Model-based calibration of an adaptive interferometric setup

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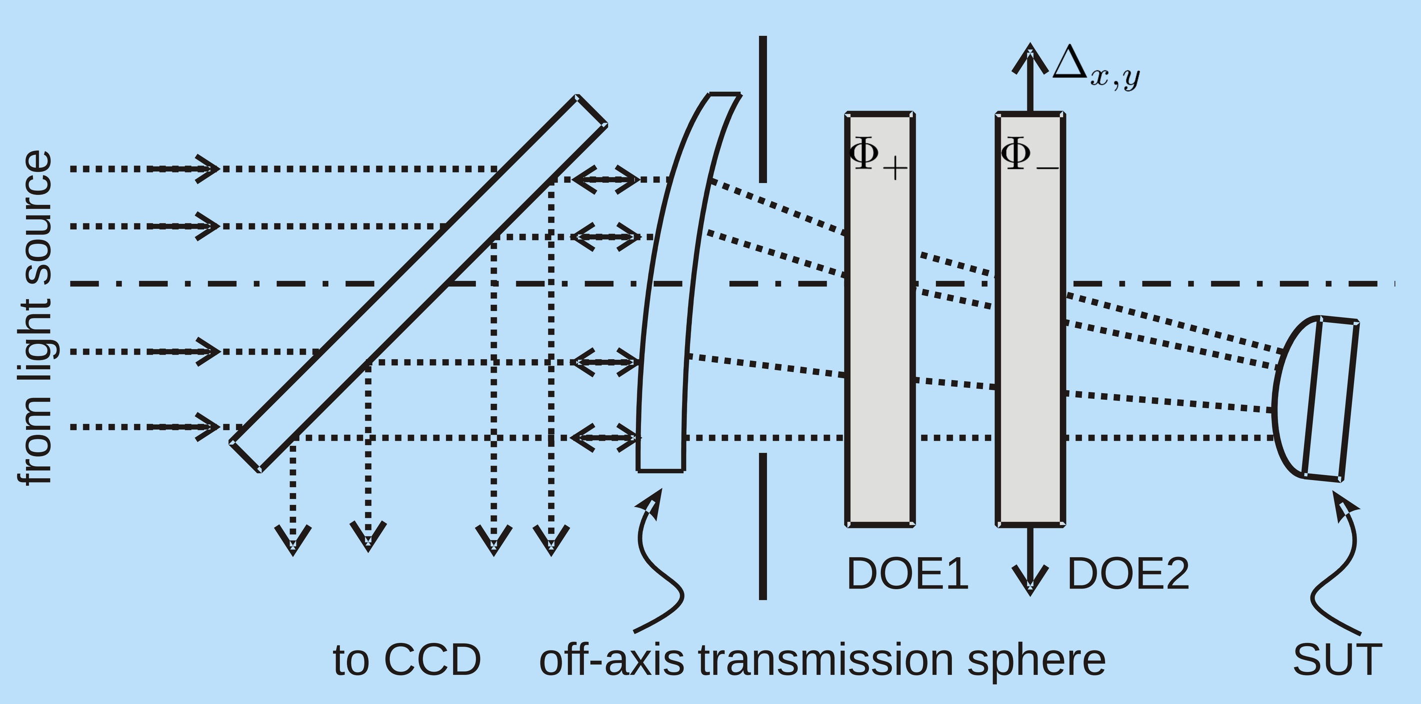
Introduction

The measurement of aspheres and freeform surfaces is one of the main challenges in optical production control. Interferometry can provide highest accuracy at specular surfaces. To measure aspherical lenses, it is necessary to **adapt fully or partially the wavefront to the surface under test**.

