Analysis of Random Segment Errors on Coronagraph Performance

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Contributions from:
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Agenda

Introduction

Review and Update of 2015 SPIE O&P presented "Preliminary Analysis of Random Segment Errors on Coronagraph Performance"

New results for Mamadou N'Diaye's Coronagraph

Introduction

Purpose is to determine how to specific telescope tolerances.

Exoplanet Science is so difficult that we must study performance of Telescope and Coronagraph as a system.

Developed MATLAB tool of contrast leakage as a function of random telescope wavefront error instability:

Primary Mirror Motion:
- Segment Piston
- Segment Tip/Tilt
- Segment Astigmatism
- Segment Trefoil
- Backplane Bending

Secondary Mirror Motion
- Coma – lateral shear
- Power - despace
- Spherical – despace

Only concerned with random motion. Assume that 'signature' of a fixed repetitive motion can be subtracted.

Don't need 10 pm Tip/Tilt – need Tip/Tilt that is stable to 10 pm.

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Preliminary analysis of effect of random segment errors on coronagraph performance

Mark T. Stahl, H. Philip Stahl,
NASA Marshall Space Flight Ctr.

Stuart B. Shaklan,
Jet Propulsion Laboratory
California Institute of Technology

Summary

At 2015 SPIE O&P we presented "Preliminary Analysis of Random Segment Errors on Coronagraph Performance"

Key Findings:

- Contrast Leakage for 4th order $Sinc^2(X)$ coronagraph is 10X more sensitive to random segment piston than random tip/tilt.
- Fewer segments (i.e. 1 ring) or very many segments (> 16 rings) has less contrast leakage as a function of piston or tip/tilt than an aperture with 2 to 4 rings of segments.

Revised Findings:

- Piston is only 2.5X more sensitive than Tip/Tilt

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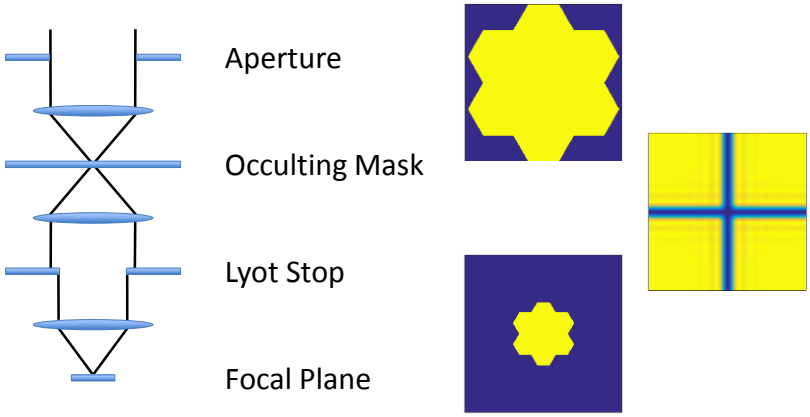
Integrated Model

Using Matlab, we created an integrated model of a segmented aperture telescope and a single stage internal linear band-limited coronagraph: $\{1\text{-}sinc^2(x) \times sinc^2(y)\}$.



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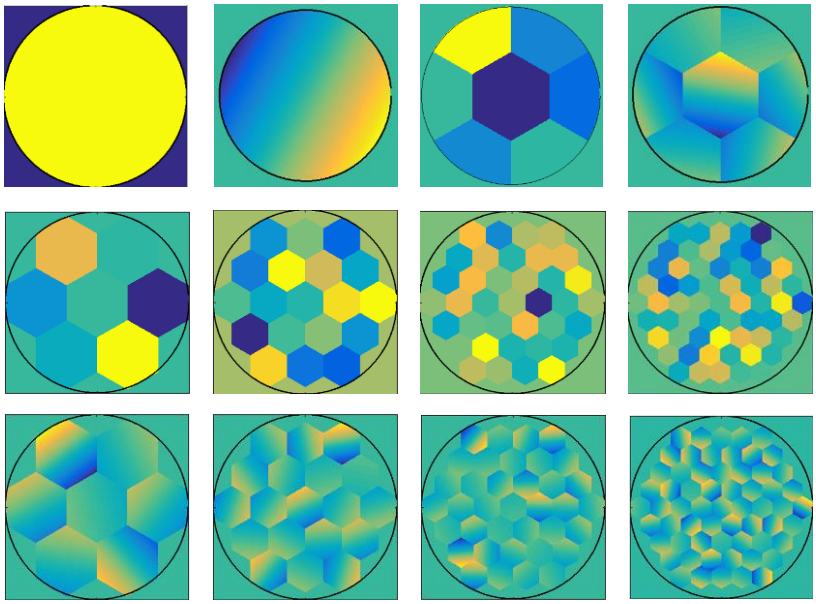
Input Pupil Functions



