Adaptive optics pre-compensation of laser beams

Szymon Gładysz

Fraunhofer Institute of Optronics, System Technologies and Image Exploitation

Ettlingen, Germany

Fraunhofer IOSB

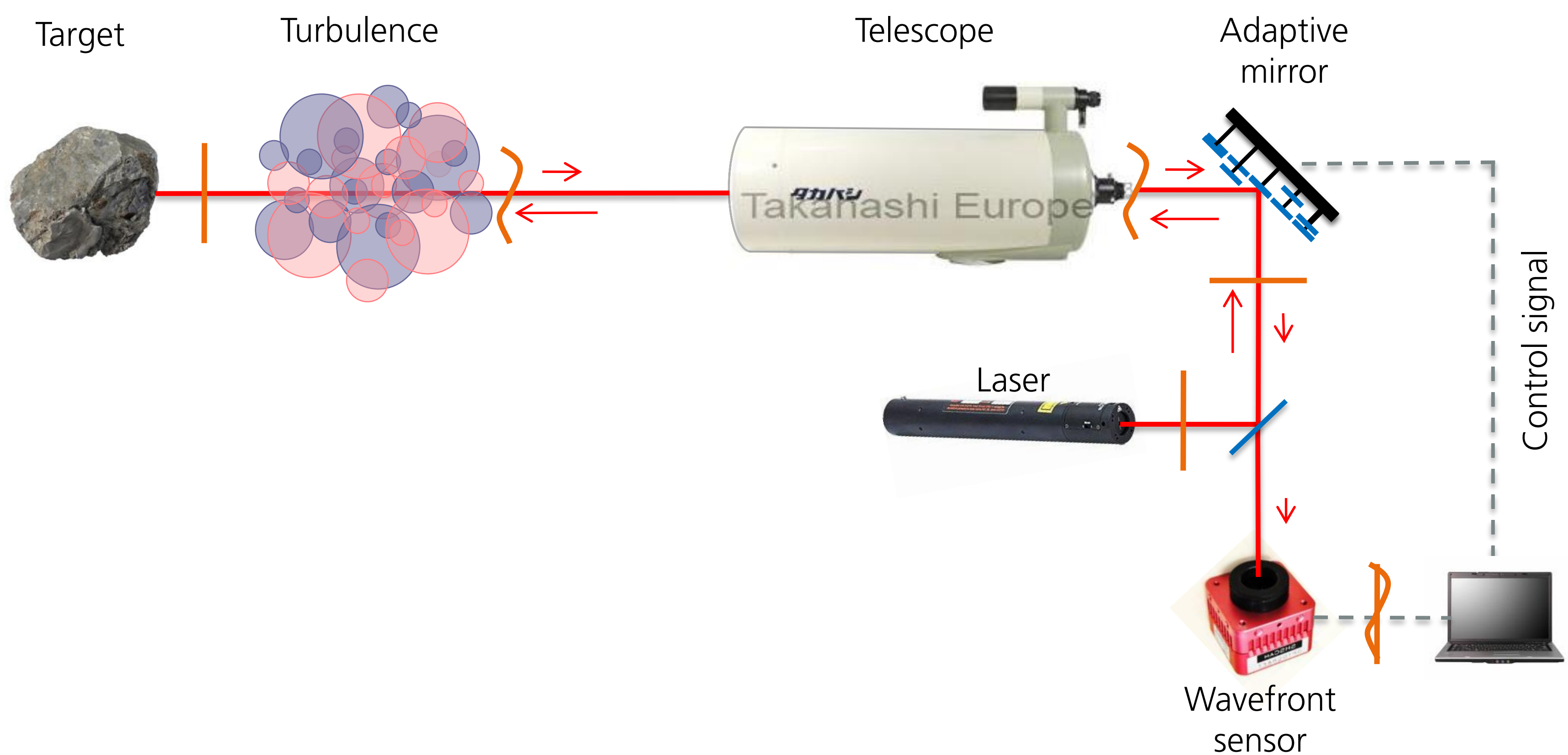
Outline

- Pre-compensation of laser beams
- Holographic wavefront sensor (HWFS)
- Possible application in astronomical AO
- Thermal-piezoelectric deformable mirror from Fraunhofer IOF

Outline

- Pre-compensation of laser beams
- Holographic wavefront sensor (HWFS)
- Possible application in astronomical AO
- Thermal-piezoelectric deformable mirror from Fraunhofer IOF

AO for laser beams



Fraunhofer IOSB

Related efforts in astronomy

- Work of Don Gavel et al. (VILLAGES project)
- Correction of static amplitude and phase aberrations of an out-going beam (Pontificia Universidad Catolica de Chile and Gemini Obs.; Bechet et al., Opt Expr, 2014)

Correction of static aberrations (beam shaping)

From Bechet et al., Opt Expr, 2014:

- Significant distortions of the GeMS laser beam have been observed during the first two years of operation.
- If the LGS spot size is reduced by 15%, it is as if the number of photons had been increased by 40%.
- From the data of April 2013, M^2 factors of 2.21 and 1.21 along x and y directions respectively were found. In October 2013, the corresponding M^2 factors were 2.23 and 1.15.

GeMS beam shapes

Bechet et al.,
Opt Expr, 2014

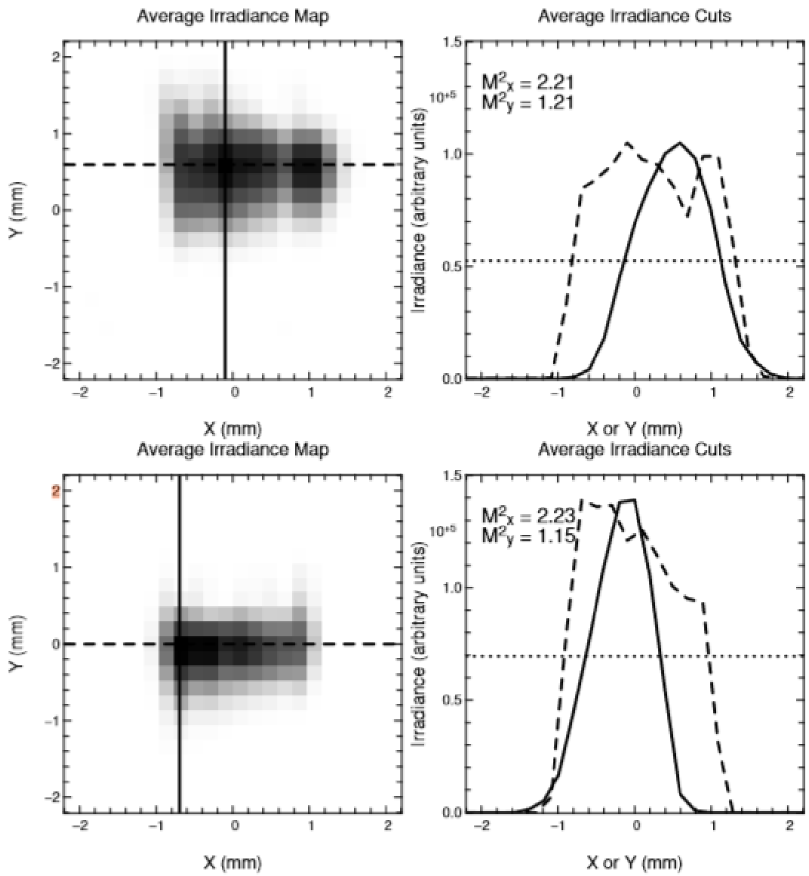


Fig. 1. Average irradiance map over 20 frames obtained from a 37 × 37 Shack-Hartmann sensor located at the output of the laser, during a run in April 2013 (top) and a run in October 2013 (bottom). **Left:** Irradiance map, with orthogonal lines of cuts through the maximum. **Right:** Cuts along x (dashed) and y-axis (solid) of the irradiance map above. The dotted horizontal line marks the half of the maximum.

Fraunhofer IOSB

Two-DM solution

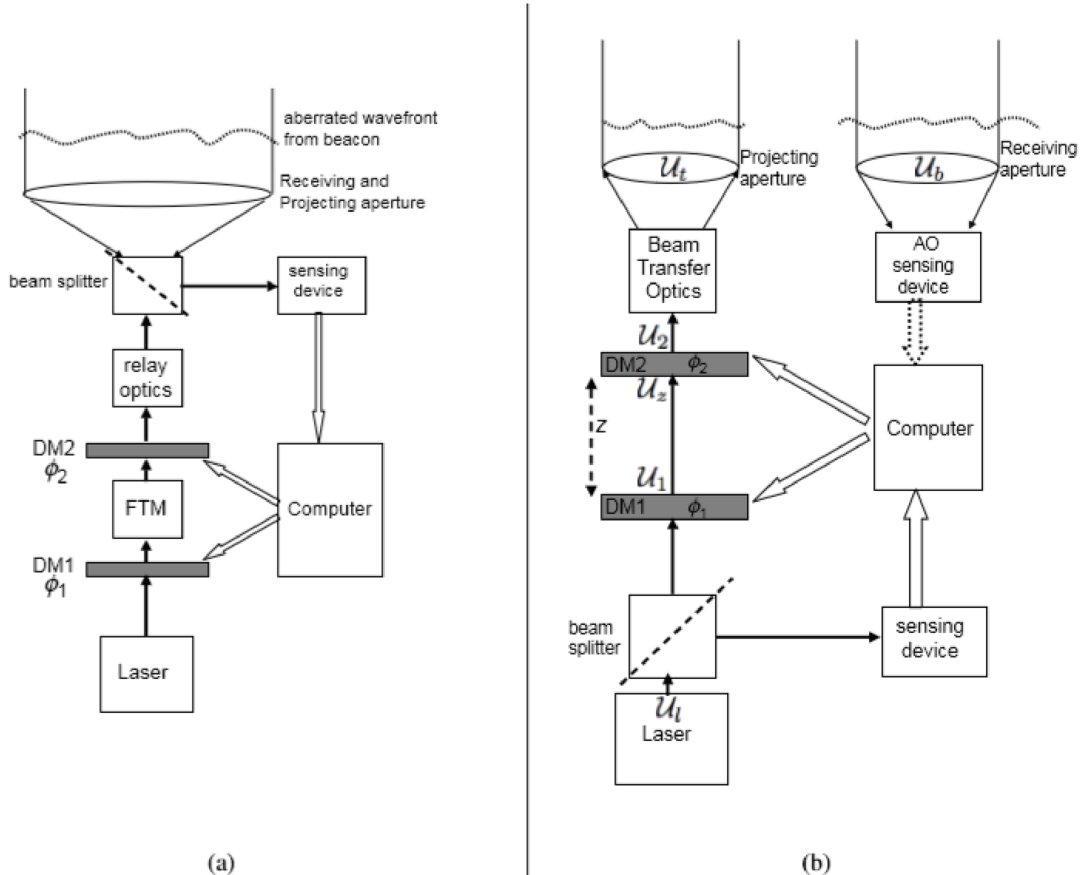
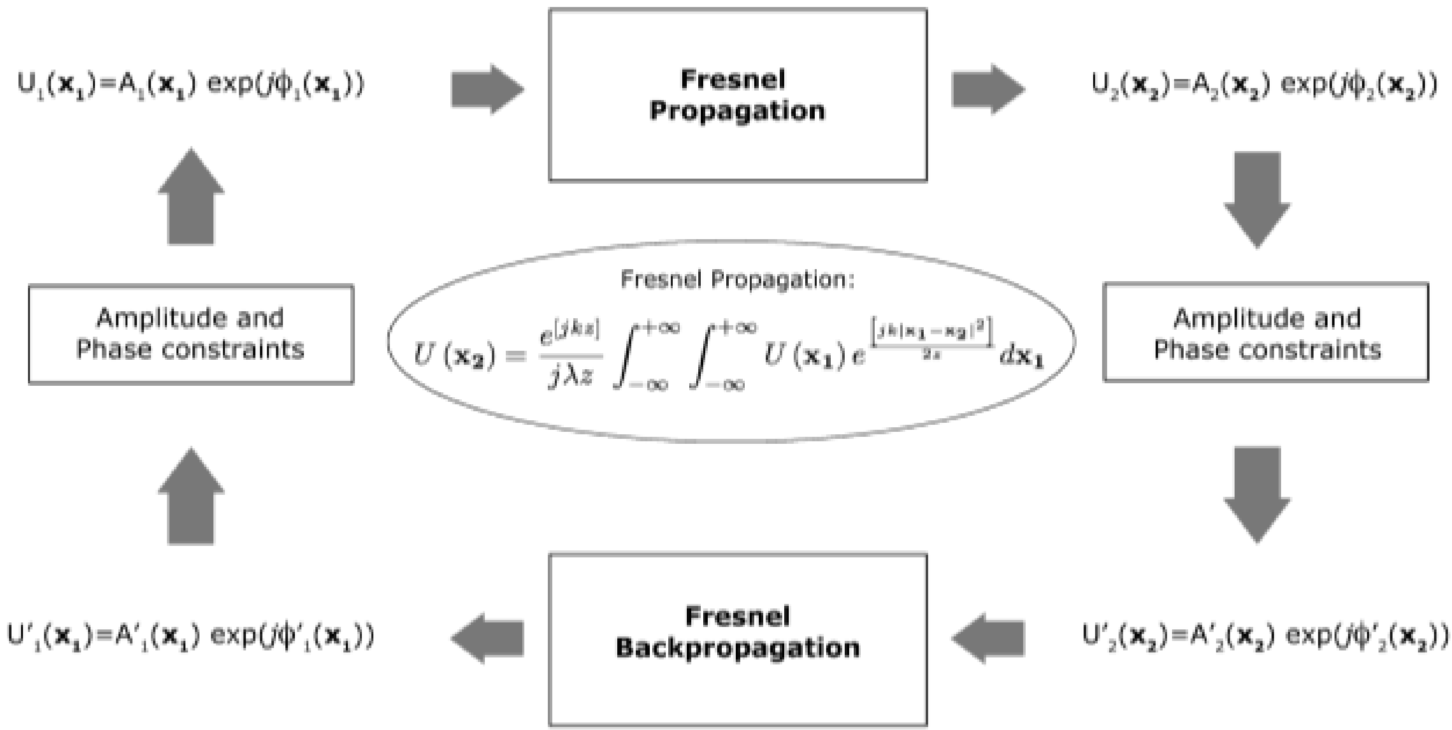


Fig. 2. Schematics of 2-DM correcting systems. **(a):** Mono-static system with DM2 in the far-field of DM1 [20]. The FTM box represents a Fourier transforming mirror. **(b):** 2-DM correcting system in the near-field proposed in this paper. DM1 is located in the near field of DM2, at a distance z. The configuration is named *bistatic* for having different receiving and projecting apertures.

