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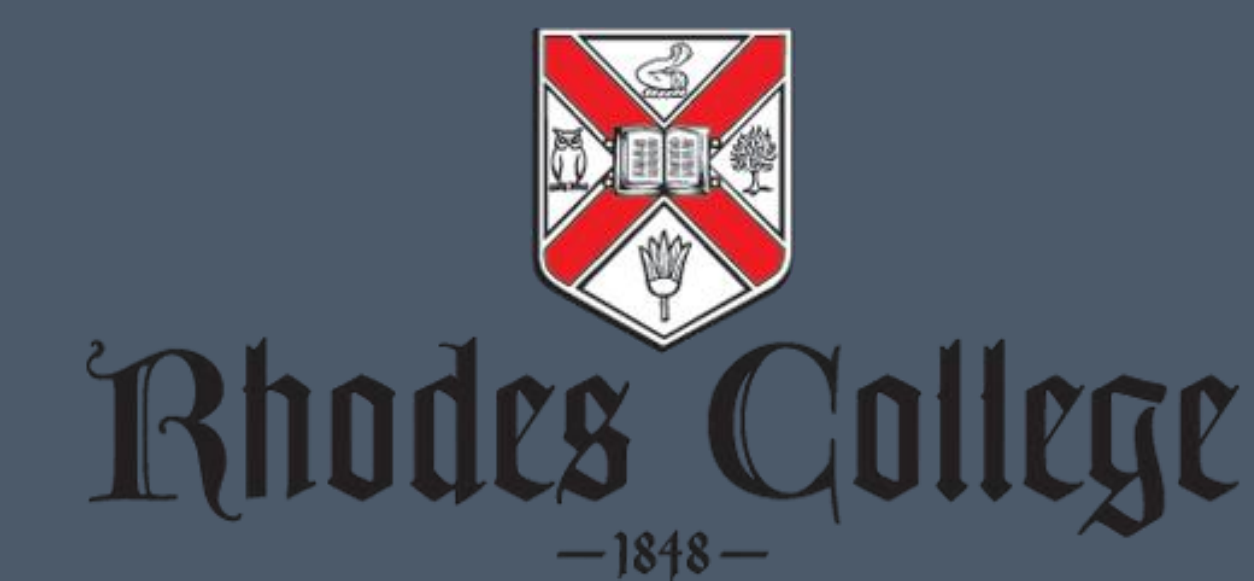
Speckle movement by deformable mirror as exoplanet direct imaging technique

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Speckle “movement” by deformable mirror as exoplanet direct imaging technique

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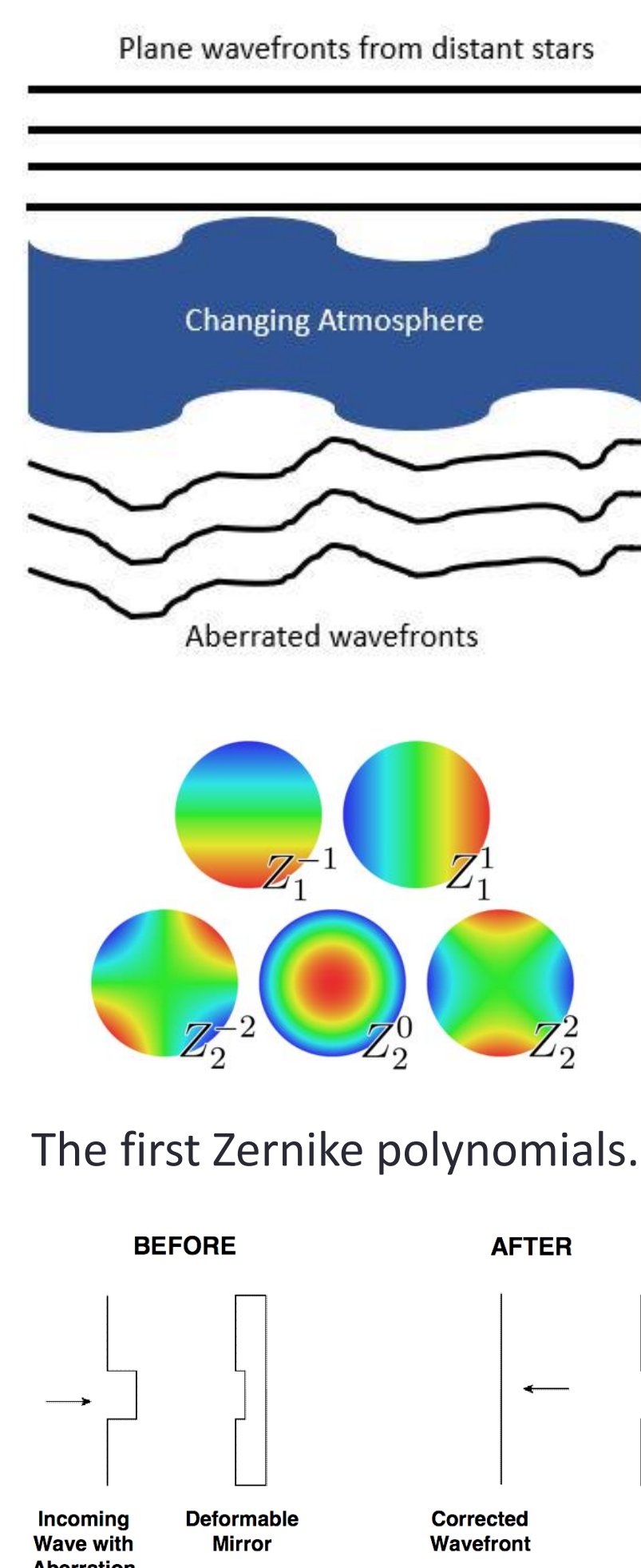


