

# Novel approach to mask imaging based on the Extended Nijboer-Zernike (ENZ) diffraction theory

S. van Haver, O.T.A. Janssen, A.M. Nugrowati, J.J.M. Braat, S.F. Pereira

Delft University of Technology, TNW-IST Optics Research Group, Lorentzweg 1, 2628 CJ Delft, The Netherlands

Email: S.vanHaver@tudelft.nl

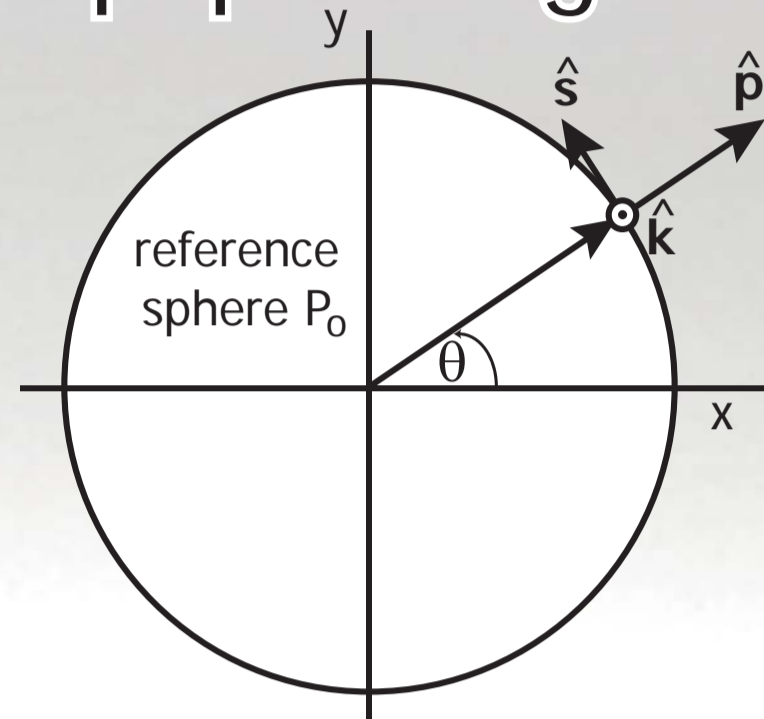
## Introduction

We present a new method to compute the aerial image produced by a given mask design. This new approach relies on an imaging algorithm based on the Extended Nijboer-Zernike (ENZ) theory of diffraction. In the artists impression below all crucial elements of this novel approach are identified and explained.

## Illumination system:

- so far, simple plane wave illumination is used
- general illumination is possible
- implementation similar to established techniques

- The near-field resulting from the interactions at the mask is propagated to the entrance pupil using an adapted implementation of the Stratton-Chu method [1].



The field on the entrance pupil sphere is decomposed into its p-, s- and k- components, allowing a straightforward transformation of the field to the exit pupil satisfying the Abbe-Sine condition.