Modified Gerchberg-Saxton algorithm



Zuniga et al.,
SPIE, 2014

Results of simulations

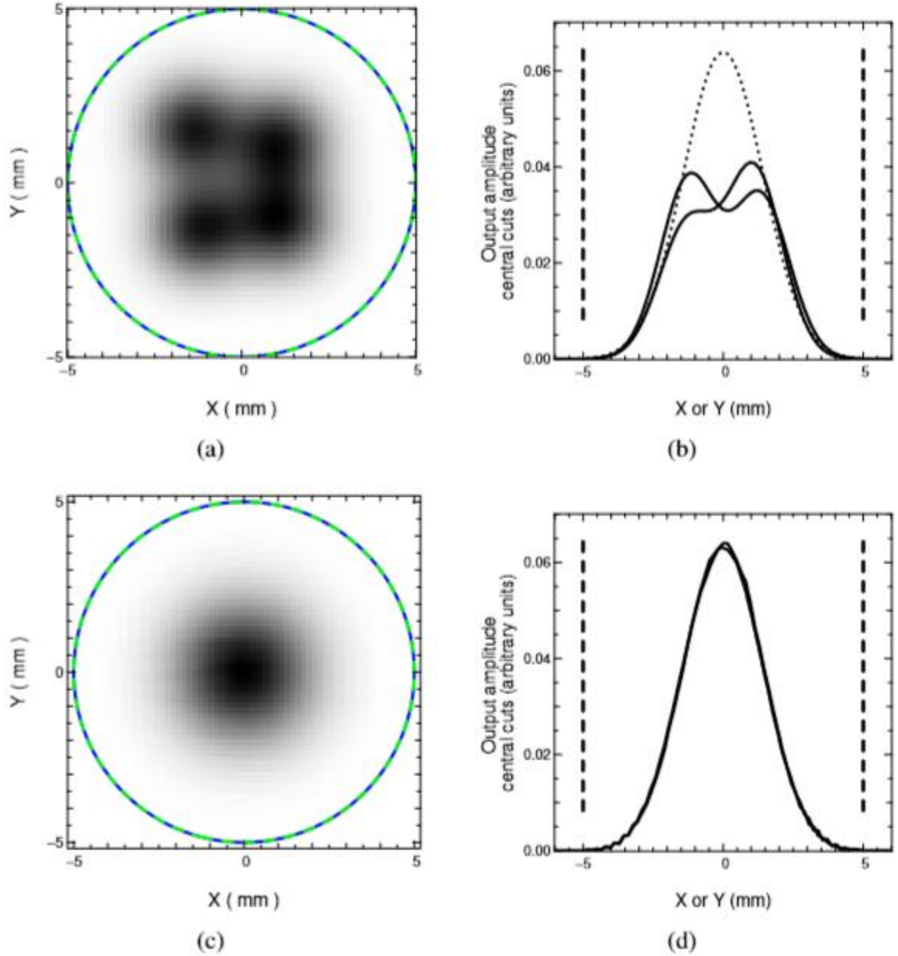


Fig. 3. Amplitudes of the output field at DM2, without correction ((a) and (b)) and with correction ((c) and (d)). Graphics (a) and (c) represent the 2D amplitude over the 1 cm aperture

Results of simulations

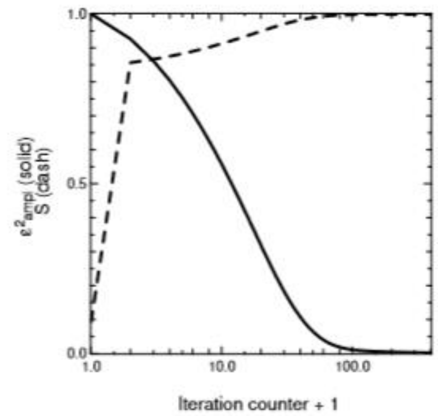


Fig. 5. Convergence of the criteria $\varepsilon^2_{\mathrm{ampl}}$ (solid) and S (dashed) defined in Eqs. (16) and (17). The iteration counter in abscissae is presented in logarithmic scale from 1 to 400.

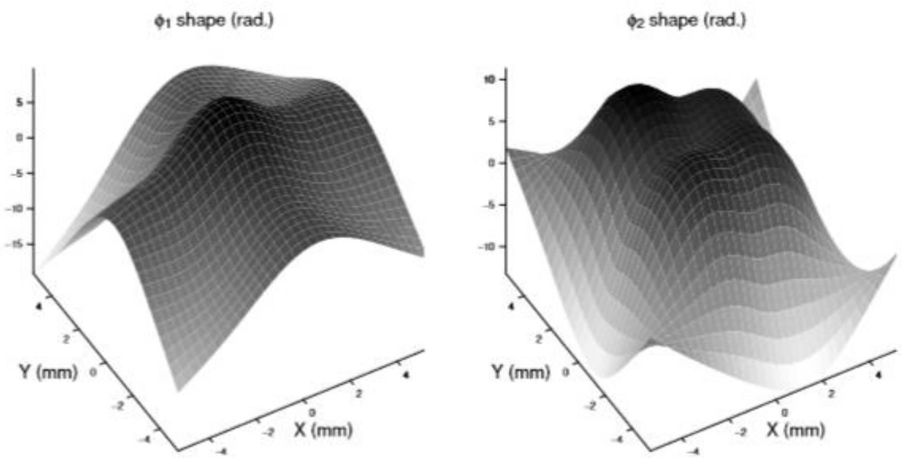
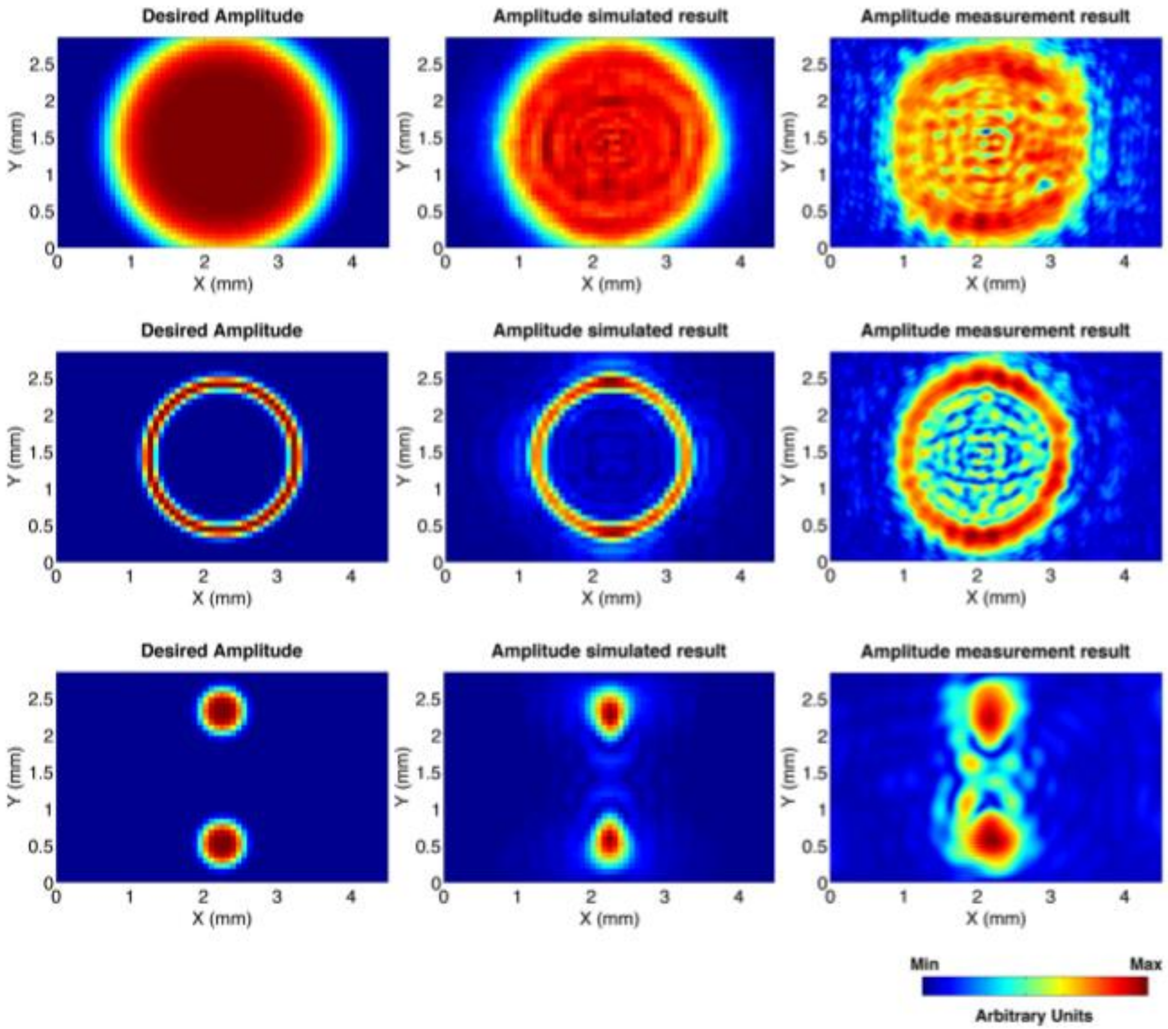


Fig. 6. Phase corrections ϕ_1 (**left**) and ϕ_2 (**right**) to be applied to DM1 and DM2 respectively, after 400 iterations.

Results of experiments



Zuniga et al., SPIE, 2014

Outline

- Pre-compensation of laser beams
- Holographic wavefront sensor (HWFS)
- Possible application in astronomical AO
- Thermal-piezoelectric deformable mirror from Fraunhofer IOF

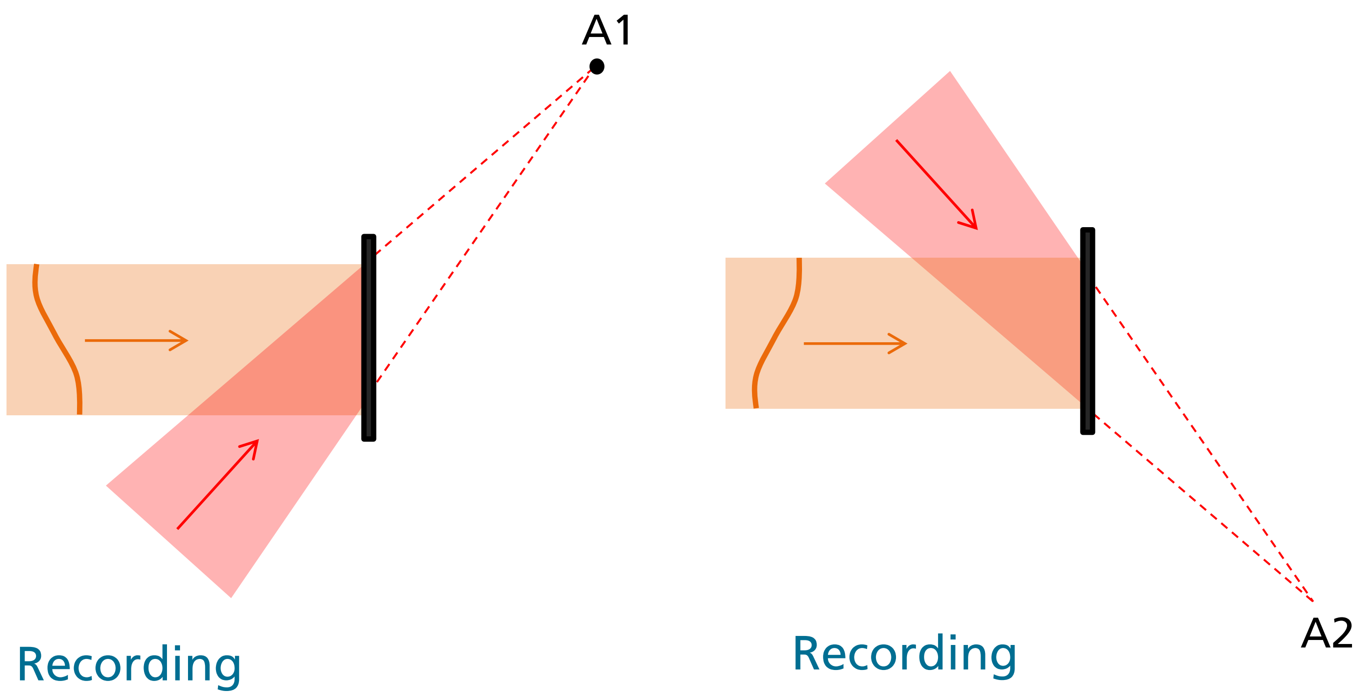
Holographic wavefront sensor

(HWFS, Neil et al., 2000; Andersen & Reibel, 2005)

Sensor implementation for one specific wavefront aberration

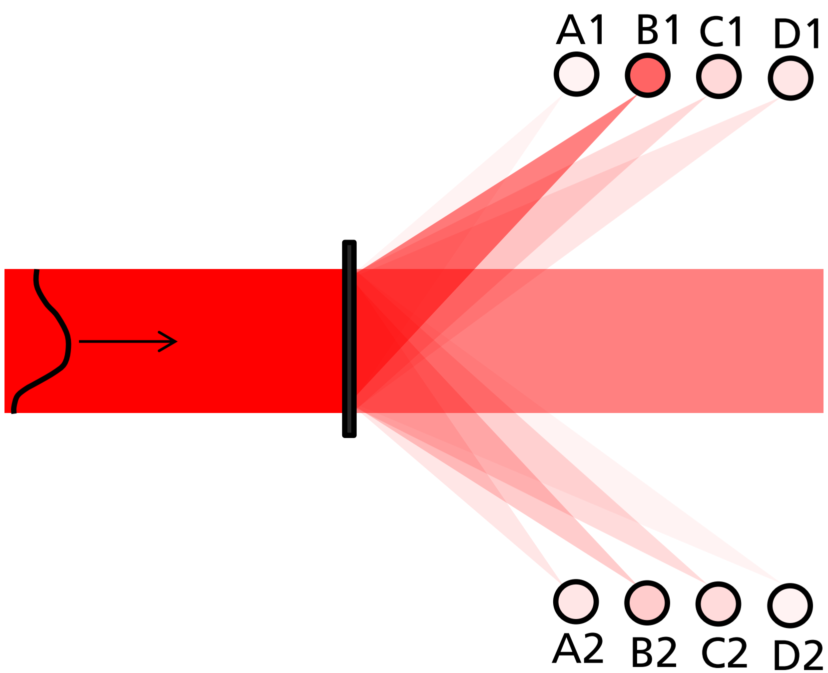
Hologram recording with

- reference beam = deformed probe beam
- object beam = converging spherical wavefront



Holographic wavefront sensor

Sensor operation for four modes.