ABSTRACT

The detection of exoplanets, planets in other solar systems, takes many forms. The most common method, observing the transit of exoplanets across their stars, effectively discovers planets close to their stars in edge-on systems. Once discovered, exoplanets may be characterized through direct imaging, allowing for their chemical makeup to be analyzed through spectroscopy and their habitability to be examined. This technique’s main challenge is isolating the planet’s light from the overwhelming light of the star. To achieve this, coronagraphs are used to redirect the star’s light, allowing for planet detection. Atmospheric differences, temperature fluctuations, and imperfect optics cause dim star light in the image (called speckles) which hide the exoplanet’s light among them. In this research, a deformable mirror (DM) is utilized to “move” these speckles in order to identify the stationary exoplanets. The laboratory consists of a laser, which serves as the star’s light; an optical setup, which fits the laser’s size to the deformable mirror and camera; a deformable mirror with 140 actuators; and an astronomical camera. Initial work shows that these speckles may be manipulated using Zernike polynomials on the deformable mirror. Further research will explore more complex ways to deform the mirror and analyze the images taken.

OVERVIEW

Wavefronts are surfaces of points having the same phase. Speckles arise from atmospheric interruption of the wavefronts from distant astronomical objects. As the flat wavefronts from those sources pass through our changing atmosphere, they become distorted and speckles are formed. Speckles are also formed by imperfect optics and temperature fluctuations. A deformable mirror can “move” these speckles by shifting the wavelengths at specific places in order to change the speckles’ appearance, as the speckles are coherent with stars’ light. By shifting their wavelengths, the speckles may destructively interfere with themselves and reveal exoplanets, whose light is not coherent with stars’ light. Zernike polynomials may be used to make these changes, as they are used to correct spherical aberrations. The way astronomical objects appear in telescopes is called their point spread function, or PSF. By “moving” the speckles and changing stars’ PSF’s, exoplanets may be discovered.