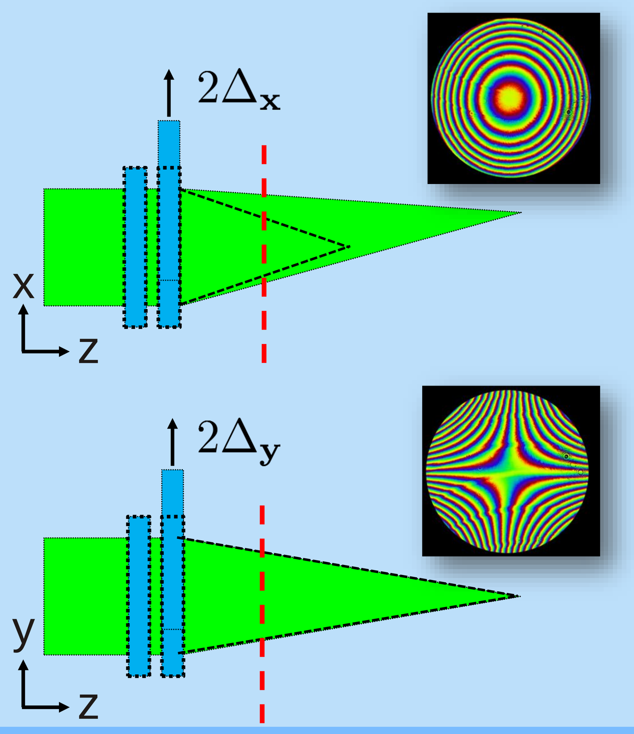
Recently, we have proposed a non-null interferometric setup with two diffractive elements for this purpose (DGaO, A23, 2014). By shifting these two elements in both lateral directions, we achieve a **variable defocus and astigmatism**. The challenge of coherent stray light has been addressed in DGaO 2014. Here we focus on calibration of this adaption setup.

Experimental setup

Fizeau-Interferometer with adaptive optics



Principle of Lohmann [1]



Lohmann phases:

$$\Phi(x,y)_\pm = \pm a\left(\frac{x^3}{3} + xy^2\right) \pm bx^2 \pm dx + ey$$

Defocus by shifting one element:

$$\Phi_+(x,y) + \Phi_-(x+2\Delta_x, y) = -2a\Delta_x \cdot (x^2+y^2)$$
$$-\mathrm{tilt}(a,b,\Delta_x)\cdot x + \mathrm{offset}(\Delta_x)$$

Astigmatism by shifting one element:

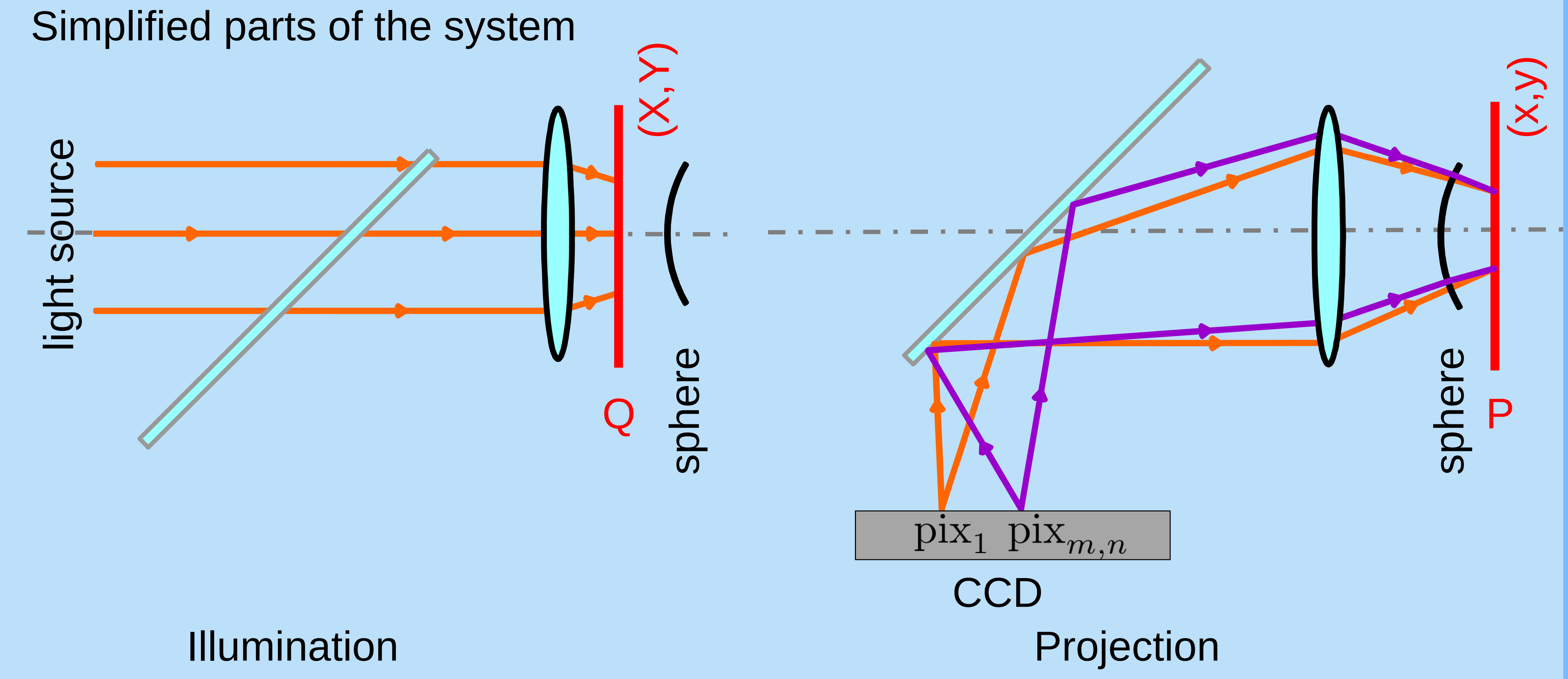
$$\Phi_+(x,y) + \Phi_-(x, y+2\Delta_y) = -4a\Delta_y \cdot xy$$