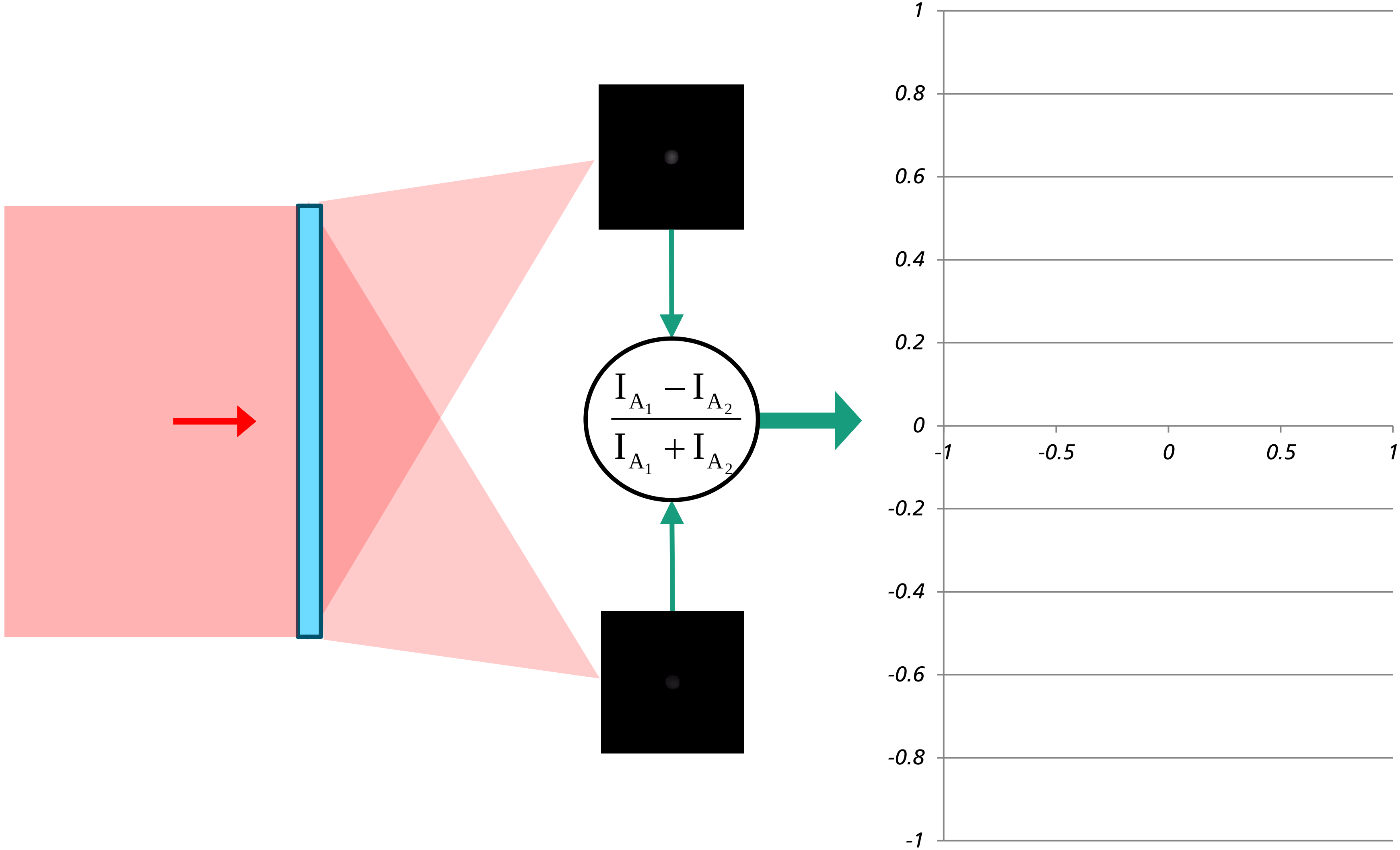
Playback

- Measurement of Zernike modes: **independent of intensity**
- Identification of the amplitude:

$$Signal = |a| \cdot \frac{I_{A_1} - I_{A_2}}{I_{A_1} + I_{A_2}}$$

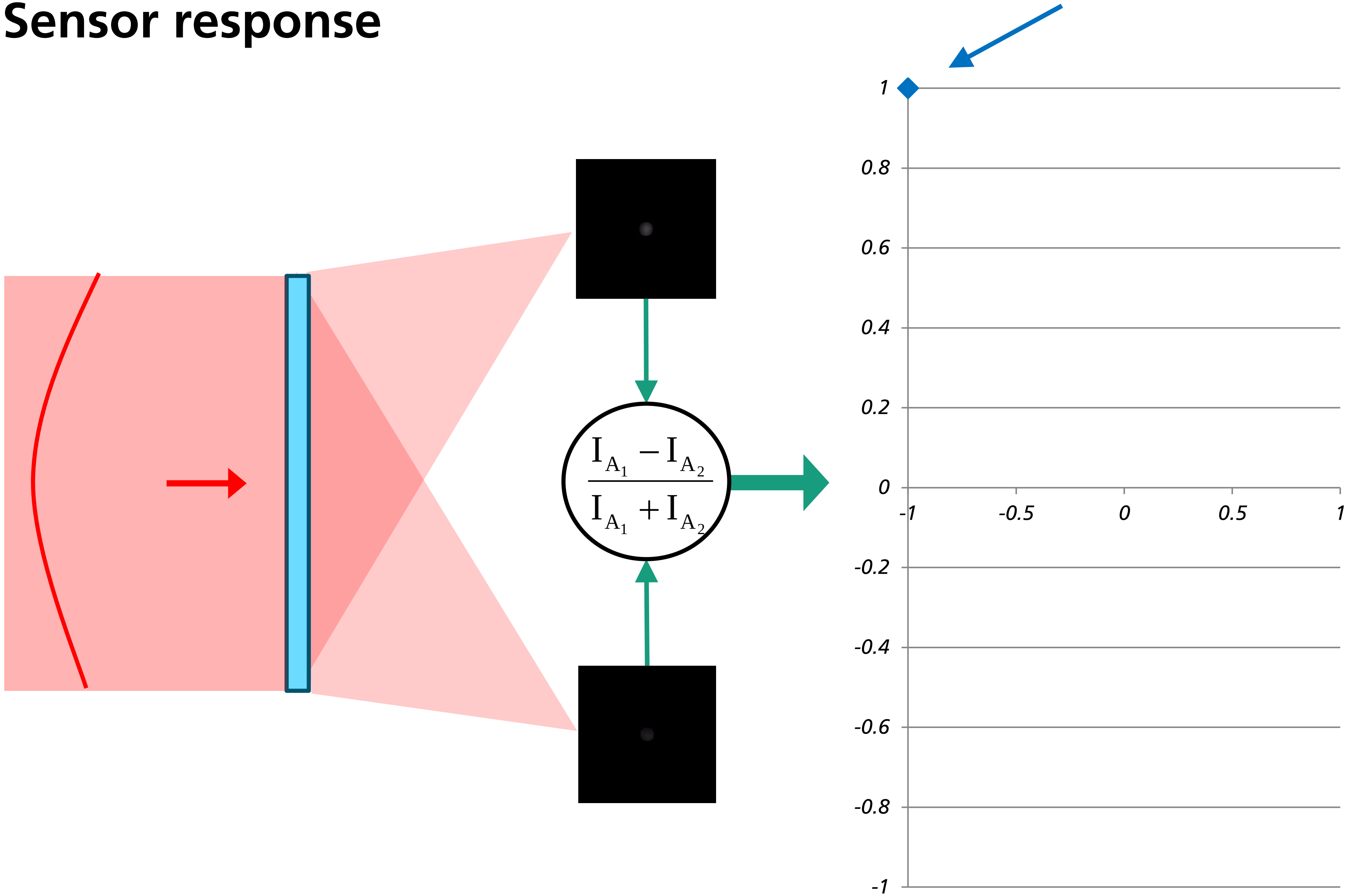
Zepp, Gladysz, Stein, J. Adv. Opt. Tech., 2013