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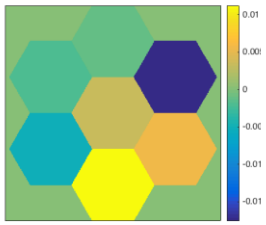
Integrated Model – Output

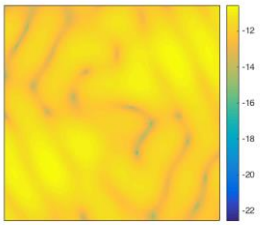
Output is Contrast (single realization & N average)

- Average inside ROI from 1-2 λ/D, 2-5 λ/D & 4-10 λ/D
- 10 pm rms piston, N = 16

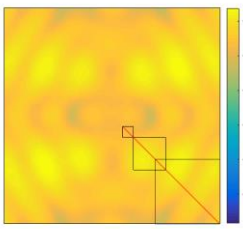
WFE



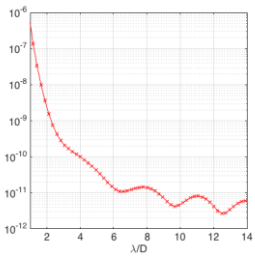
Single Intensity Plane



Averaged Intensity Plane



Contrast Leakage



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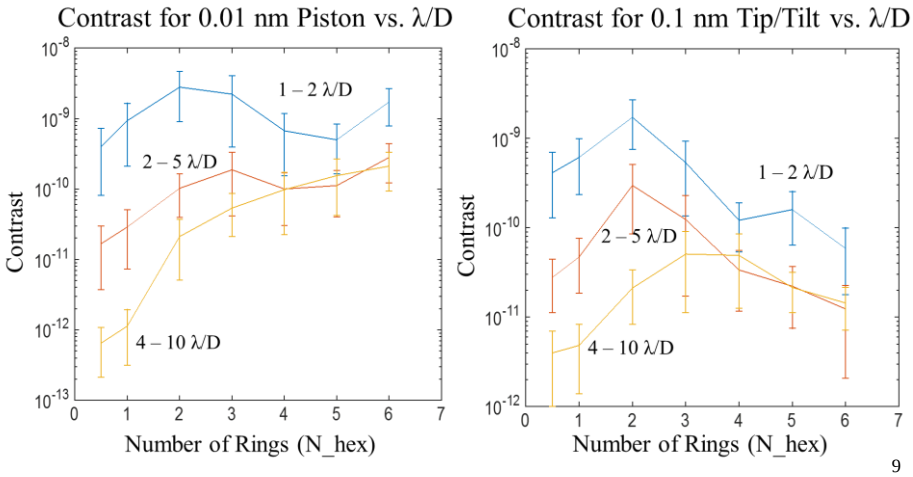
WFE Sensitivity vs Number of Segments - OLD

- Contrast Leakage is 10X more sensitive to Piston than Tilt.
- Contrast Leakage is less for fewer segments



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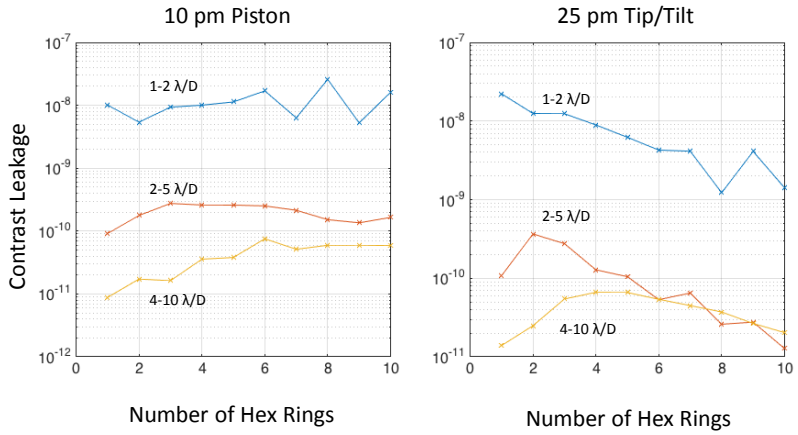
WFE Sensitivity vs Number of Segments

