Modeling coronagraphic extreme wavefront control systems for high contrast imaging in ground and space telescope missions

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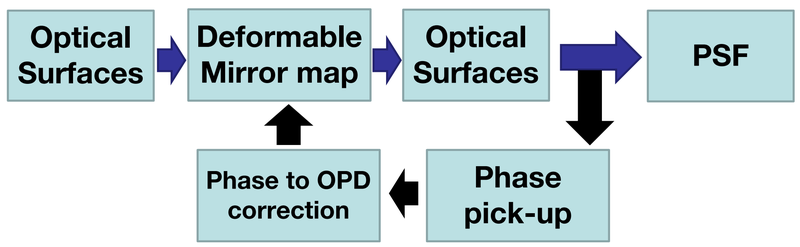
Introduction

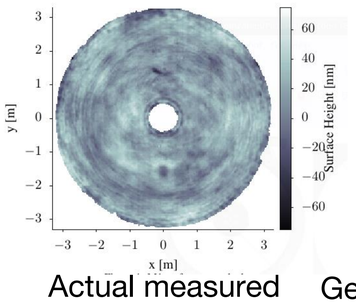
Large segmented aperture ground and space based telescopes are undergoing development to enable direct imaging for extrasolar planets. This may be achieved with high contrast imaging using extreme adaptive optics. The challenges of high contrast imaging may be achieved through extensive end-to-end testbed simulation model characterization using a Fresnel propagation module.

Modeling Process

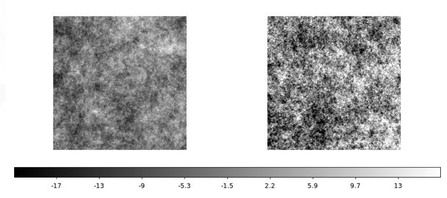


The modeling process uses the Fresnel propagation module contained within Physical Optics Propagation in Python (POPPY).

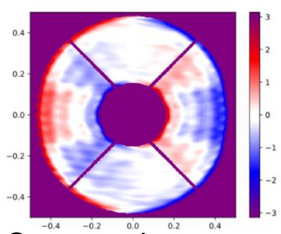
Optical Surface Maps



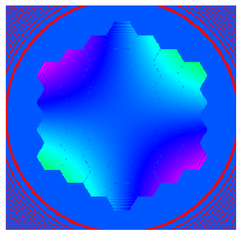
Actual measured surface map (Magellan M1)



Generated from Power Spectrum Densities (lambda/100 flats PV)



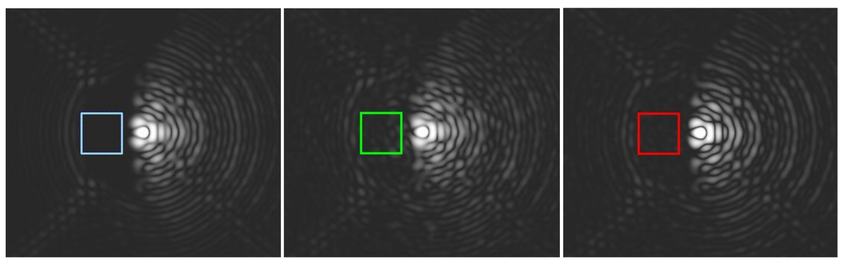
Custom phase maps (vAPP Coronagraph)



POPPY's built-in custom optical element surfaces

MagAO-X

Goal 1: Are the surface quality specifications set for the MagAO-X optical elements sufficient enough to form the high contrast dark hole? Can the DM help alleviate the surface quality requirements?



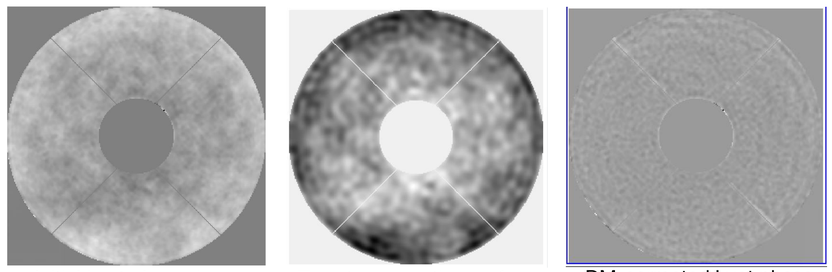
Without Surfaces
ROI Avg Contrast: 5.13 (10^{-6})

With Surfaces, No DM
ROI Avg Contrast: 1.81 (10^{-4})

With Surfaces and DM
ROI Avg Contrast: 6.16 (10^{-5})

Deformable Mirror Correction

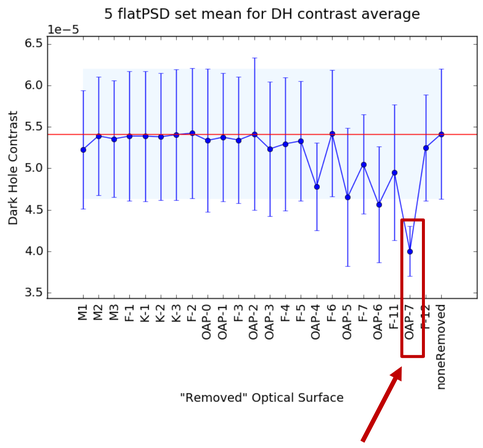
The pick-off point is at the Lyot plane. The phase here undergoes a low pass filter and is converted to inverse OPD, which is inserted into the Tweeter plane. The whole system runs again with the DM correction in place.