Sensor response

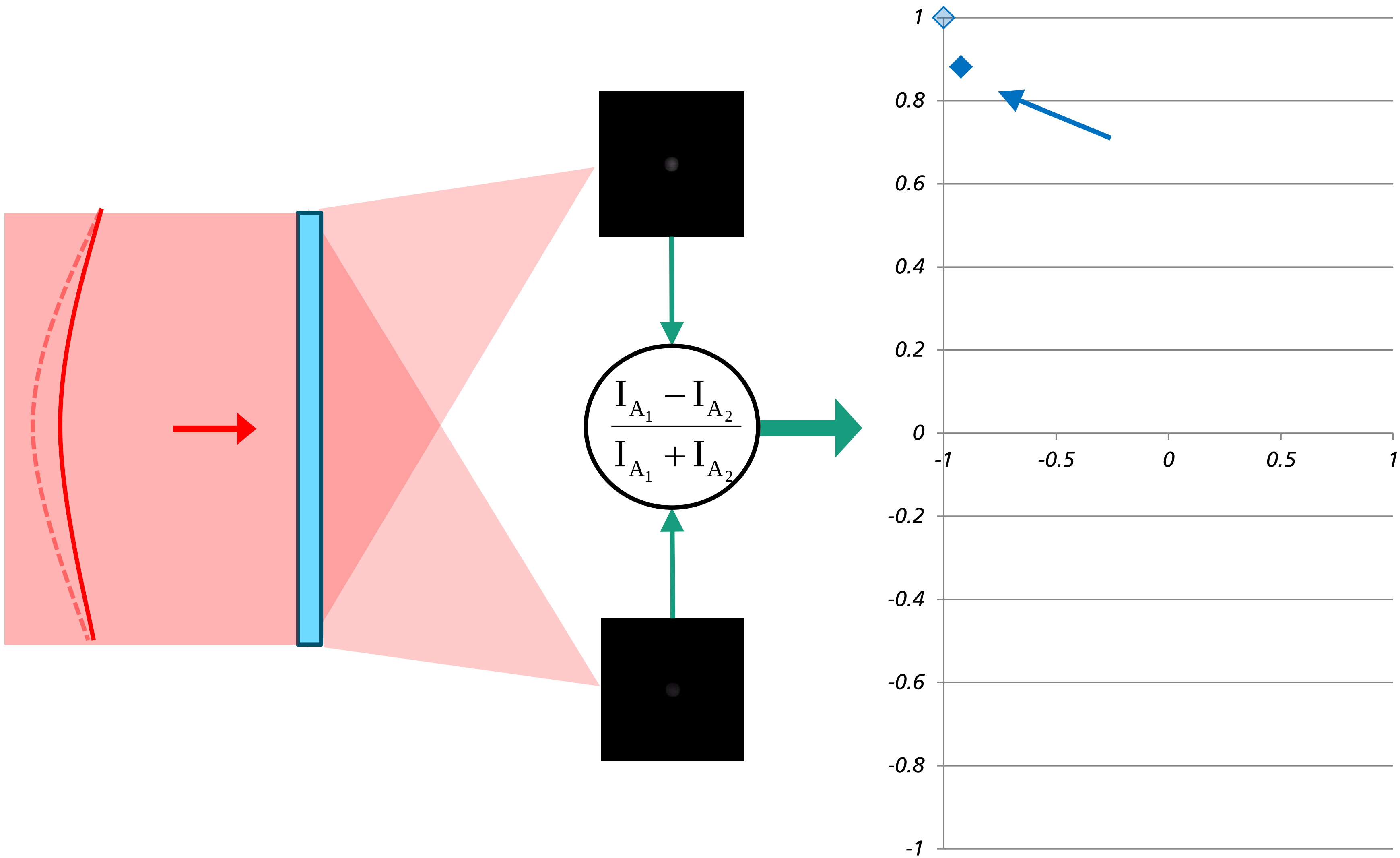


Fraunhofer IOSB

Sensor response

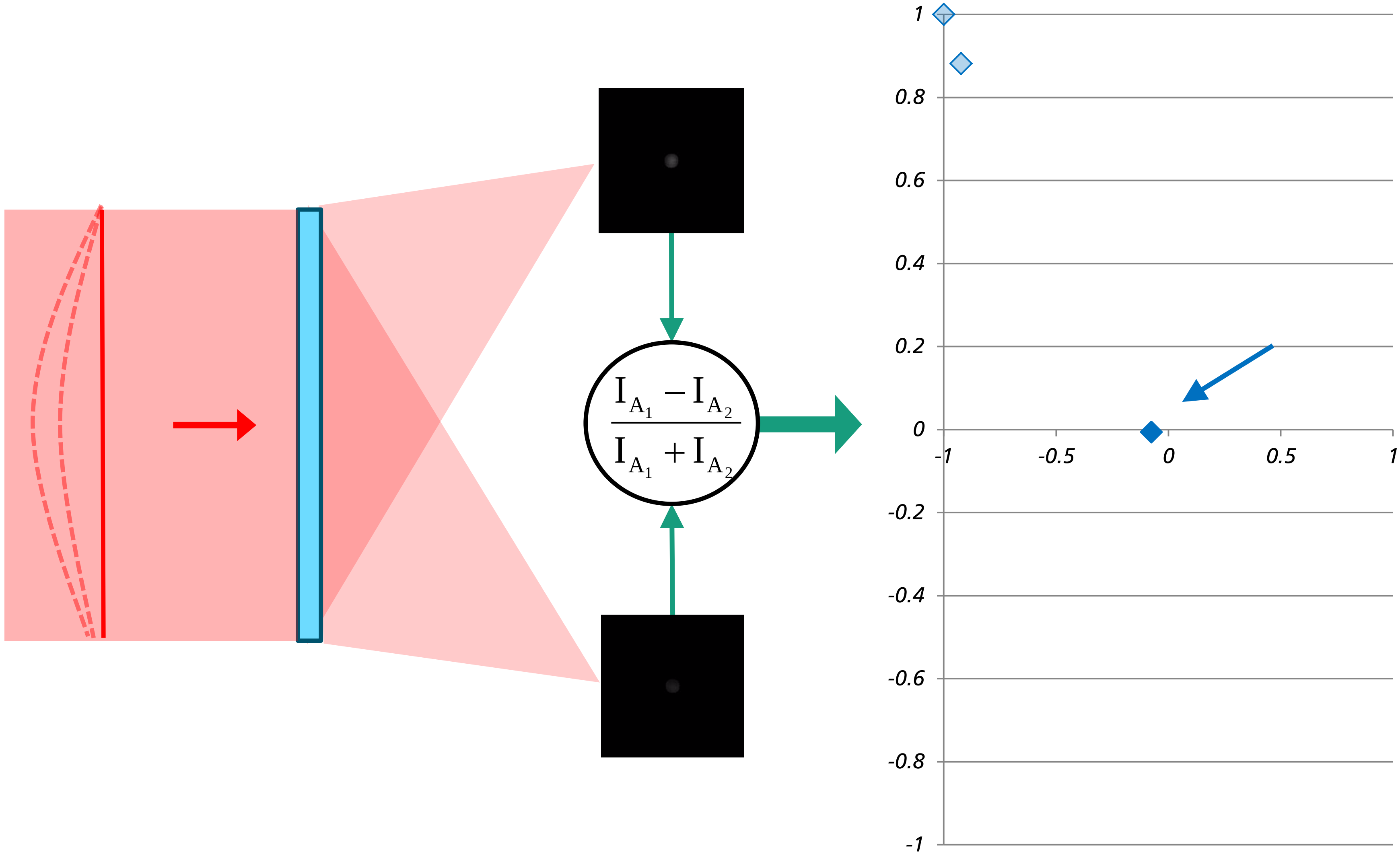


Sensor response



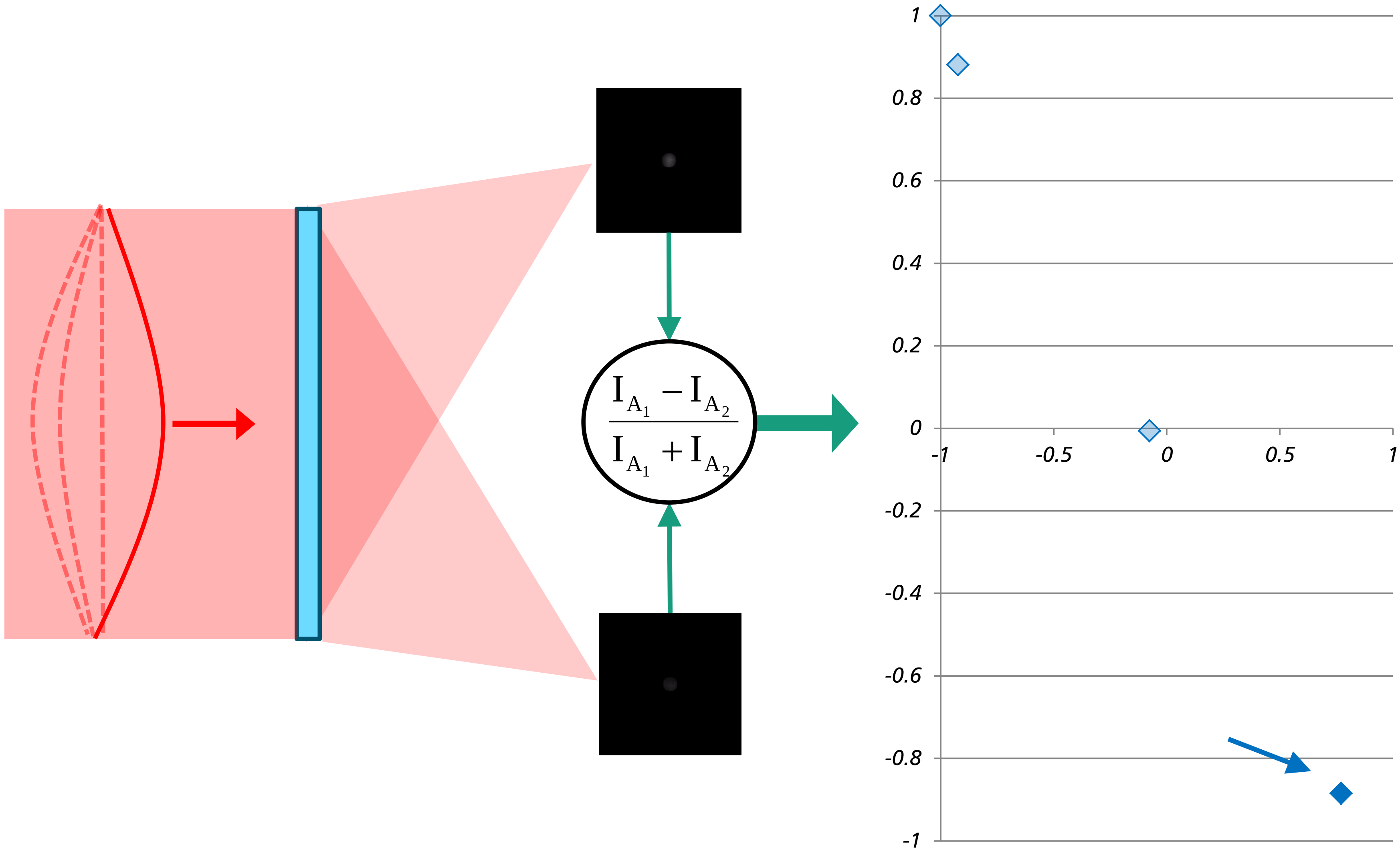
Fraunhofer IOSB

Sensor response

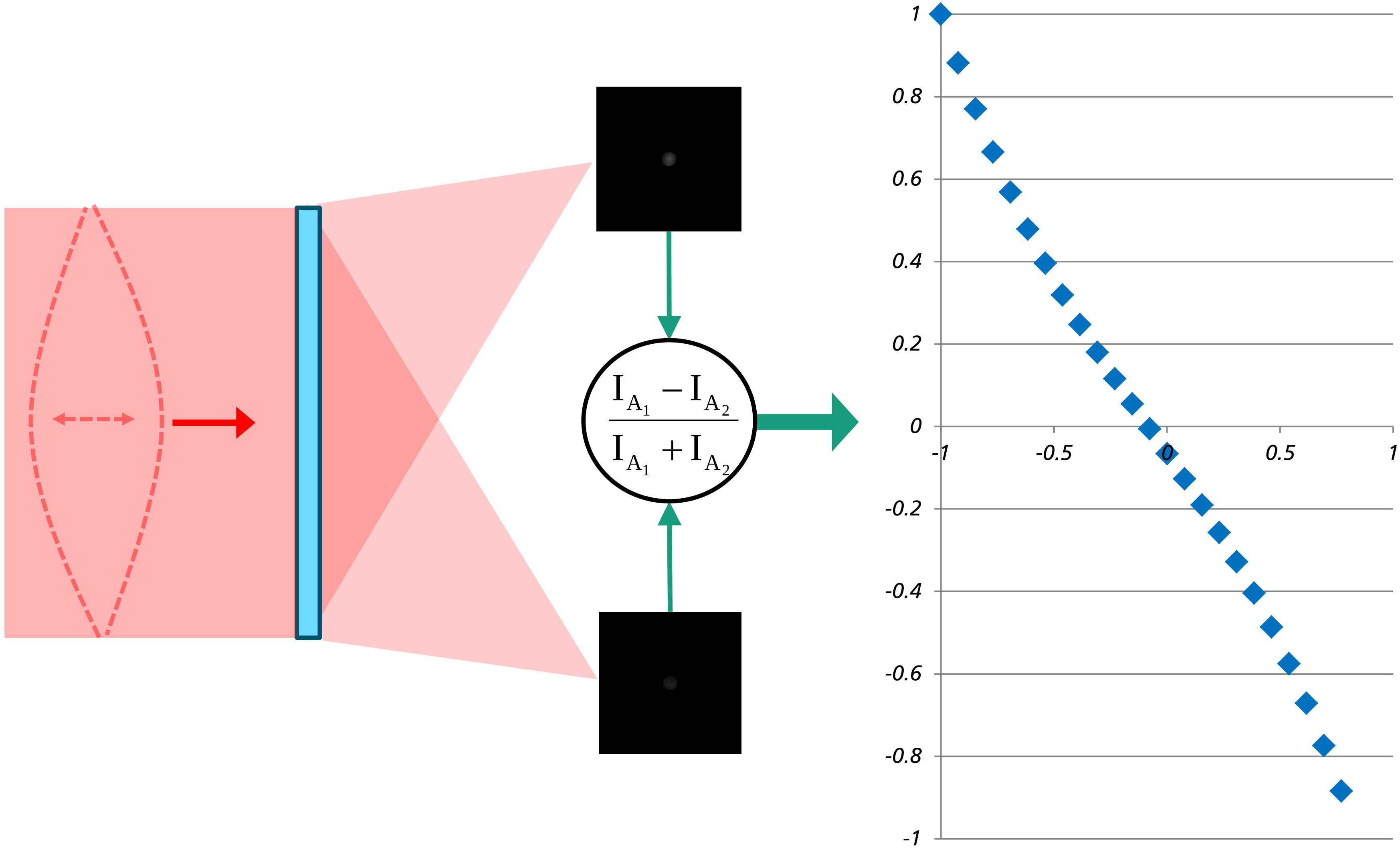


Fraunhofer IOSB

Sensor response



Sensor response

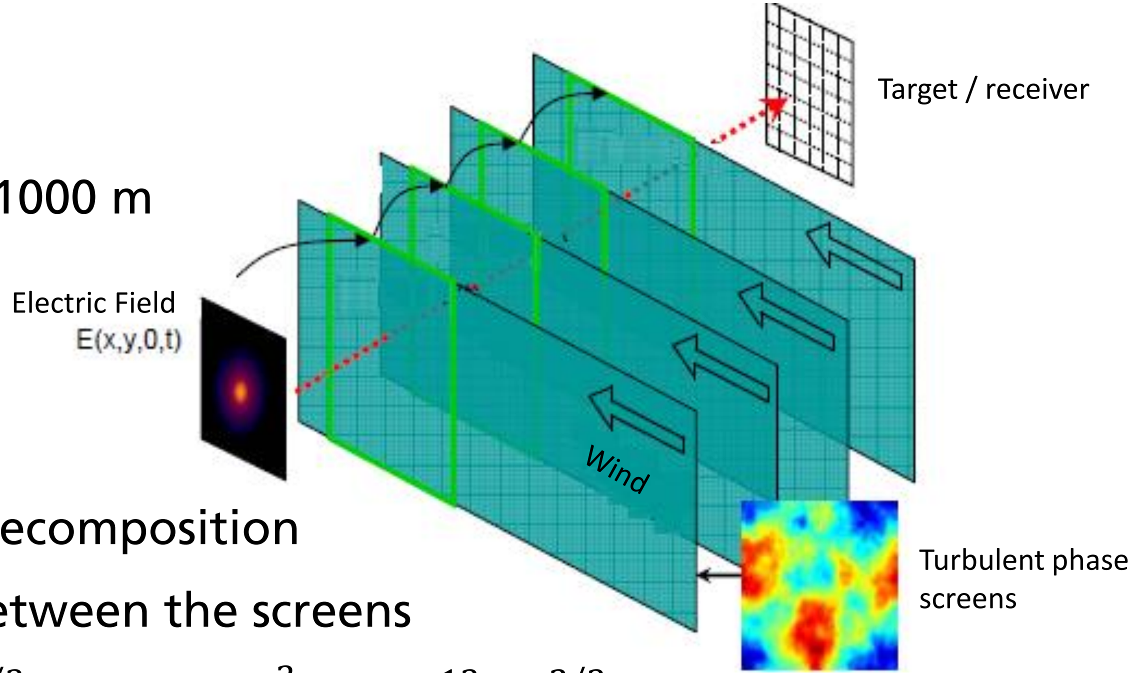


Optimal design of the holographic wavefront sensor for pre-compensation

DESCRIPTION OF THE PARAMETERS OF THE SIMULATION

Parameters:

- Output radius: 10 cm
- Propagation distance: 1000 m
- Focal length: 1000 m



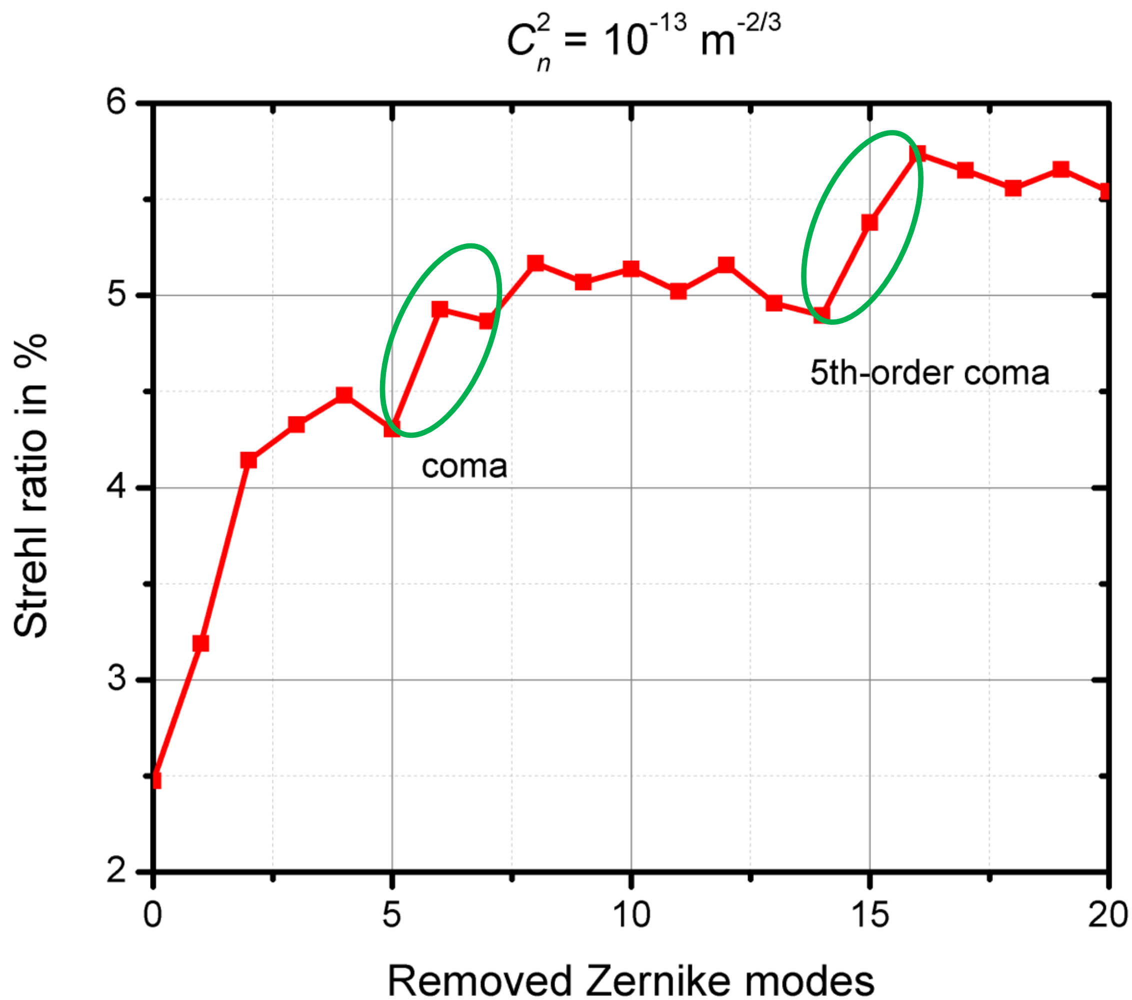
Atmosphere:

- Zernike phase screen decomposition
- Fresnel propagation between the screens
- Weak: ${C_n}^2 = 10^{-15} m^{-2/3}$; strong: ${C_n}^2 = 10^{-13} m^{-2/3}$

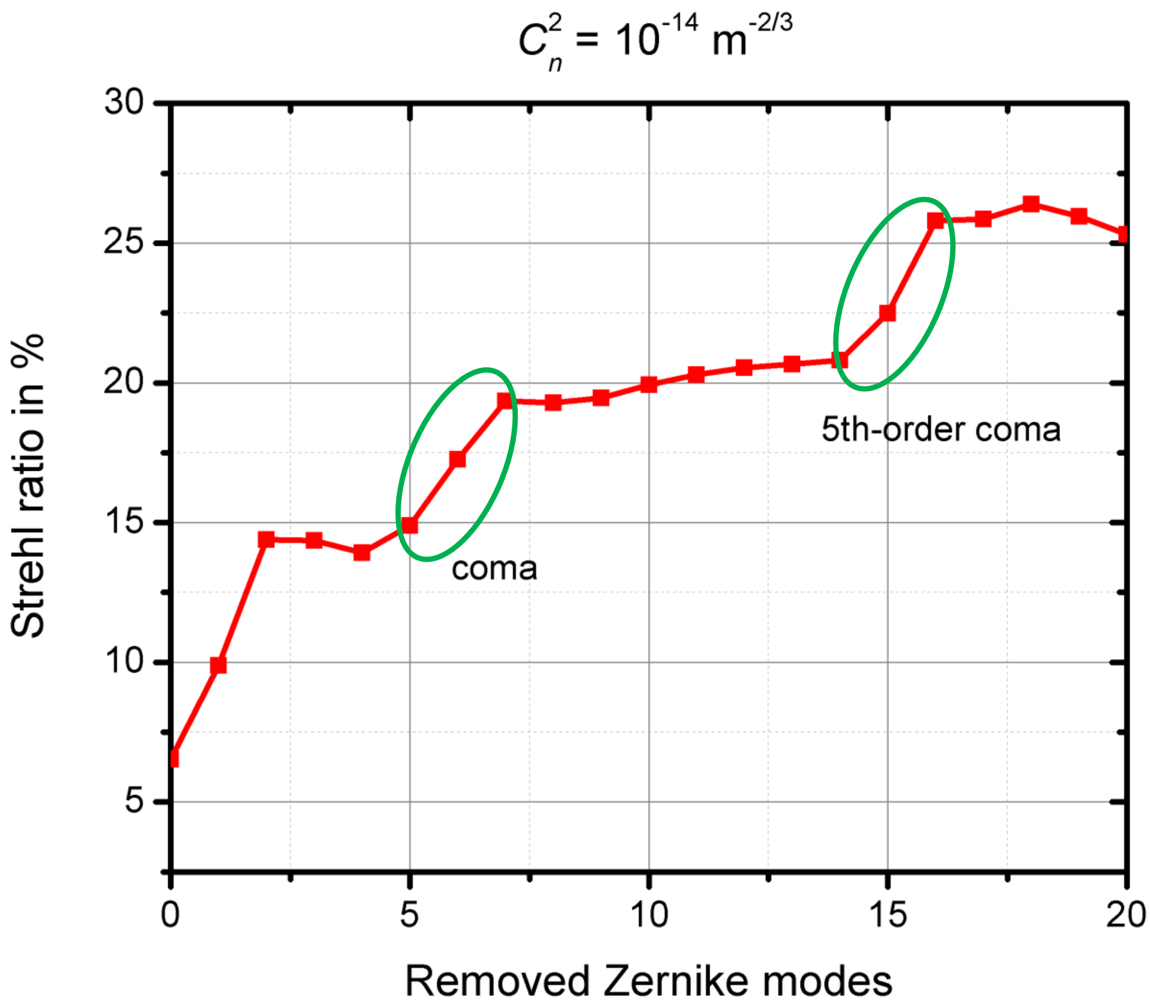
Metric:

- Strehl ratio

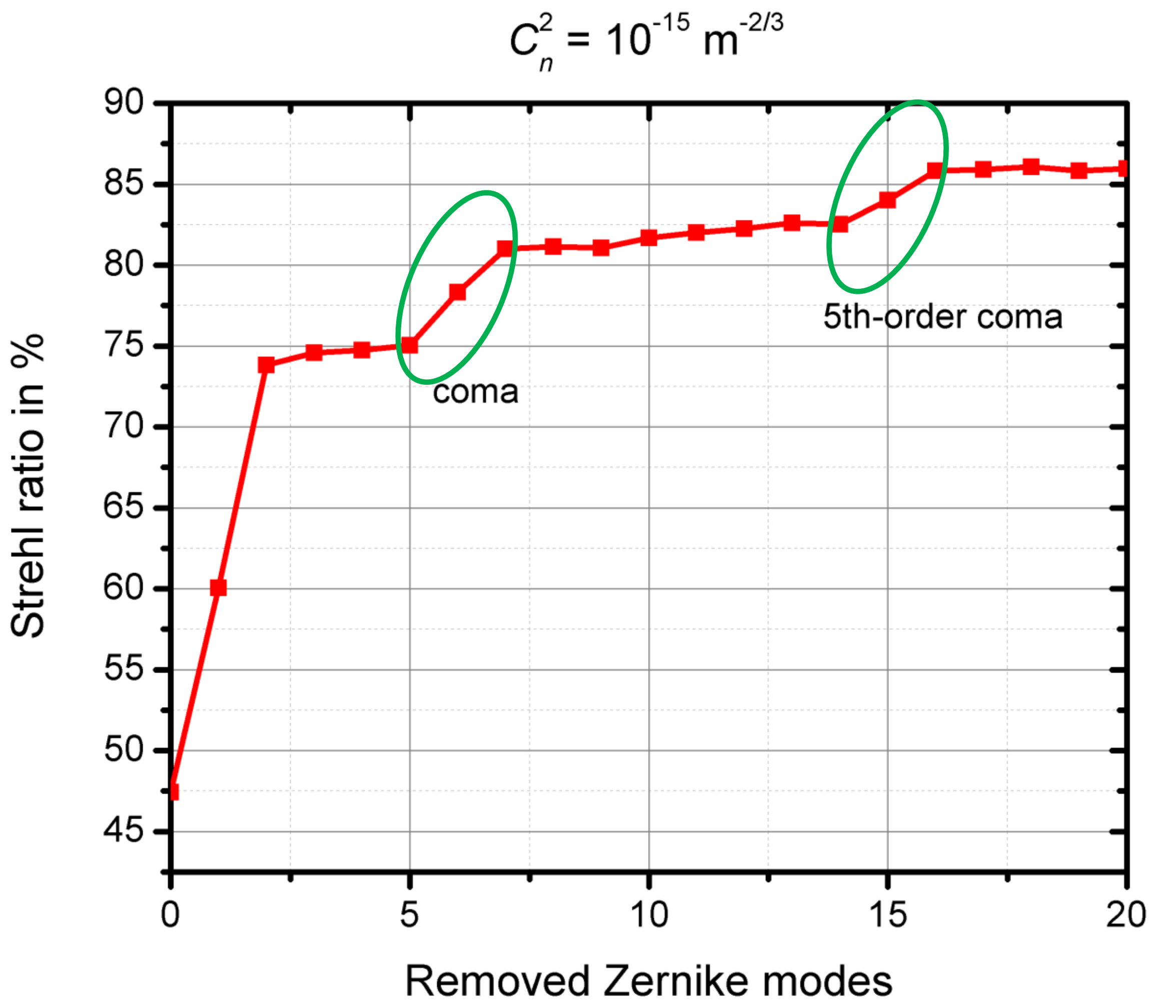
Optimal pre-compensation



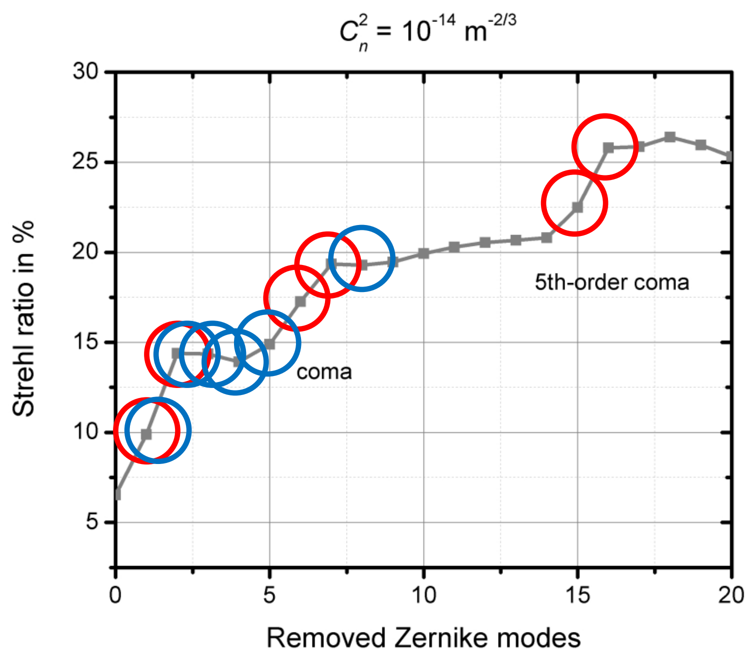
Optimal pre-compensation

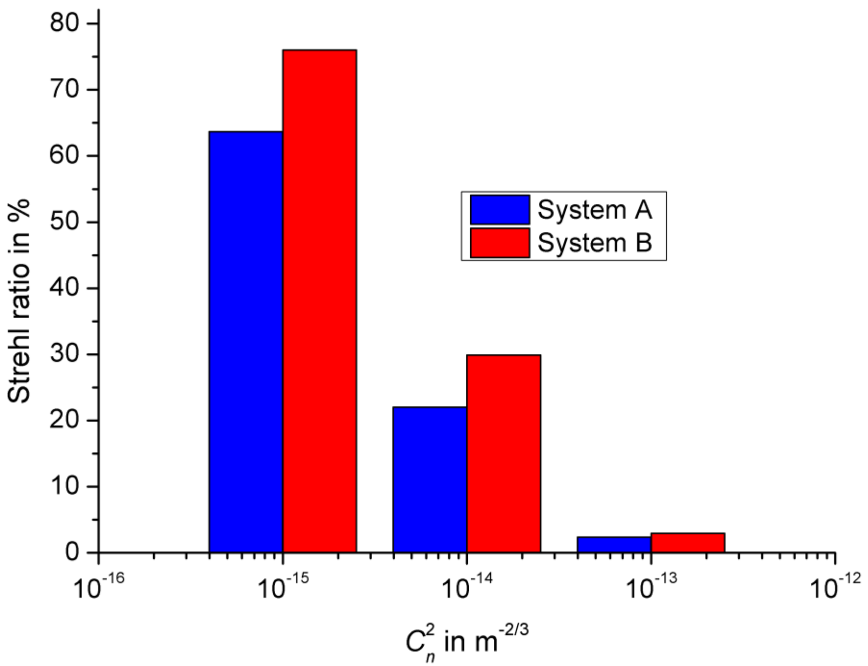


Optimal pre-compensation



Optimal pre-compensation



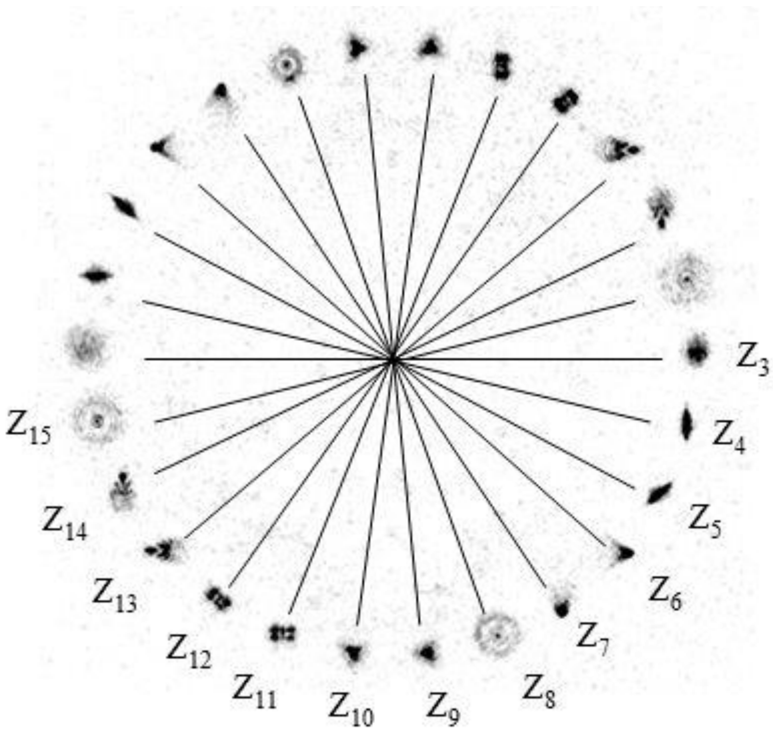


- Gain can be as high as 30%.

Azarian & Gladysz, SPIE, 2014

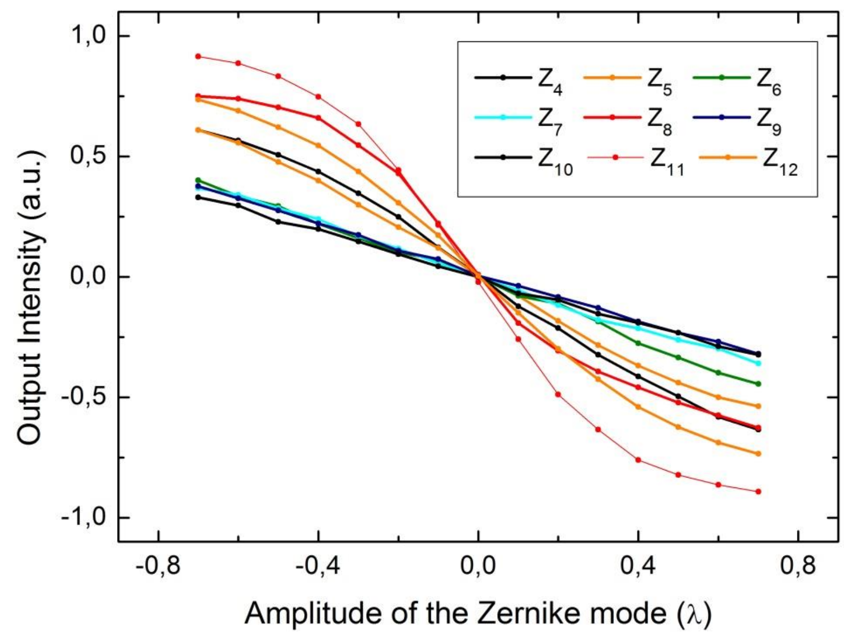
Digital holographic wavefront sensor

- Implementation for several modes in an optimized geometry

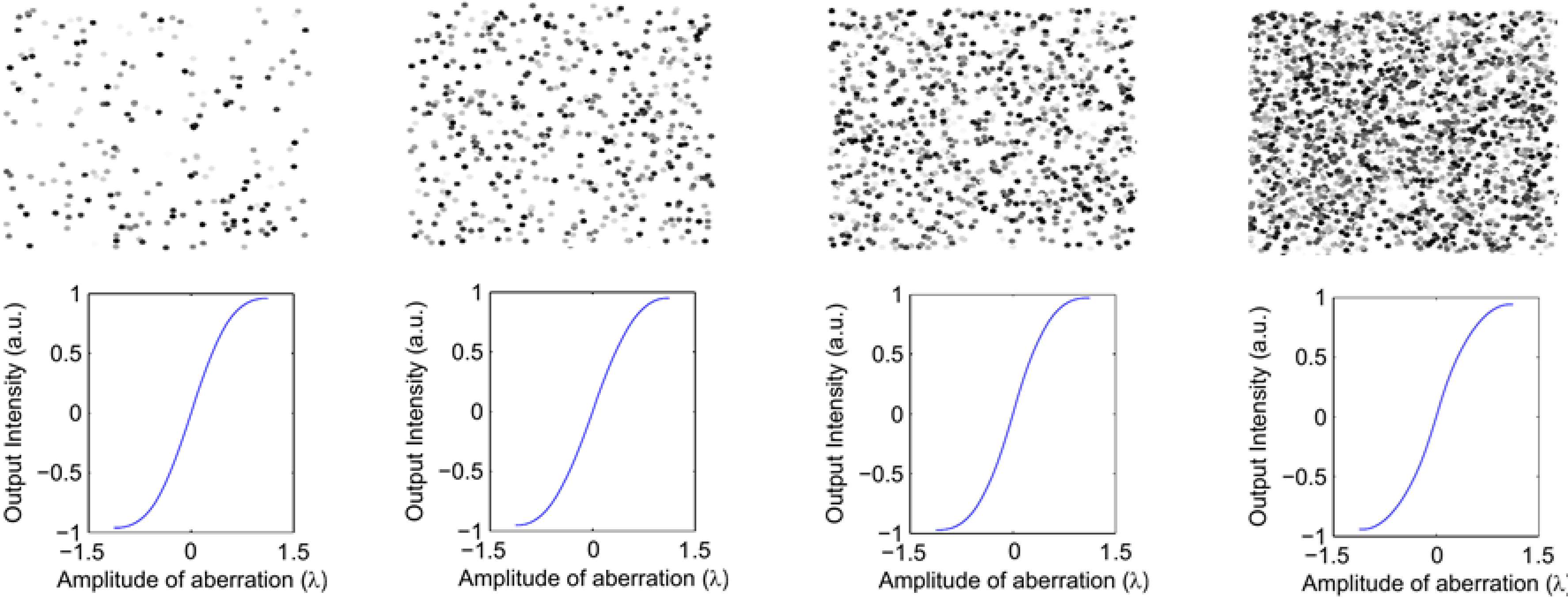


Marin, Zepp, Gladysz, SPIE, 2014

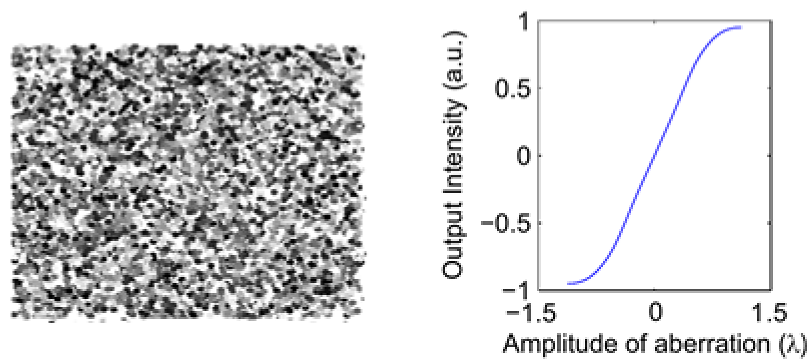
- Linearity optimization



Scintillation simulation



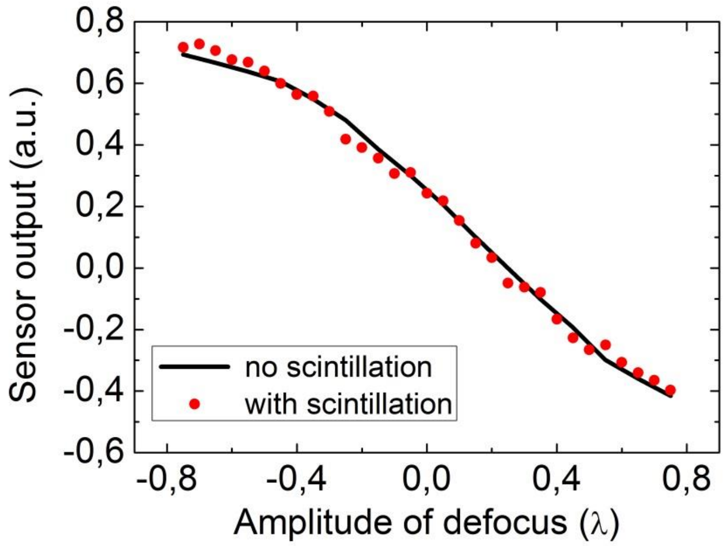
Marin, Zepp, Gladysz, SPIE, 2014

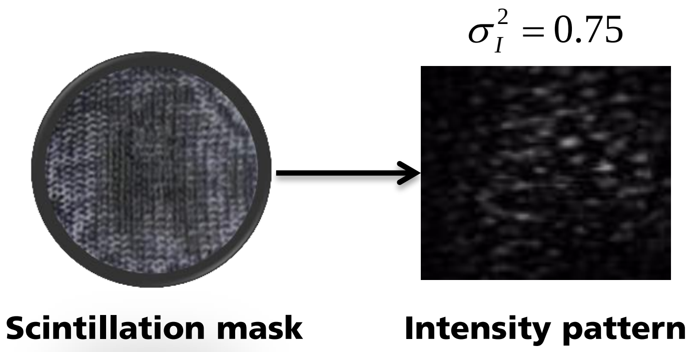


Fraunhofer IOSB

Defocus detection mode

- Effect of scintillation



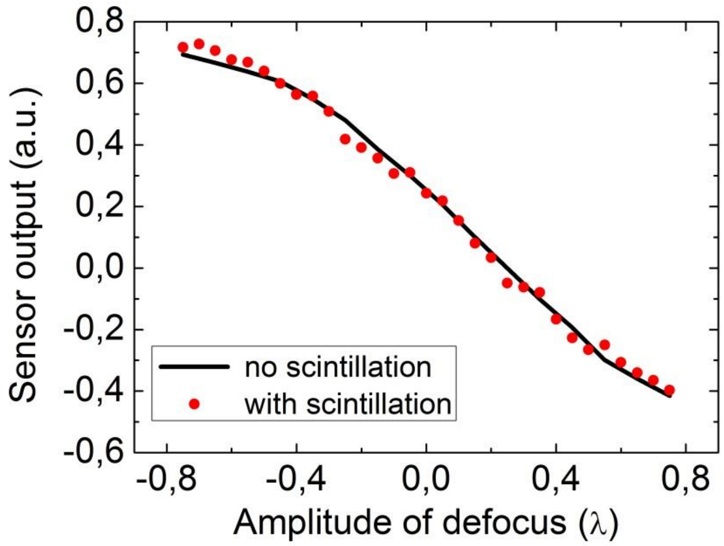


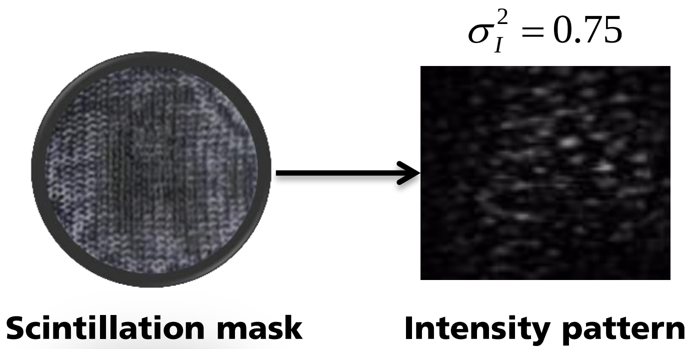
➢ Intensity reduced 90% due to the mask

Marin, Zepp, Gladysz, SPIE, 2014

Defocus detection mode

- Effect of scintillation





➢ Changing Scintillation under constant aberration:

Detector radius (ω_0)	2.4	4.0	6.0	7.0	8.0	9.0
Std.dev. (λ)	0.062	0.054	0.036	0.037	0.038	0.039

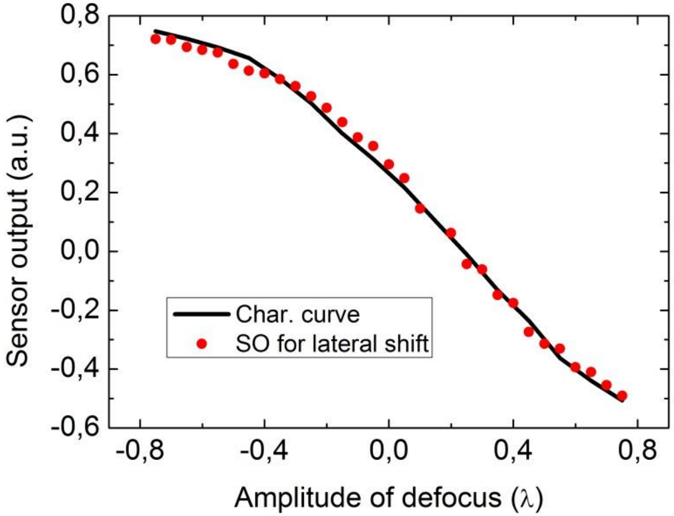
➢ The variability due to scintillation depends on the detector radius