- Contrast Leakage is 2.5X more sensitive to Piston than Tilt.
- Contrast Leakage is less for fewer segments



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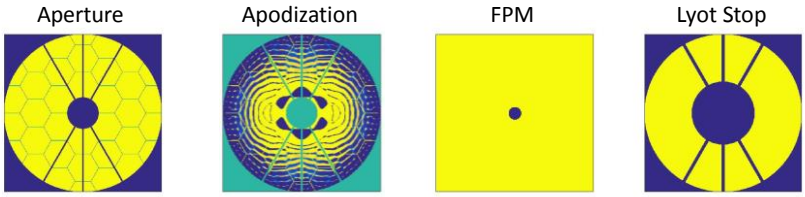
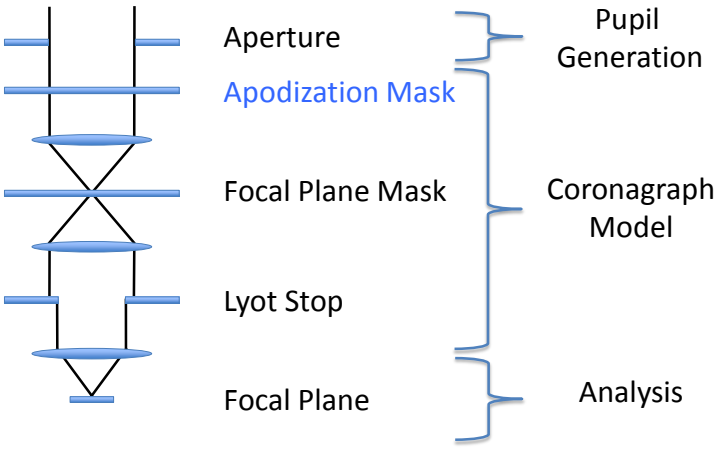
Analysis of Random Segment Errors on Performance of Mamadou N'Diaye's Coronagraph



N'Diaye et al.. "Apodized pupil Lyot coronagraphs for arbitrary apertures v hybrid shaped pupil designs for imaging Earth-like planets with future space observatories", ApJ (2016).

Integrated Model



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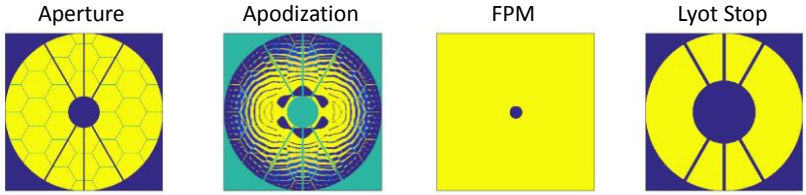
STScI Coronagraph Model

- APLC/SP design for an ATLAST-like aperture
  - Model supplied by Mamadou N'Diaye
  - Segment gaps applied using grey scale edge blending
  - Apodization mask is grey scale (not fully binary)
  - Uses a 4 λ/D radius Focal Plan Mask (FPM)



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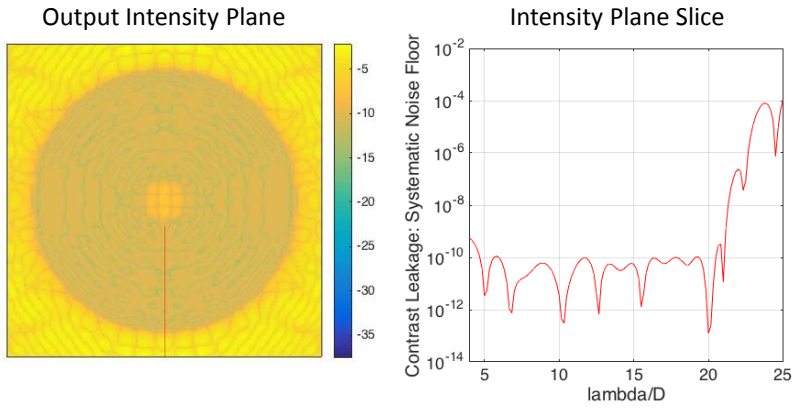
Ideal Performance – 4 λ/D IWA