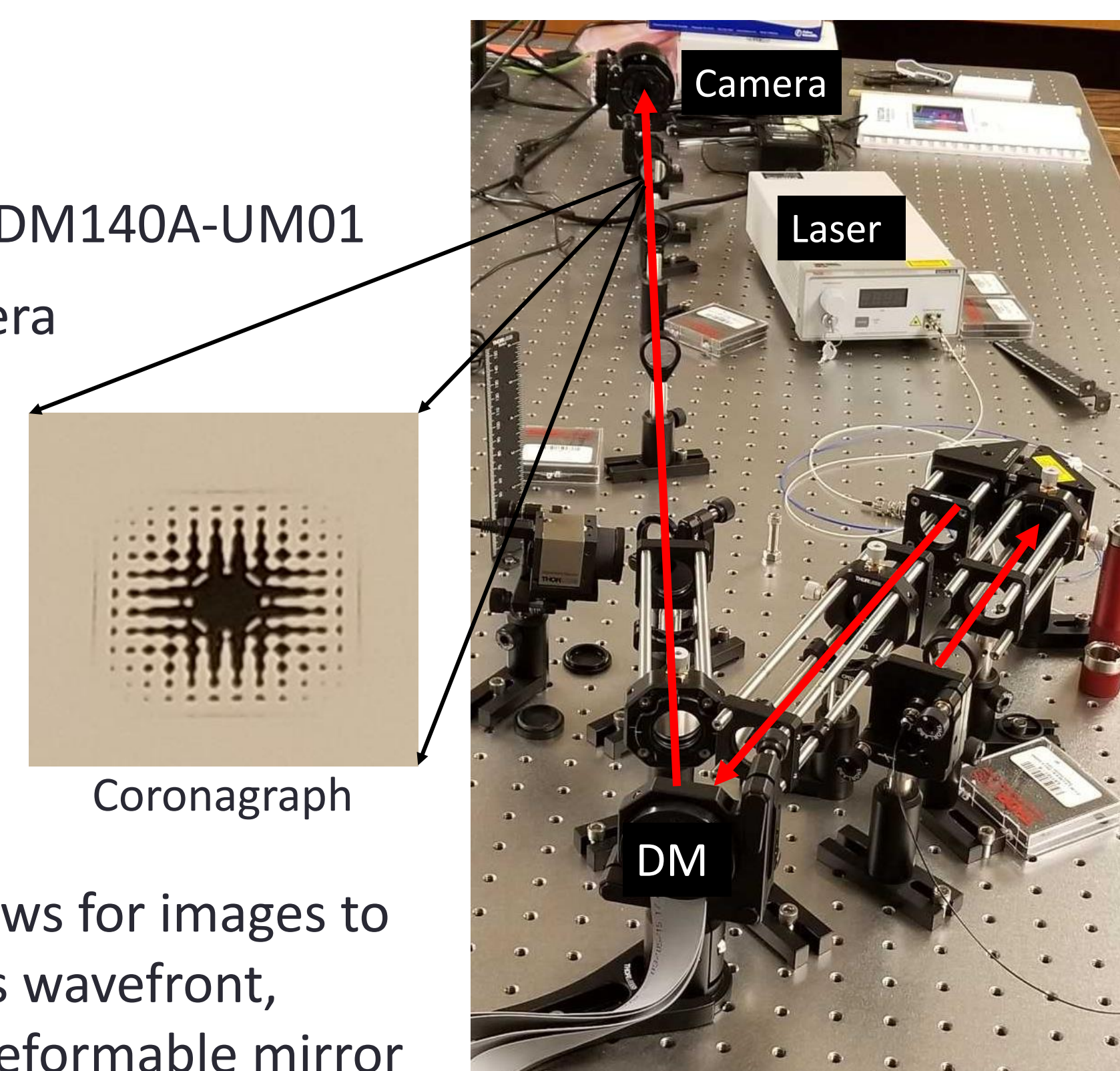
OBJECTIVES

- To align the AOK7 and AOK1 kits and attain photographs
- To control the DM through MATLAB
- To assess the effect of MATLAB commands on the DM and images
- To program Zernike polynomials and apply them to the DM

