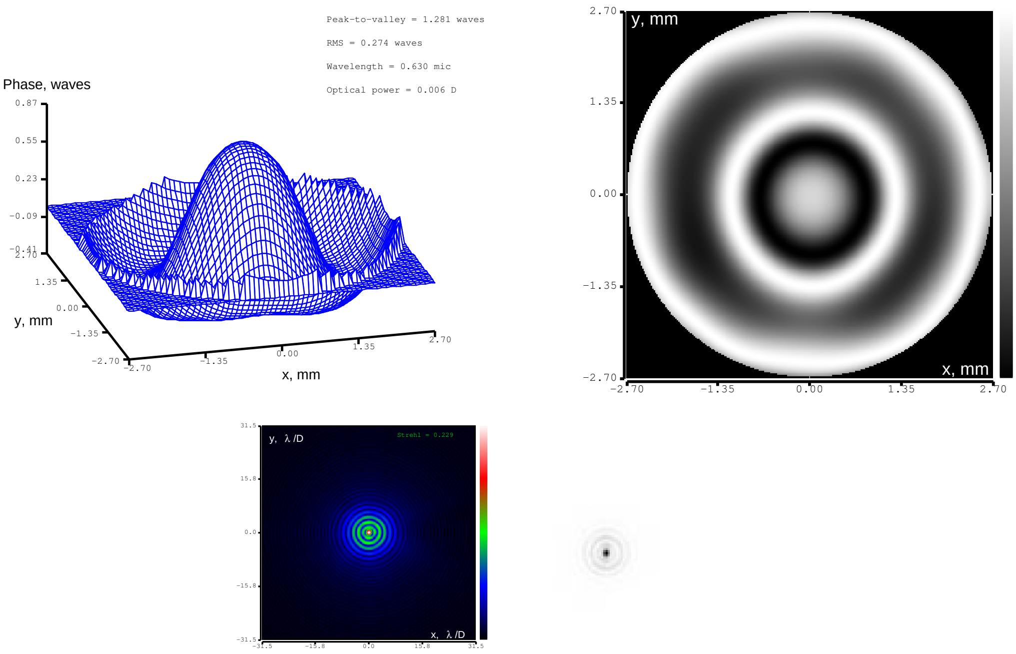

Figure 37: *Spherical aberration (Zernike term Z[4,0]) of amplitude* $0.5\mu m$ *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