- Aberration free input



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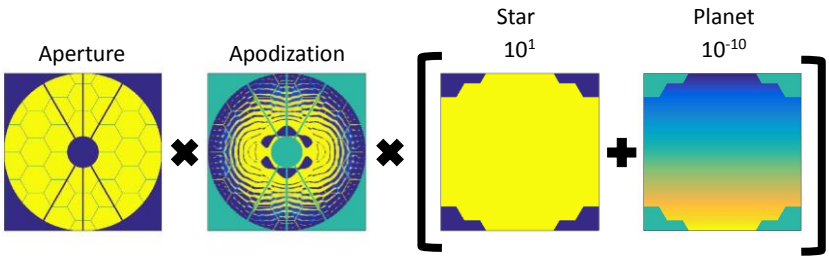
Pupil Function – No WFE

- Pupil Function models the telescope
- Pupil(x,y) = Aperture(x,y) * Phase(x,y) = $A(x,y)e^{-i\Phi(x,y)}$
- Aperture Mask
  - Defines segments, secondary obscuration, spiders
  - Apodization mask application
- Phase defines telescope WFE
  - Global tilt used to simulate a planet
  - Planet flux set to 10^-10



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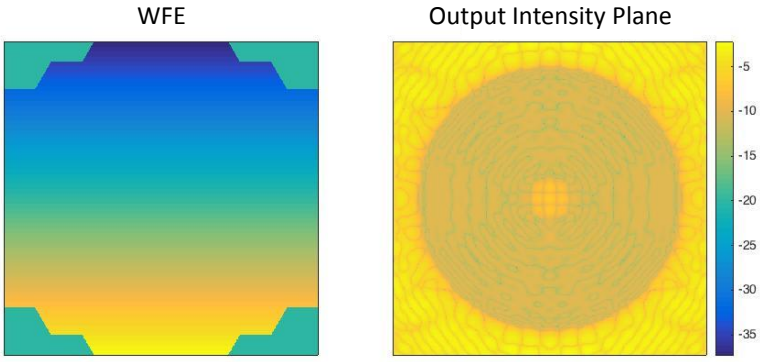
Exoplanet

- 10^{-10} flux exoplanet added using global tilt at 6 λ/D



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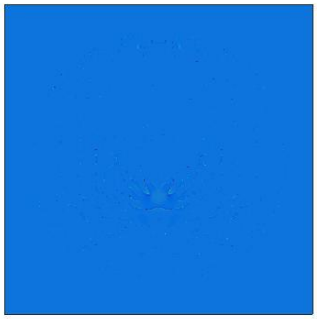
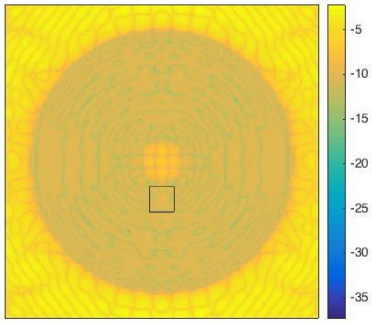
Exoplanet @ 6 λ/D

- PSF subtraction use to view planet
- 4 x 4 mas ROI box

Planet



Output Intensity Plane



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Pupil Function – with WFE

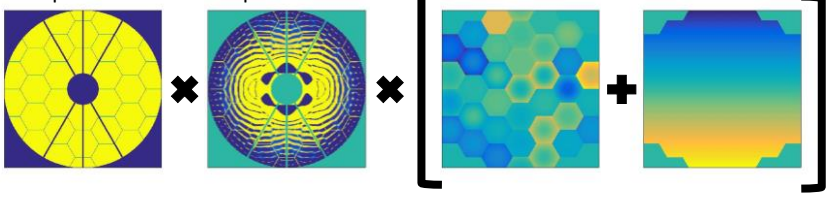
- Pupil Function models the telescope
- Pupil(x,y) = Aperture(x,y) * Phase(x,y) = $A(x,y)e^{-i\Phi(x,y)}$
- Aperture Mask
  - Defines segments, secondary obscuration, spiders
  - Apodization mask application
- Phase defines telescope WFE
  - Global and segment aberration application (starlight)