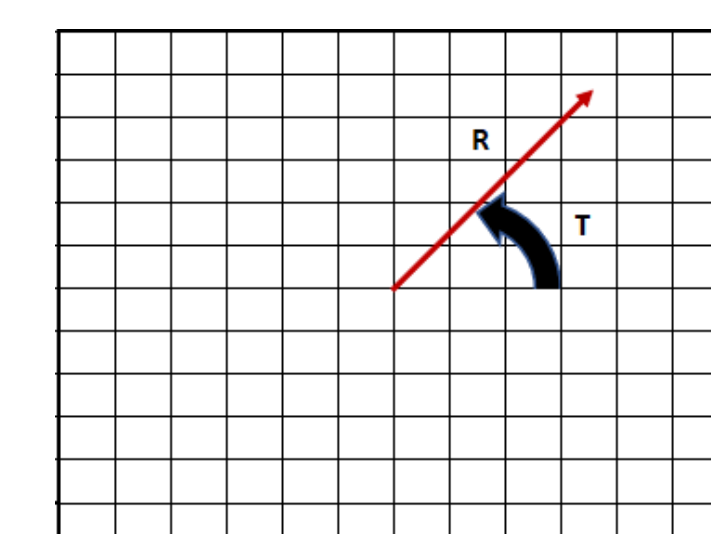
METHODS

Lab setup includes:

- 637nm HeNe laser
- AOK1 optical kit with DM140A-UM01
- Trius-SX694 CCD camera
- Shaped Pupil Coronagraph



This optical setup allows for images to be taken of the laser’s wavefront, manipulated by the deformable mirror and coronagraph. By controlling the deformable mirror through MATLAB, different shapes may be put on the DM to “move” the speckles. The method by which the DM is coded in MATLAB is shown at the right.



Each actuator is assigned polar coordinates, R and T.

RESULTS

The initial setup produced a near-perfect airy pattern without the coronagraph, which is expected of a point source. Once the coronagraph was put in place, both the AOK7 and AOK1 kits displayed expected results. The AOK1 kit gave higher quality images, as it contains a more advanced deformable mirror. These images were then analyzed in MATLAB, which revealed a contrast of 10^{-4} with the coronagraph in place. The first test of manipulating the DM through MATLAB, placing a random set of values on it, yielded a randomized PSF. This result demonstrated that the DM could be fully manipulated through MATLAB.