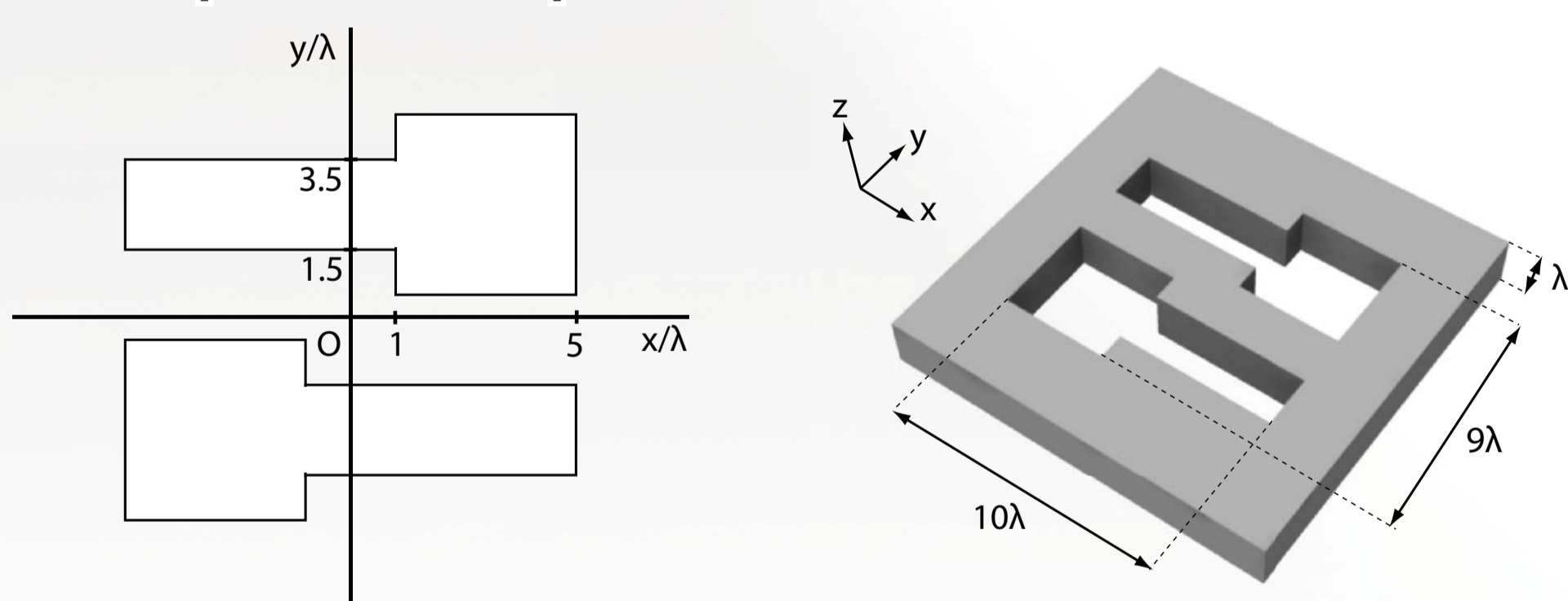
## Propagation to the entrance pupil

## Interaction at the mask

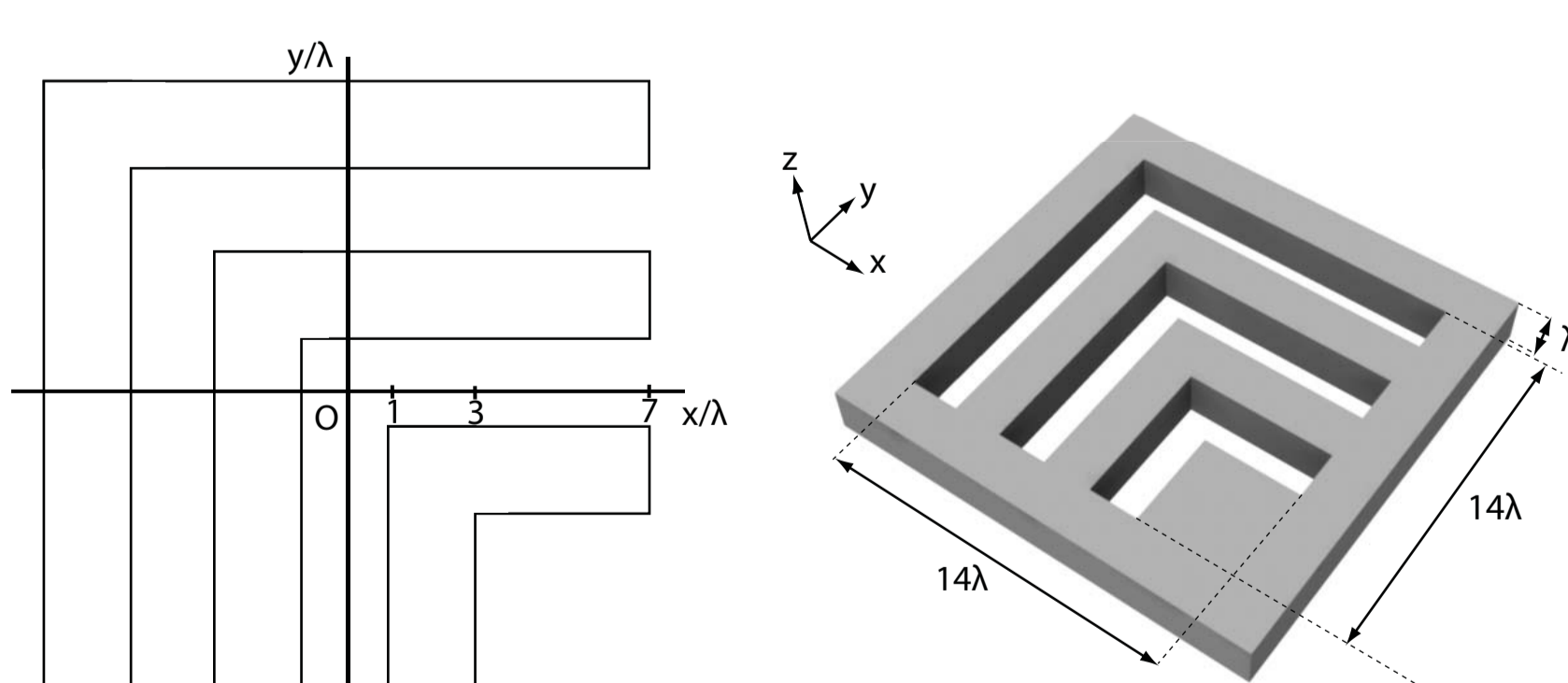
An in-house developed FDTD solver is used to calculate the near-field resulting from the interaction between the incident illumination and the mask.