Model for black-box calibration

For the calibration, the system is split in two black-boxes [2].

The first black-box describes the **illumination part** from the light source to the test area (Q), the second one the **projection part** from the fourier plane of the test area (P) to the camera.

Simplified parts of the system



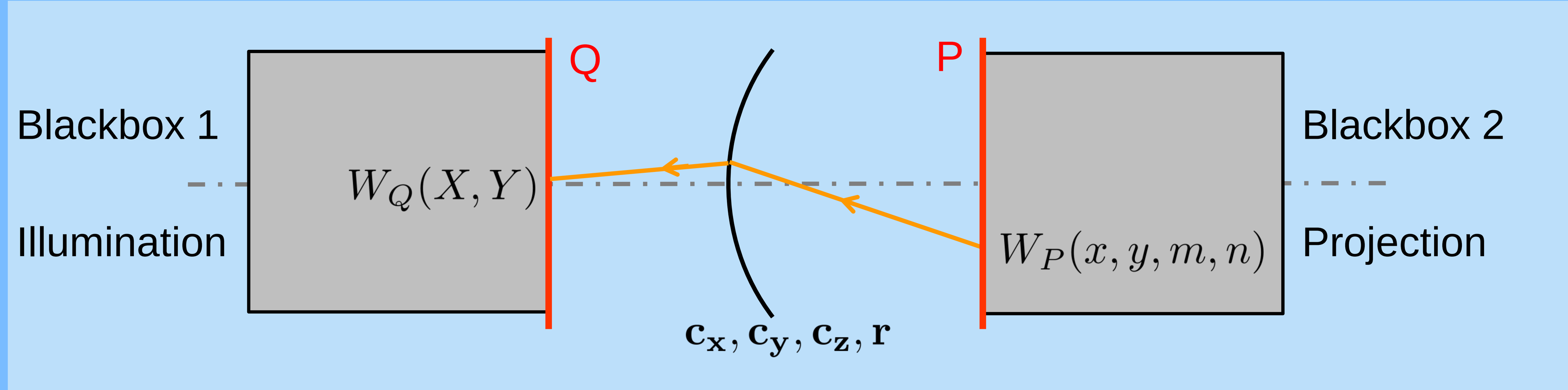
$$W_Q(X,Y) = \sum_i q_i Z_i(X,Y)$$

$$W_P(x,y,m,n) = \sum_{k,l} P_{kl} Z_l(m,n) Z_k(x,y)$$

The wavefronts of the light source and every pixel are described by different sets of Zernike polonomials for Q and P.