Fig.1 Airy pattern

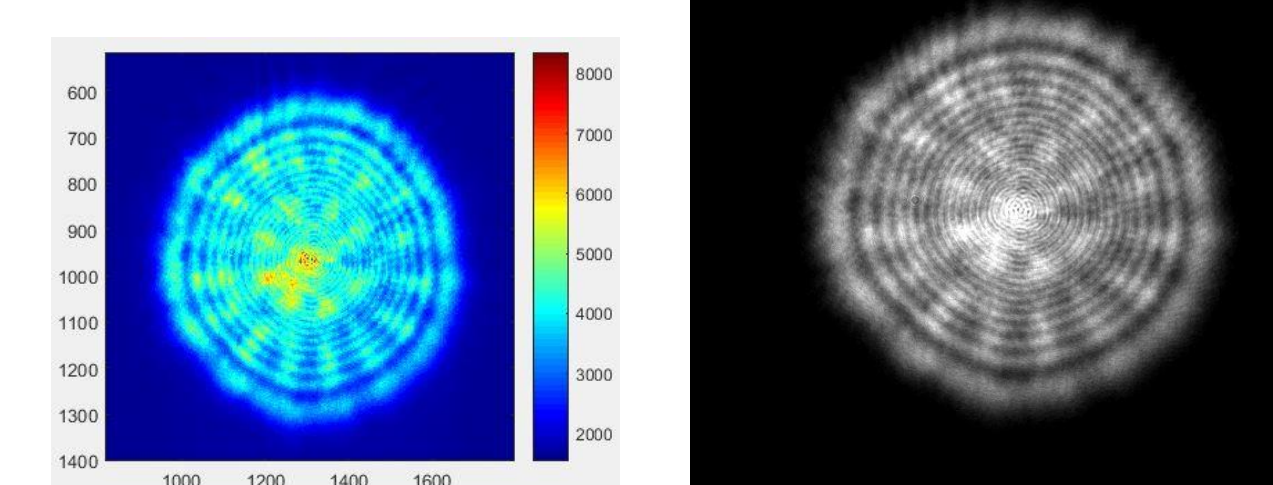


Fig.2 AOK7 with coronagraph

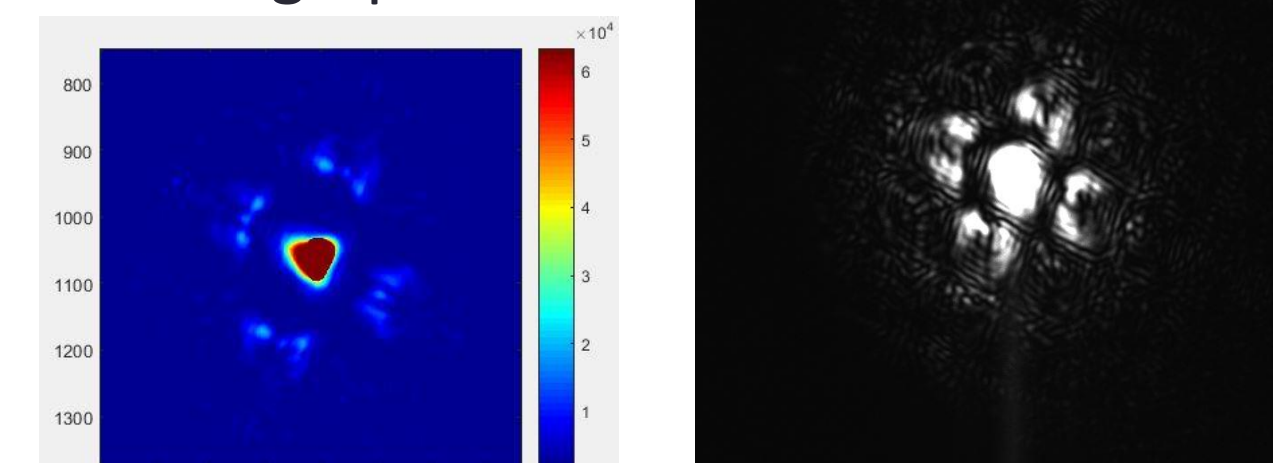