## Some example mask objects

Example 1: hammerhead object in a simple absorption mask.



Example 2: elbow structure.



## Imaging apparatus

The imaging system is represented by its transfer function  $T$ , giving:

$$P_{exit} = T_{system} \cdot P_{entrance}$$

where  $T$  includes all aberrations present in the imaging system.

## Aerial image in the focal region

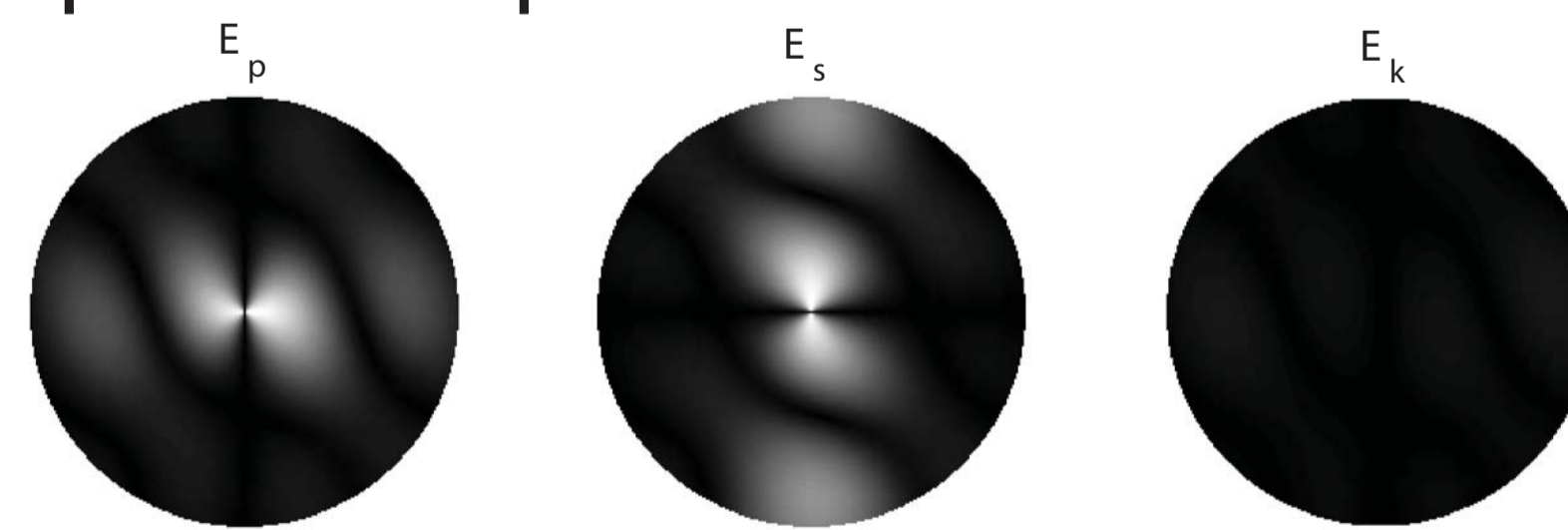
Finally, the field in the exit pupil is represented by a Zernike expansion:

$$P(\rho, \theta) = \sum_{n,m} \beta_n^m R_n^{|m|}(\rho) \exp(im\theta).$$

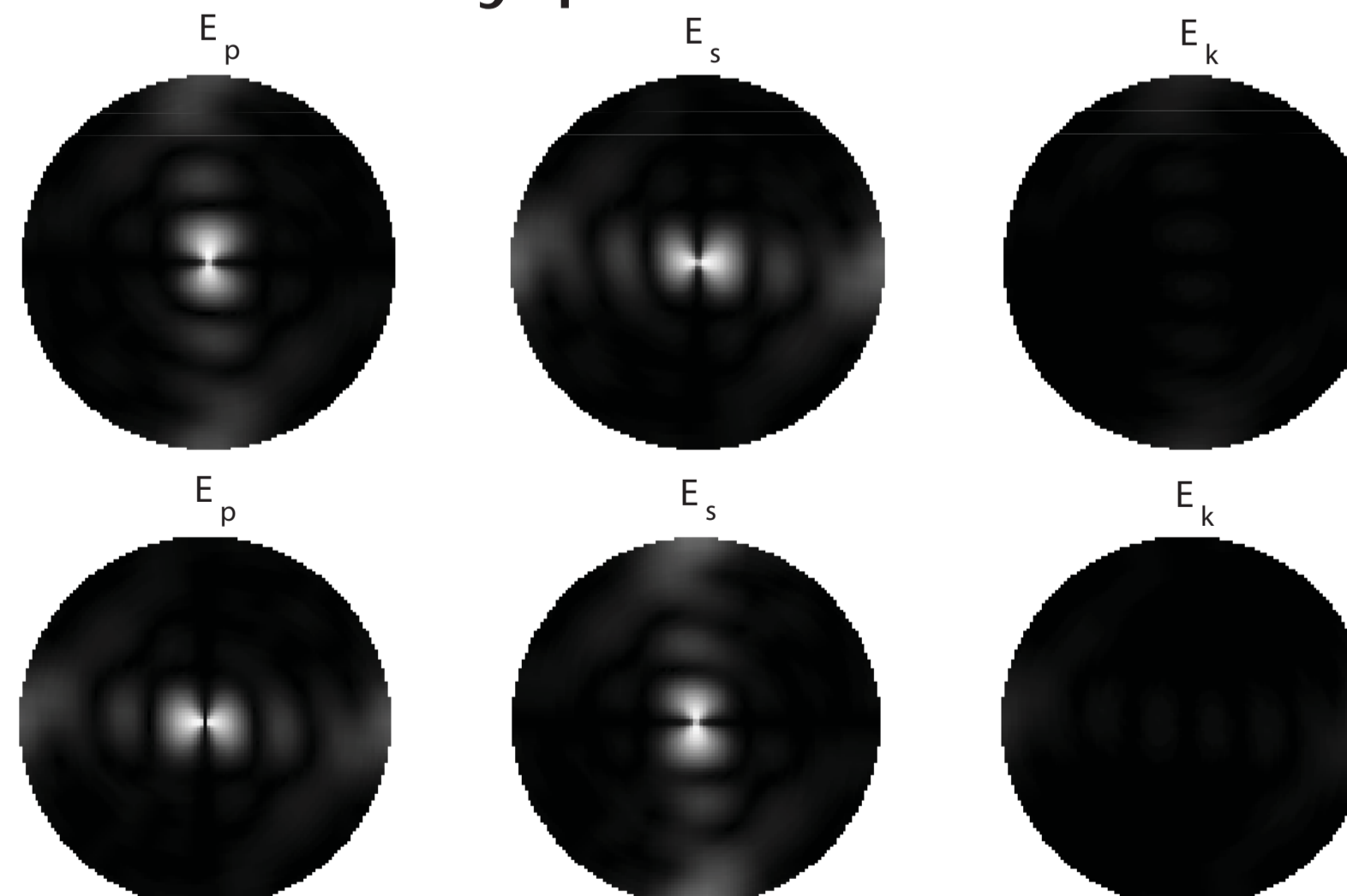
Based on this Zernike expansion, the through-focus aerial images follow from ENZ-theory [2].

## Resulting exit pupil

Example 1: exit pupil fields for x-polarized plane wave illumination.