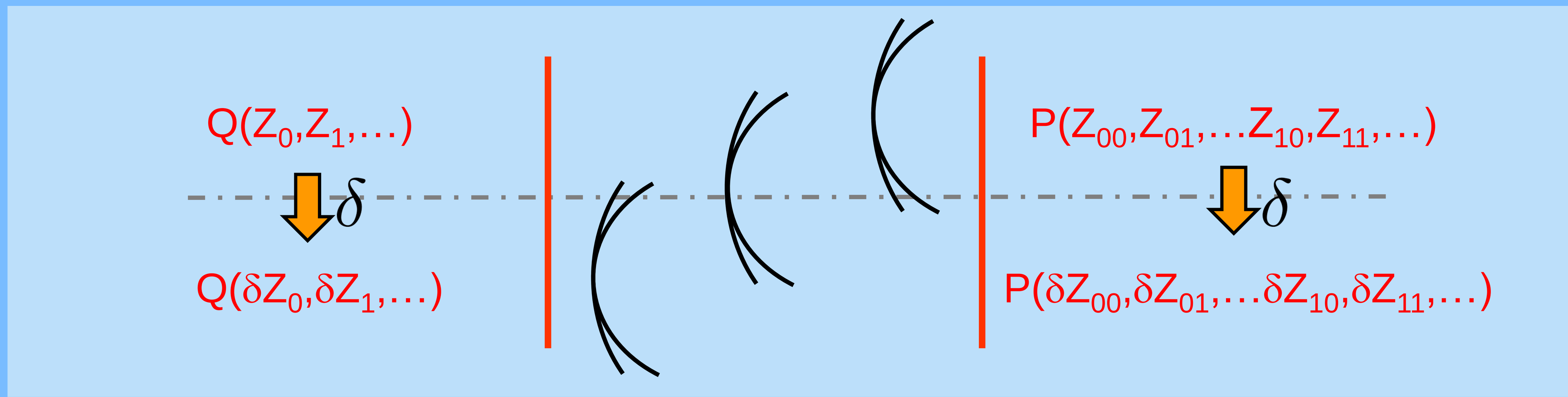
Calibration procedure

1. Measurement of known spheres with different radii (r) at different positions (c_{xyz})
2. Simulation of all total optical paths by raytracing through the system with Q and P determined by Zemax



$$OPL_{tot}(X,Y,x,y,c_x,c_y,c_z,r) =$$
$$W_Q(X,Y) + W_P(x,y,m,n) + OPD_{geom}(c_x,c_y,c_z,r)$$

3. Variation of Q, P, c_{xyz} until the difference between measured and simulated OPLs are minimal for all positions and radii

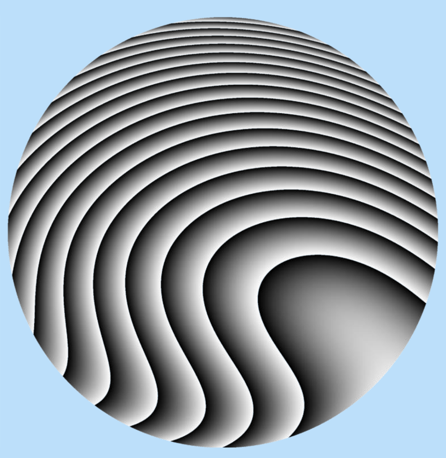


Simulation of calibration

1. Setup at one position for phase plates

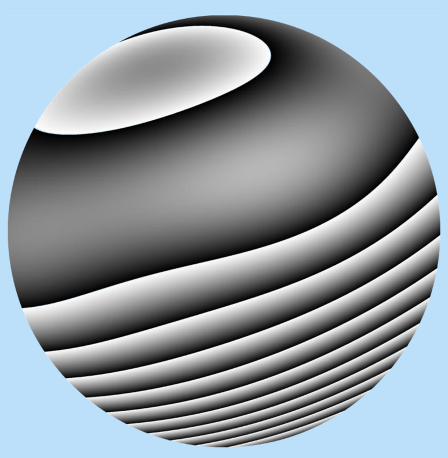
$\Delta_{x,y} = \mathrm{const.}$

2. Interferogram of sphere in one exemplary position



3. Pertubation of the System in Zemax

Interferogram of sphere in the same position



4. Variation of Q, P and c_{xyz} until all interferograms are equal.

This results in a calibration-matrix A, which is used for measurement.

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[1] Lohmann., "A New Class of Varifocal Lenses," Applied Optics 9/7, 1669-1671 (1970).
[2] Baer et al., "Calibration of a non-null test interferometer for the measurement of aspheres and free-form surfaces," Optics Express Vol 22 (2014).

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