Fig.3 AOK1 with coronagraph

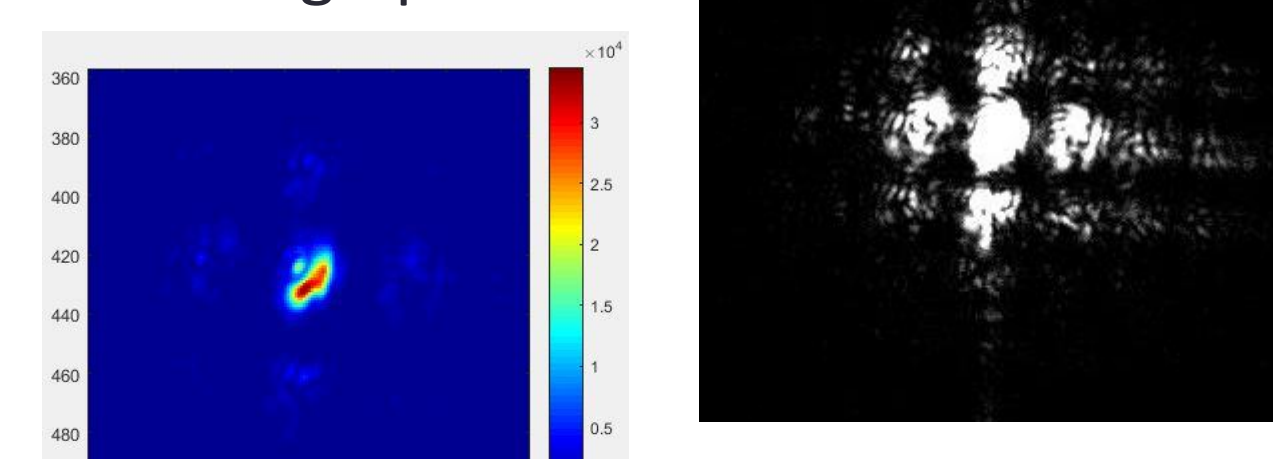
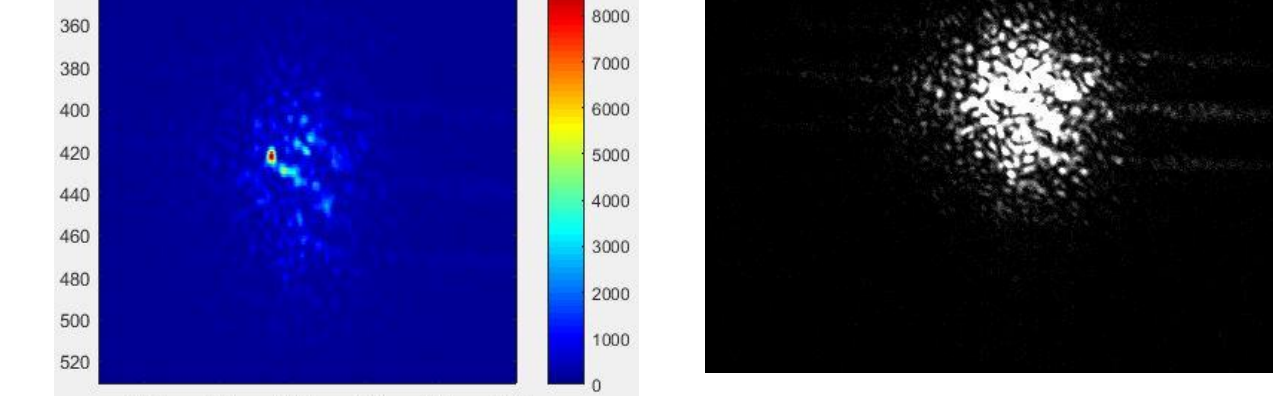