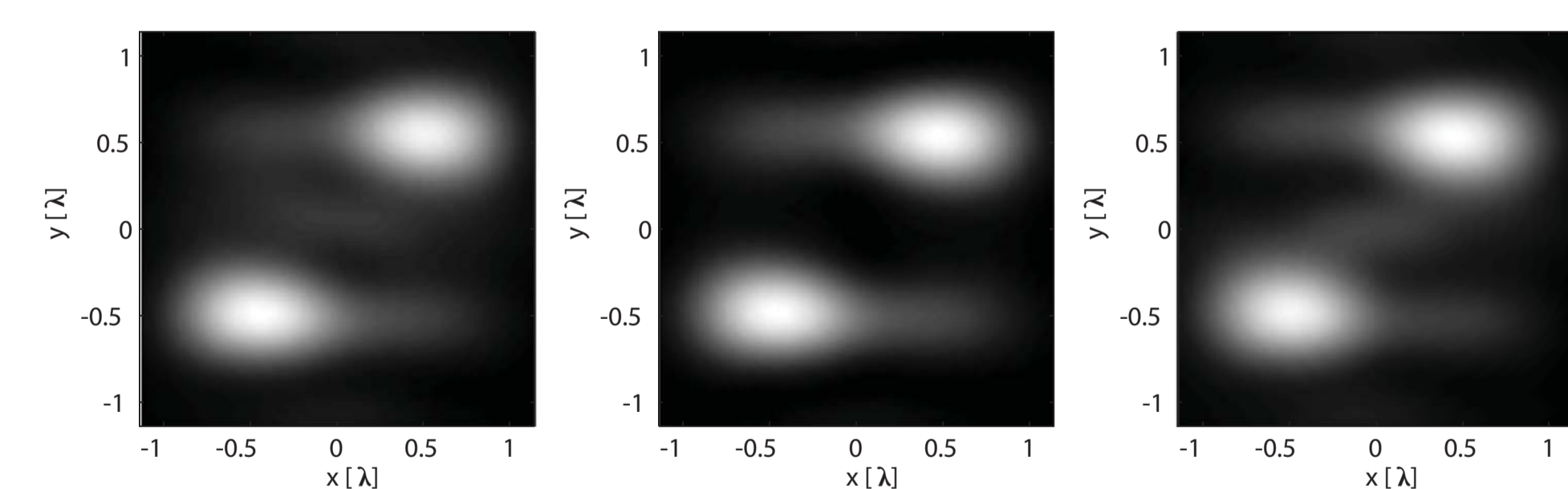


Example 2: exit pupil fields for both x- and y-polarized illumination.

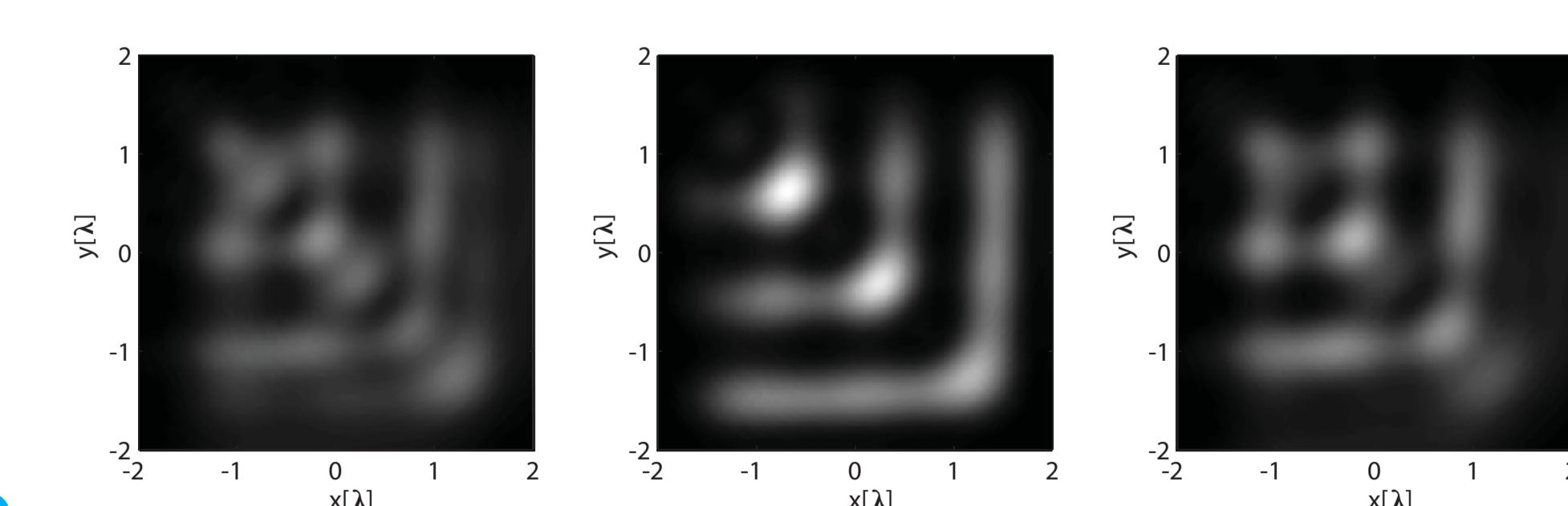


## Through-focus mask image

Example 1: through-focus image for an aberration-free imaging system (x-pol illumination, NA=0.95).



Example 2: through-focus image for natural illumination (incoherent sum of x- and y- illumination, x-pol., NA=0.95).



[1] X. wei, et al., J. Opt. Soc. Am. A 24 (2007), pp. 866-881.

[2] J.J.M. Braat, et al., J. Opt. Soc. Am. A 20 (2003), pp. 2281-2292.