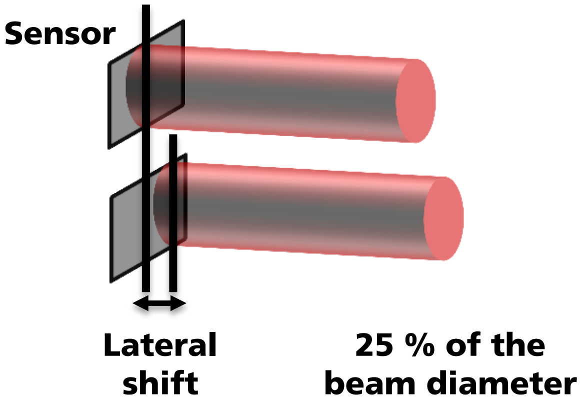
➢ The sensor is insensitive to scintillation

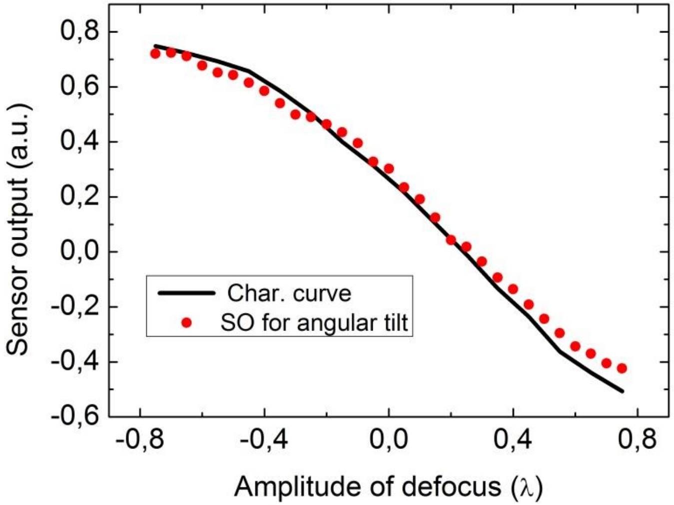
Fraunhofer IOSB

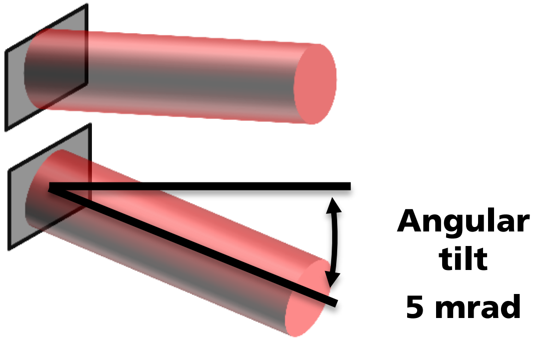
Defocus detection mode

- Effect of beam wander



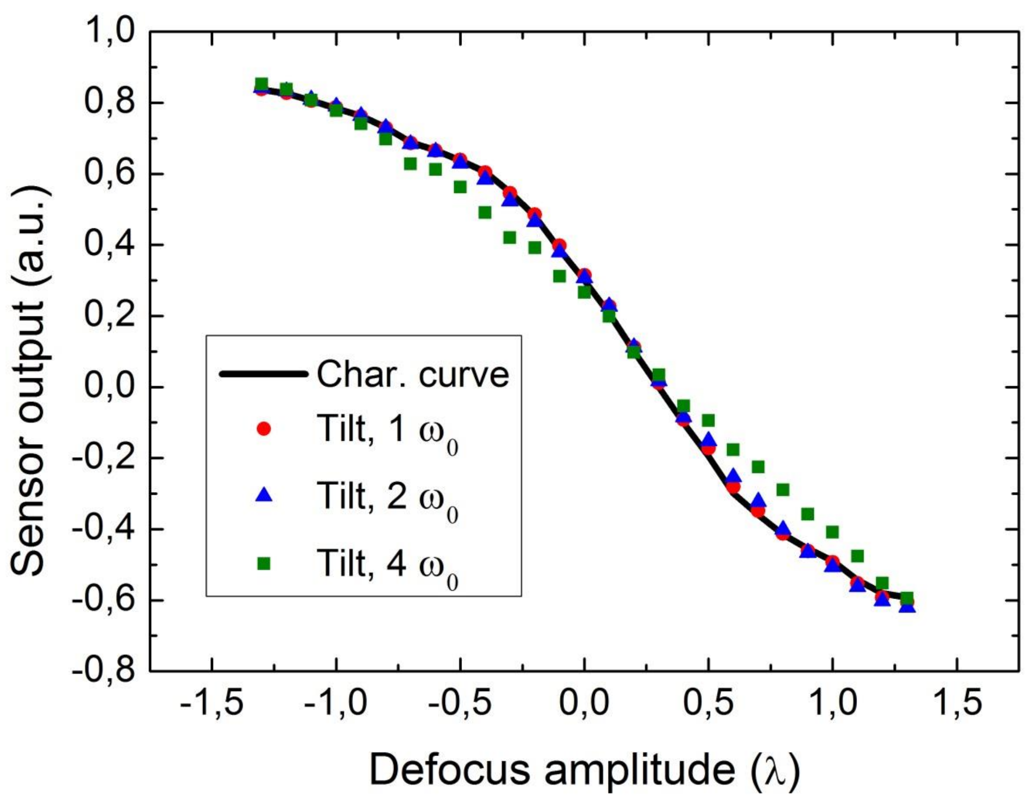


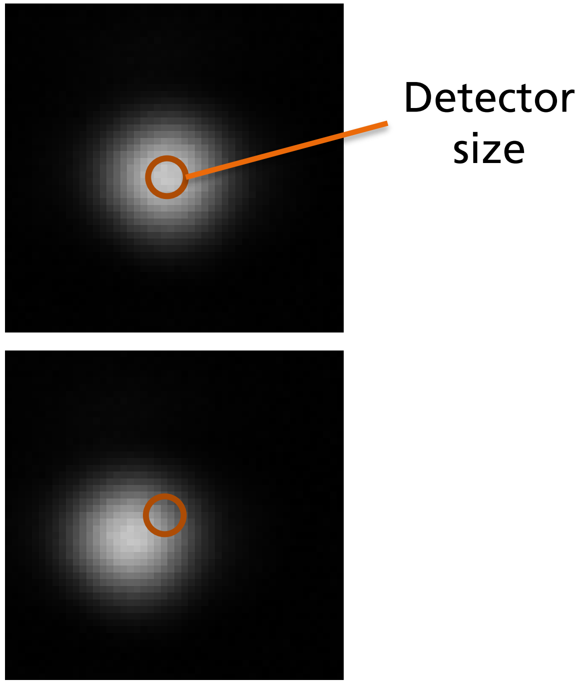




Defocus detection mode

- Effect of tip and tilt





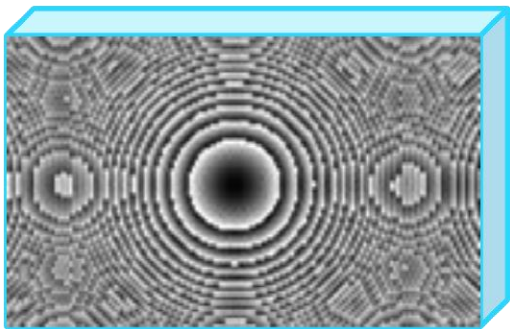
Shift of optical axis

Outline

- Turbulence effects on laser propagation
- Pre-compensation of laser beams
- Holographic wavefront sensor (HWFS)
- Possible application in astronomical AO
- Thermal-piezoelectric deformable mirror from Fraunhofer IOF

Optimization of HWFS for astronomical applications

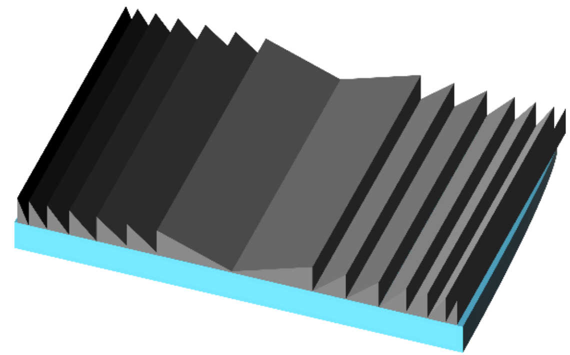
- Lithography: Hologram to blazed grating



Holographic plate

50% in 1st order

Lithography →



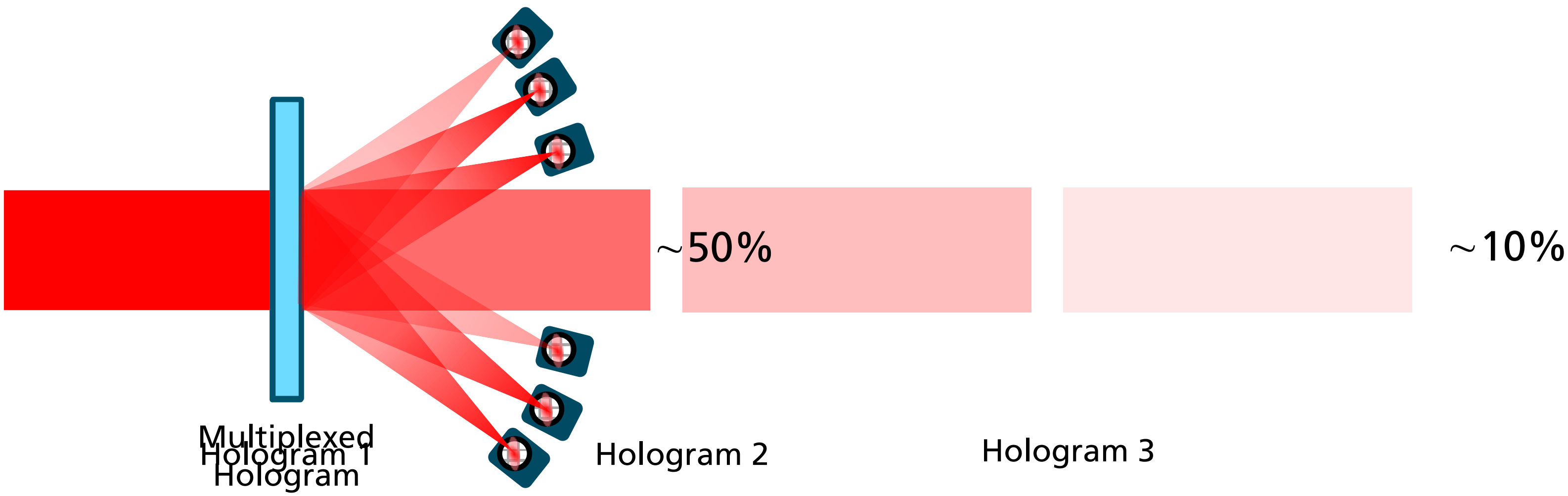
Blazed Grating

95% in 1st order

Optimized to achieve maximum diffraction efficiency in a given order

Optimization of HWFS for astronomical applications

- Optimize diffraction efficiency

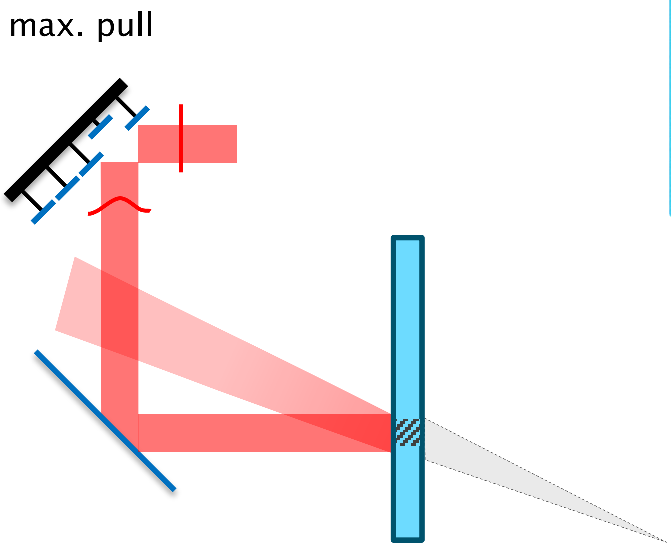


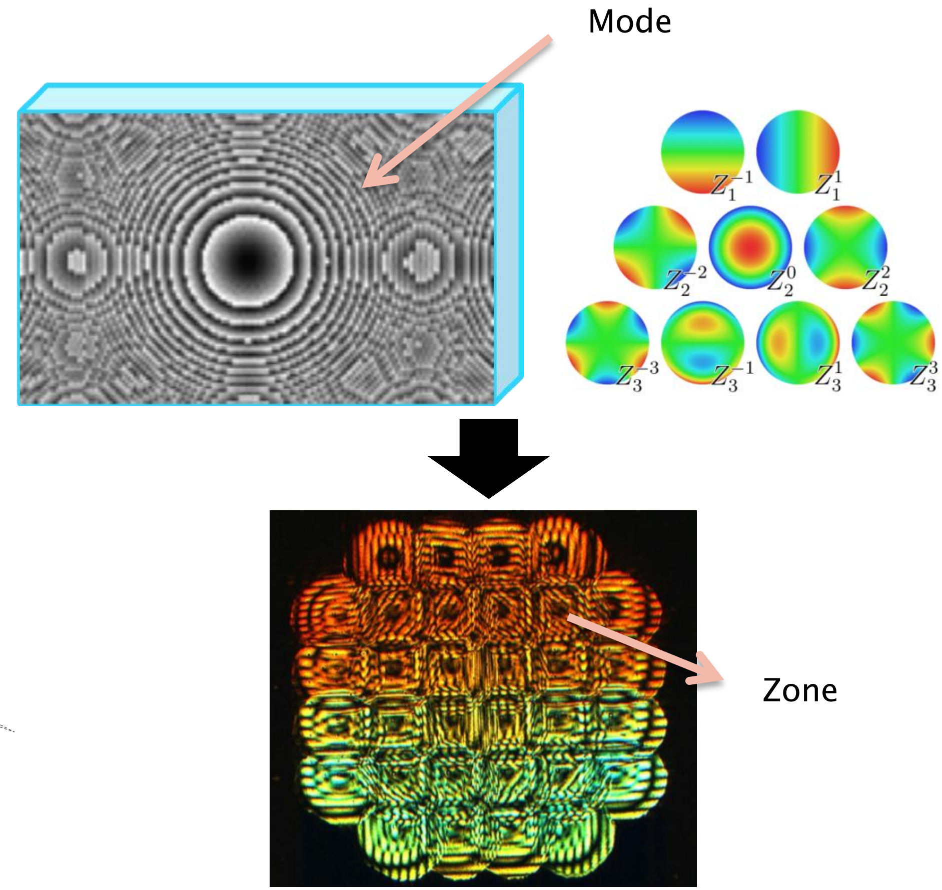
Sequential holographic wavefront sensor

Optimization of HWFS for astronomical applications

- From modal to zonal wavefront sensor

Zonal recording:





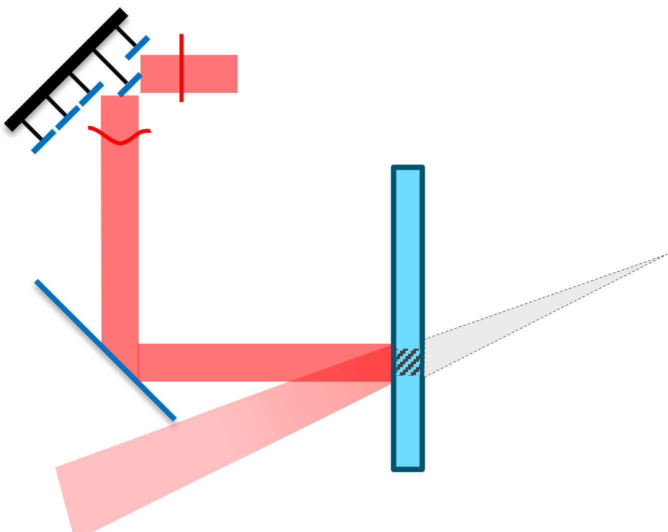
G. Andersen et.al. (2014) OSA

Optimization of HWFS for astronomical applications

- From modal to zonal wavefront sensor.

Zonal recording:

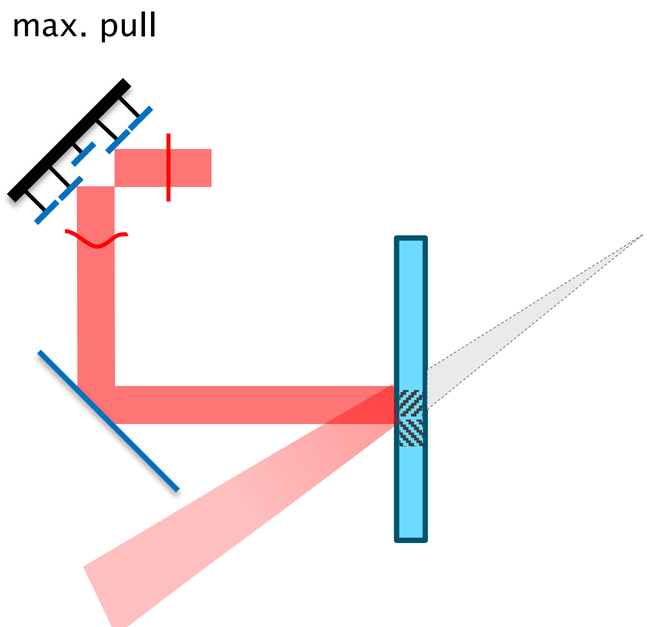
max. push



Optimization of HWFS for astronomical applications

- From modal to zonal wavefront sensor.

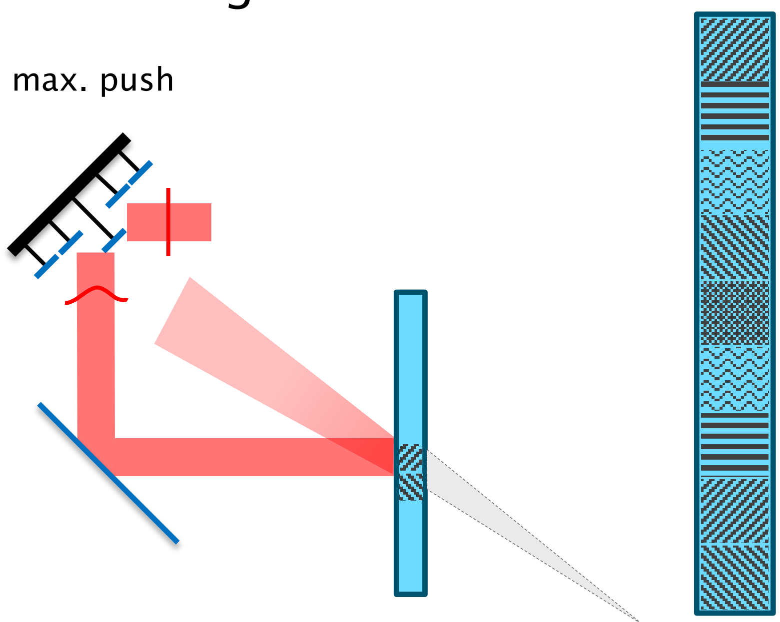
Zonal recording:

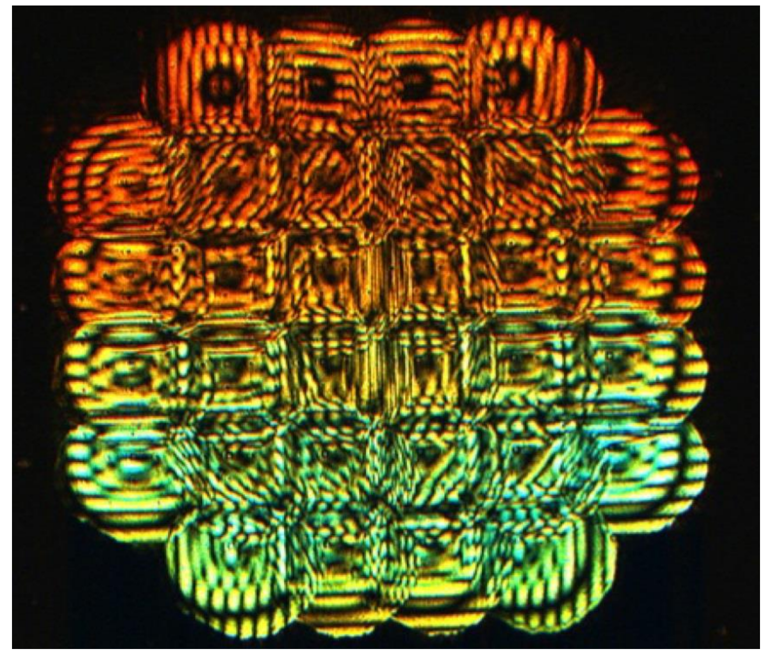


Optimization of HWFS for astronomical applications

- From modal to zonal wavefront sensor.

Zonal recording:



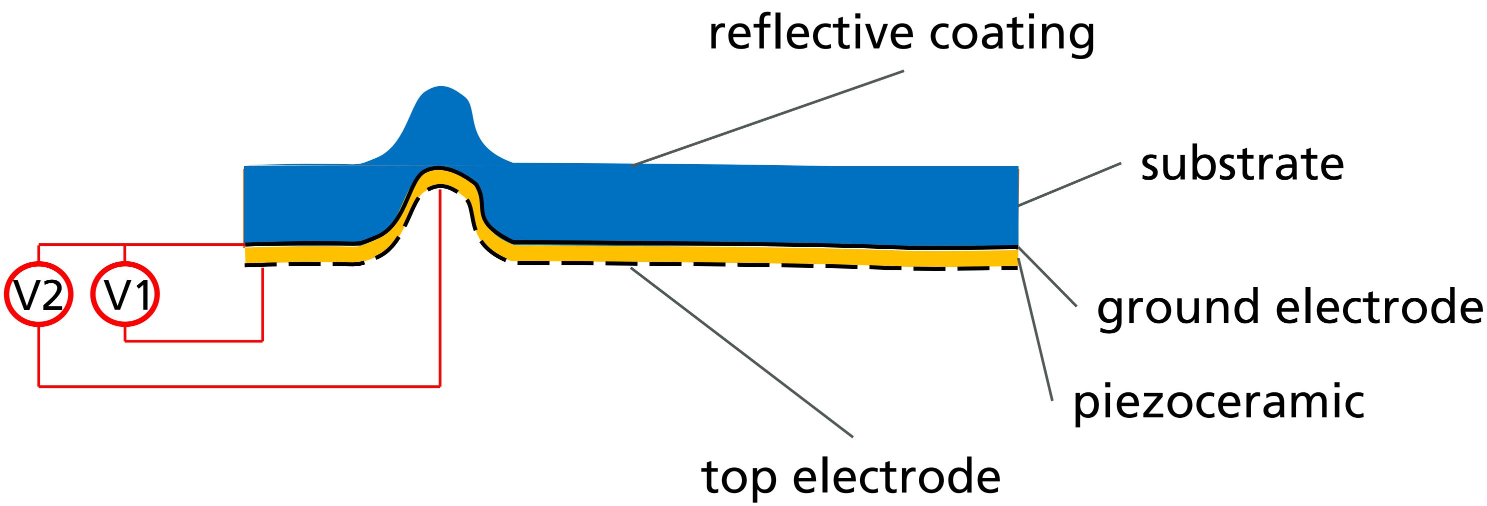


Andersen et al. (2014) Opt Expr

Outline

- Turbulence effects on laser propagation
- Pre-compensation of laser beams
- Holographic wavefront sensor (HWFS)
- Possible application in astronomical AO
- Thermal-piezoelectric deformable mirror from Fraunhofer IOF

Unimorph deformable mirrors

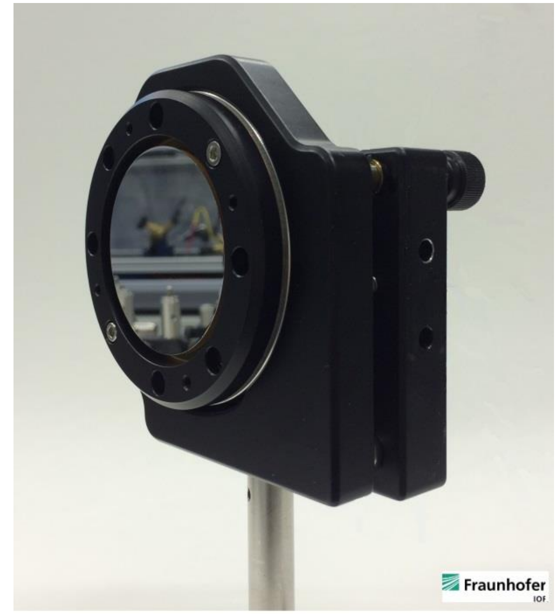


Application of an electric field (V1) to the piezoceramic between ground and top electrode results in a deformation of the optical surface.

Standard mirror setup with adhesively bonded piezoelectric layer and glass substrate.

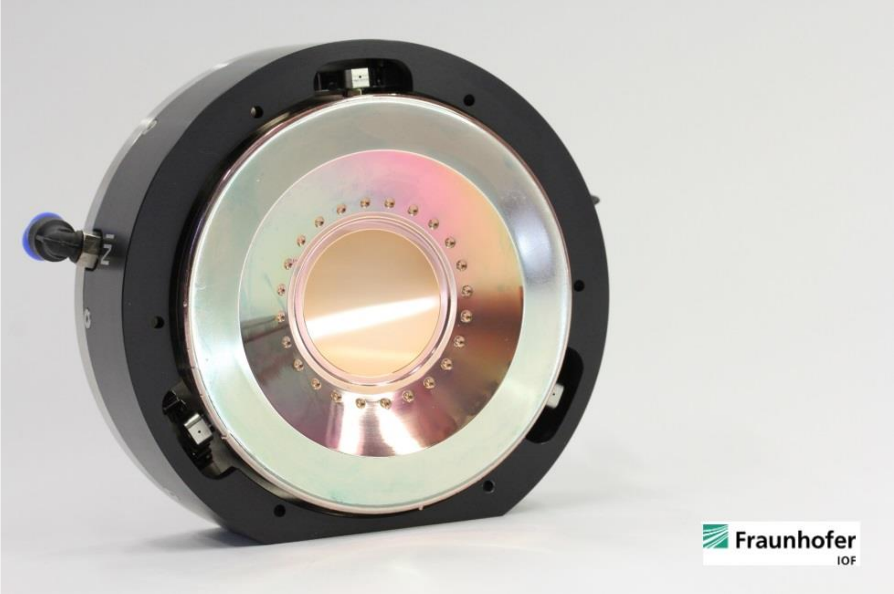
- Single actuator stroke between 1.5 and 3.5µm
- 40 actuators for reproduction of Zernike shapes

- Technology is used for mirrors with 210x210mm aperture and focus-only mirrors



Focus-only mirror
Mirror diameter: 50mm
aperture: 25 mm
Stroke: 180µm -> focal length -0.8m @ 800 V supply voltage

Thermal piezoelectric deformable mirror



Thermal piezoelectric deformable mirror with sinter-fused piezoceramic layer and multimaterial substrate.

- 40 actuators for reproduction of Zernike shapes
- Single actuator stroke between 1.5 and 3.5µm
- Additional temperature sensors and actuators

- Mirror shapes beams with 6.2kW on an aperture of 22mm (2kW/cm²)

Credits: Zepp, Marin, Baena Galle, Barros, Keary, Yatcheva, Hübner, Toselli, Sprung, Wollgarten, Stein

Fraunhofer IOSB