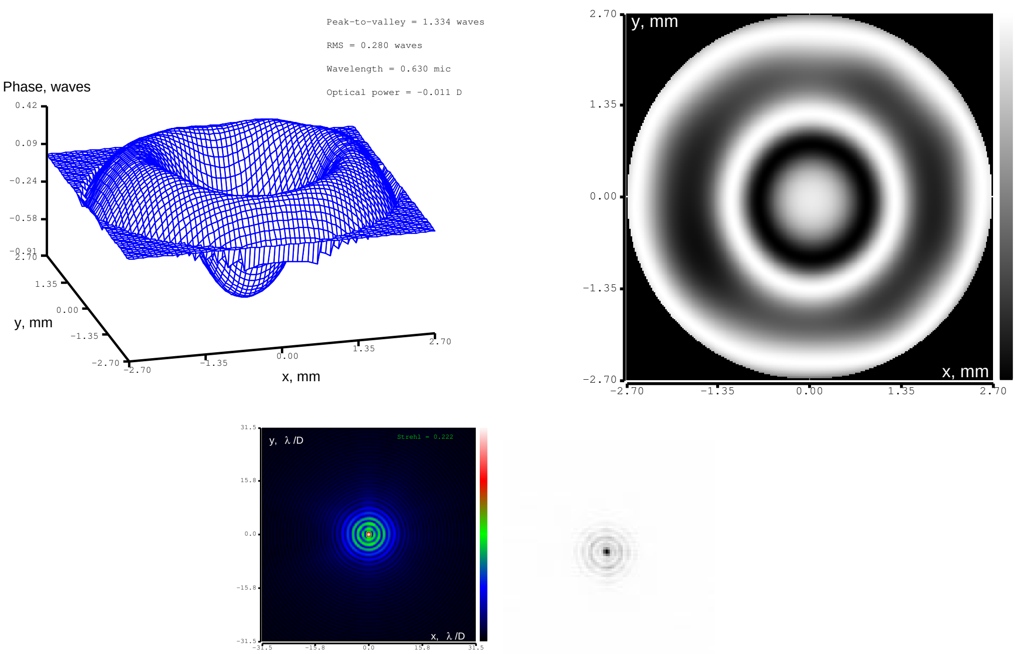

Figure 38: *Spherical aberration (Zernike term Z[4,0]) of amplitude* $-0.5\mu m$ *generated. Top row: reconstructed wavefront (left) and simulated interferogram (right). Bottom: image of the fiber tip as seen through the system, reconstructed (left) and registered with an imaging camera (right, shown inverted).*

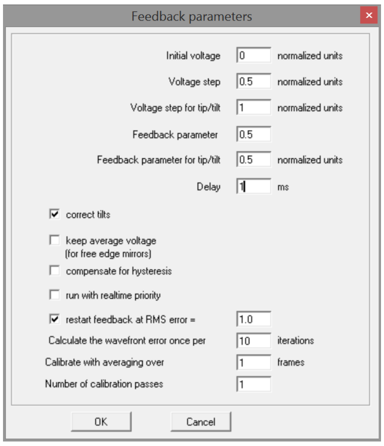

Figure 39: *Settings in the "Feedback parameters" dialog box used throughout the tests.*

Figure 40: *Closed feedback speed and rms in Normal an Subsampling x2 modes (top to bottom*

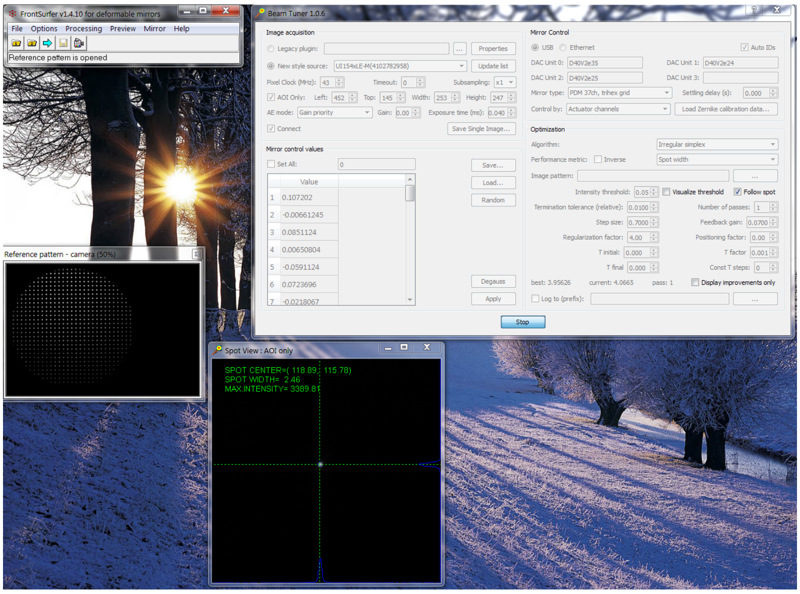

Figure 41: *Combined use of BeamTuner and FrontSurferin one AO system (general screen shot obtained with another system). BeamTuner is used to find the mirror shape that compensates for the initial system aberration. The corresponding Hartmann pattern is used as the reference for FrontSurfer.*

6 Using BeamTuner software to obtain a reference pattern

BeamTuner [3] is a stand-alone Windows application used in wavefront sensor-less systems to optimize the beam quality in the focal plane. The software finds the optimal shape of the deformable mirror using the focal spot image (PSF) as the feedback to compensate for a static aberration present in the system. In the systems with imaging camera, the result of the optimization with BeamTuner can be used as a reference for the closed loop mode (see Fig. 41). This usually provides better results than using a flat mirror reference or an absolute reference.

References

[1] OKO Tech, FrontSurfer wavefront analysis and control system: manual, `http://www.okotech.com/pdfmanual`

[2] C. Paterson, I. Munro, C. Dainty, A low cost adaptive optics system using a membrane mirror, Optics Express **6**, 175-185 (2000).

[3] BeamTuner, Windows application for compensating of a static aberration in an optical system with a deformable mirror, `http://www.okotech.com/beamtuner`

7 Contact

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