Initial Lyot plane phase (RMS: 1.104 rad)

Tweeter correction surface (OPD of LPF on Lyot phase)

DM-corrected Lyot phase (RMS = 0.1696 rad)



OAP7 has critical impact on DH contrast!

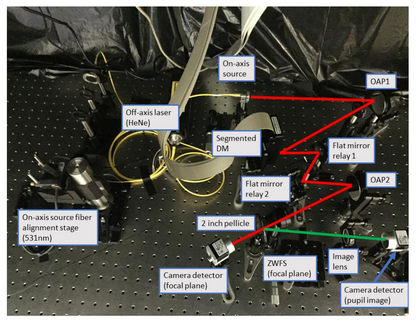
Goal 2: Are there specific optics that will affect the dark hole contrast that should be carefully examined?

Process:

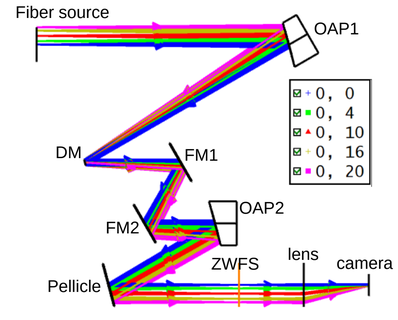
1. Remove testing optical surface and propagate
2. Analyze dark hole contrast

Laser Guide Star for Large Aperture Segmented Space Telescopes

Goal: Perform a testbed modeling demonstration showing how a formation flying cubesat acting as an artificial star for segmented space telescopes can help achieve picometer segment stability.

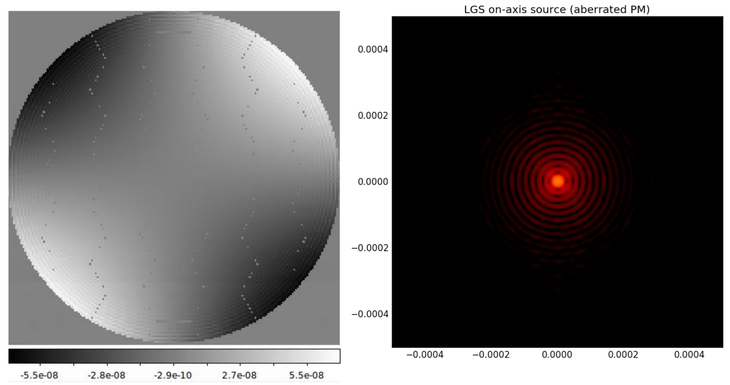


LGS Testbed at University of Arizona Extreme Wavefront Control

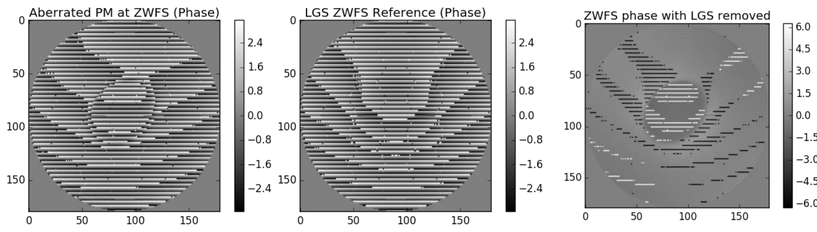


ZEMAX raytrace model of LGS Testbed

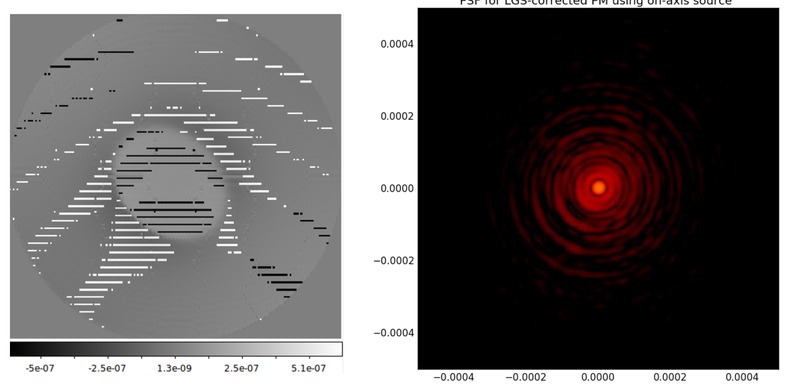
Aberrated Primary Mirror (on-axis)



LGS Correction with Zernike WFS



1st Closed Loop LGS Correction Onto PM



Acknowledgements

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REFERENCES

1. M. Perrin, et al. Physical Optics Propagation in PYthon (POPPY). https://github.com/mperrin/poppy
2. MagAO-X Preliminary Design Review Documentation, 2017
3. Feinberg et al, "Ultra-stable Segmented Telescope Sensing and Control Architecture." SPIE 2017