Aperture

Apodization

WFE
10^{1}

Planet
10^{-10}



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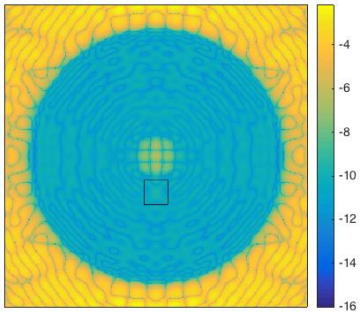
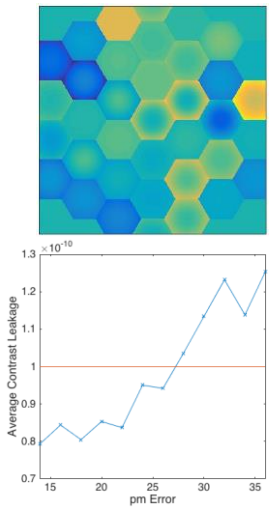
Sensitivity Analysis

- Average 50 realizations of pupil WFE
- Quantify contrast over 4x4 mas 'planet' ROI
- Plot Average Contrast Leakage vs. Aberration Amplitude





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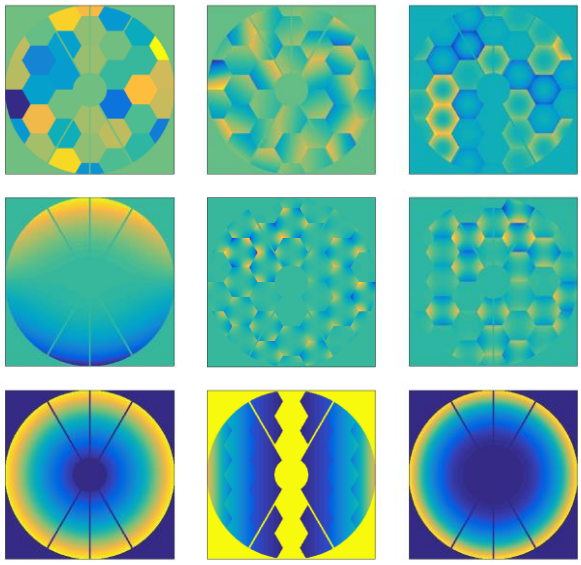
Aberrations Studied



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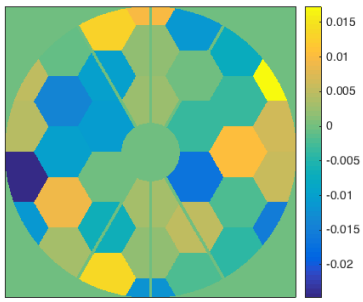
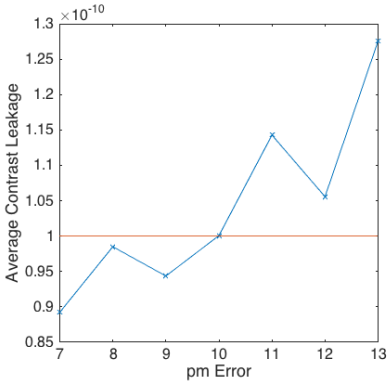
Segment Piston – 10 pm rms

Single Random WFE



Average Contrast Leakage of 50 WFEs



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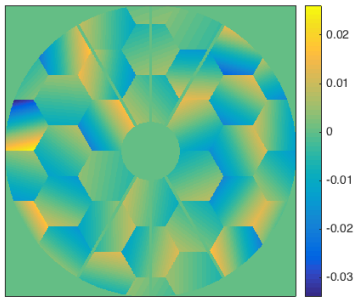
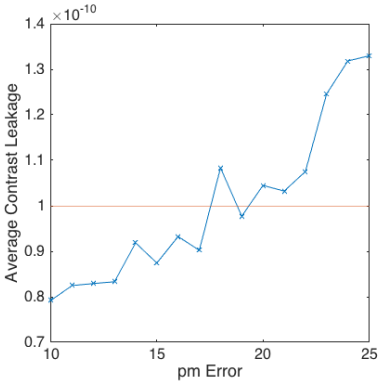
Segment Tip / Tilt – 20 pm

Single Random WFE



Average Contrast Leakage of 50 WFEs



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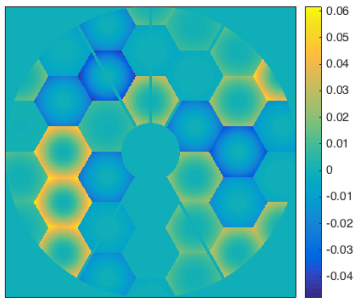
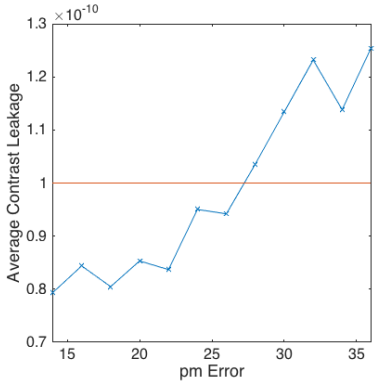
Segment Power – 30 pm