Fig.4 Random function on DM



RESULTS

Placing the Zernike tilt-x on the DM resulted in a correct shift of the PSF in the x-direction. This deformation resulted in the highest contrast of the Zernikes displayed. The application of the Zernike polynomial for spherical aberration and defocus displayed a spherical PSF which corresponds with the expected wavefront shape.

Fig.5 Tilt-x: $r \cdot \cos(t)$

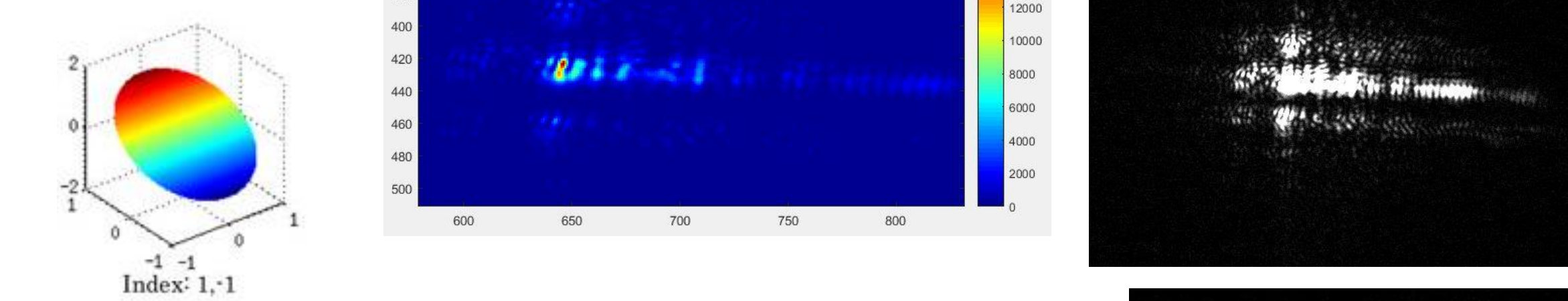


Fig.6 Spherical aberration, defocus: $6r^4 - 6r^2 + 1$

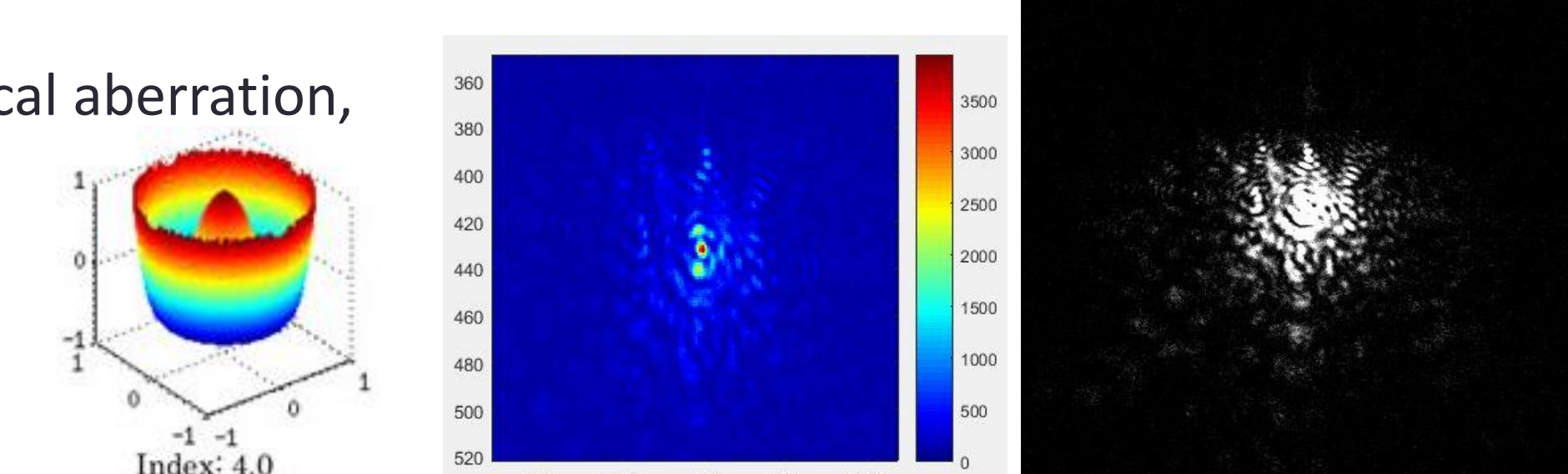
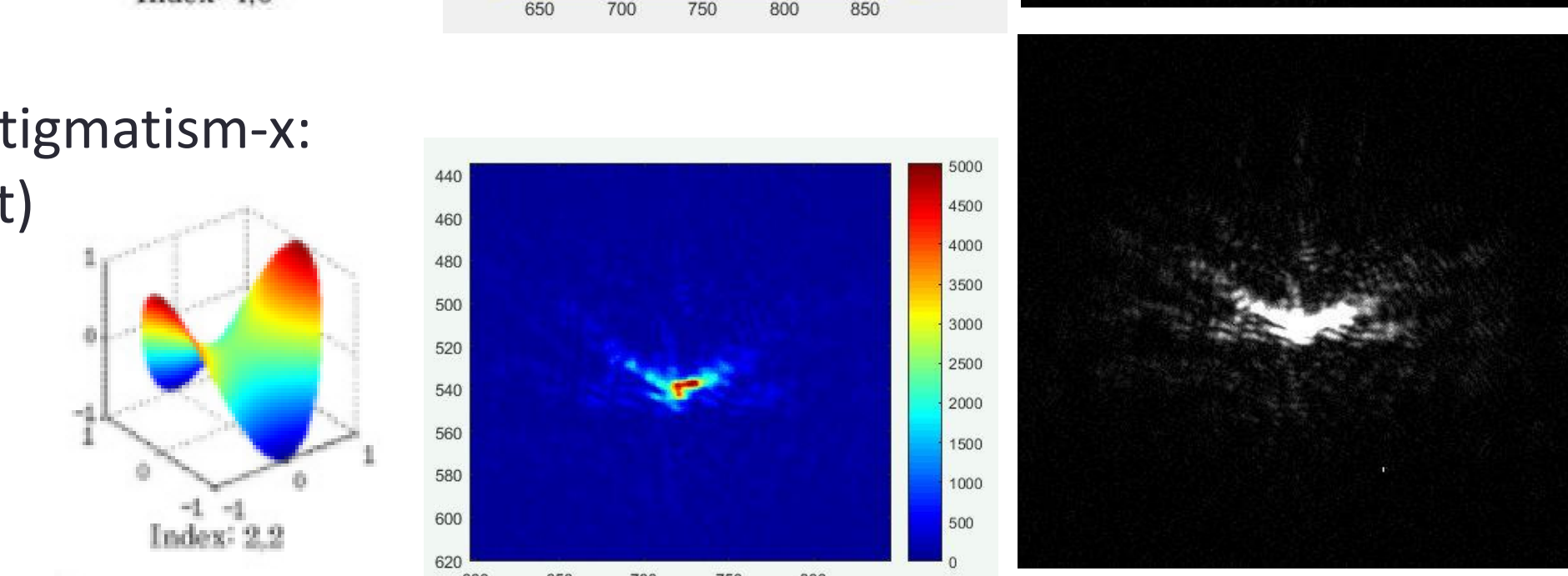
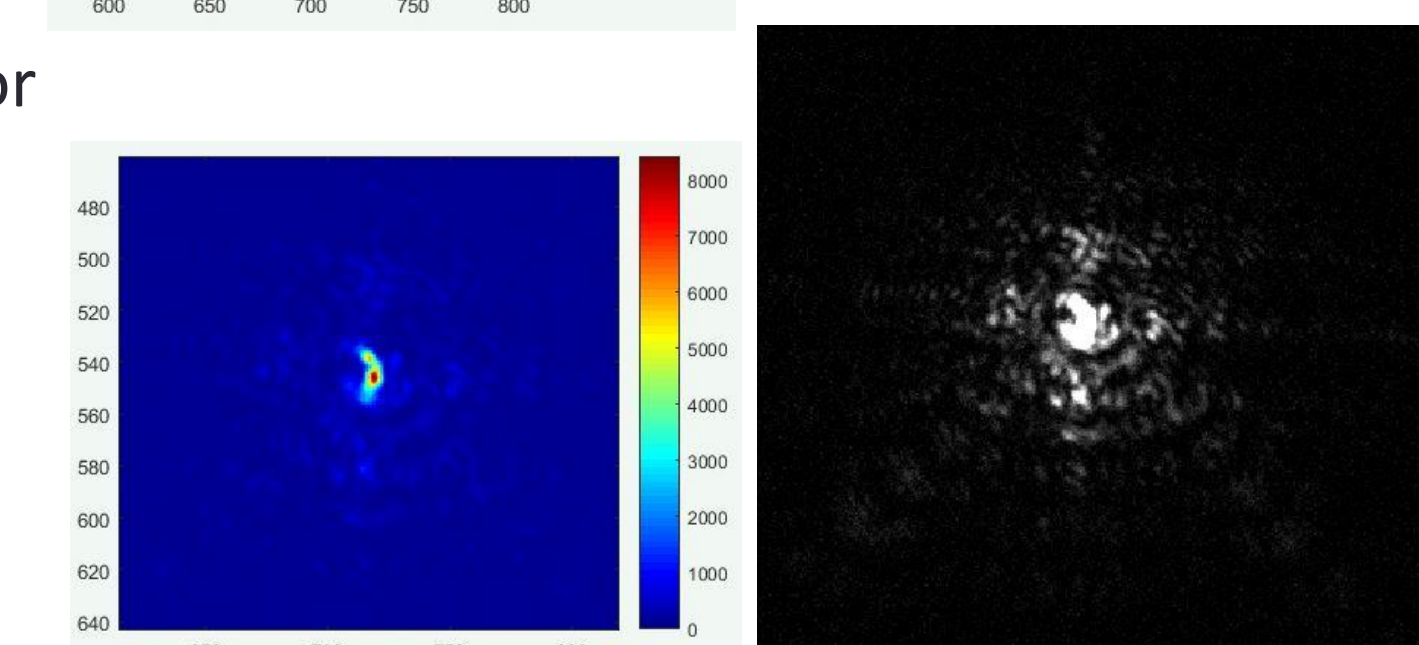


Fig. 7 Astigmatism-x: $r^2 \cdot \cos(2t)$



The Zernike for astigmatism in the x corresponds with the expected wavefront shape. One of the highest Zernikes, for quaternary spherical aberrations, resulted in an interesting concentric PSF.

Fig. 8 Quaternary spherical: $252\rho^{10} - 630\rho^6 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1$



CONCLUSIONS AND FURTHER RESEARCH

In conclusion, the DM may be used to effectively manipulate the speckles of a point source’s aberrated wavefront using Zernike polynomials.

Further research would explore more advanced ways to deform the DM and locate a “planet” in the laboratory. Eventually, the techniques developed would be applied to a telescope equipped with coronagraphs and a DM.

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