Single Random WFE



Average Contrast Leakage of 50 WFEs



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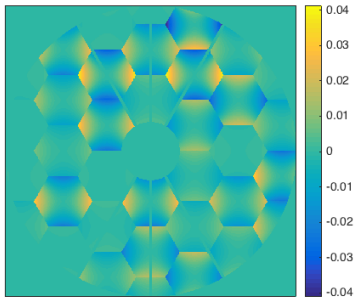
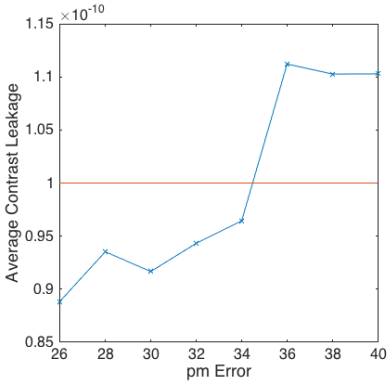
Segment Astigmatism – 35 pm

Single Random WFE



Average Contrast Leakage of 50 WFEs



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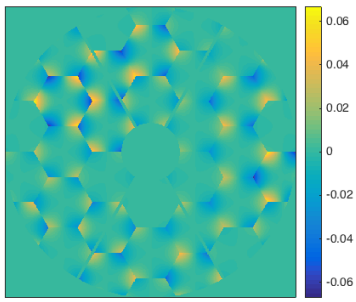
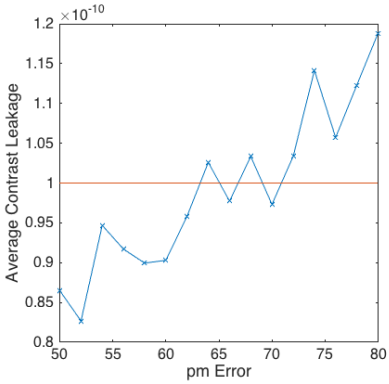
Segment Trefoil – 65 pm

Single Random WFE



Average Contrast Leakage of 50 WFEs



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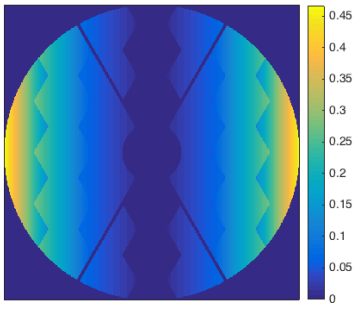
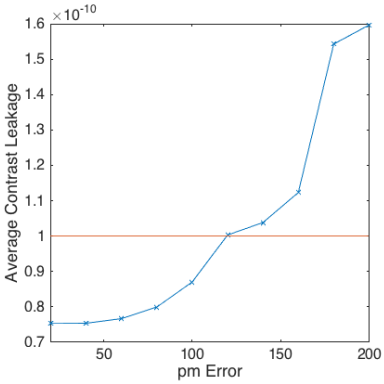
Back Plane Bend About Y – 120 pm

Single Random WFE



Average Contrast Leakage of 50 WFEs



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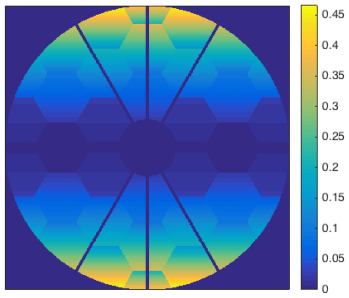
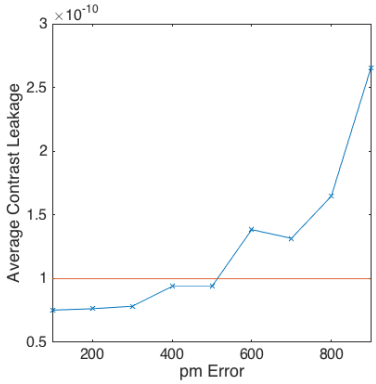
Back Plane Bend About X – 500 pm

Single Random WFE



Average Contrast Leakage of 50 WFEs



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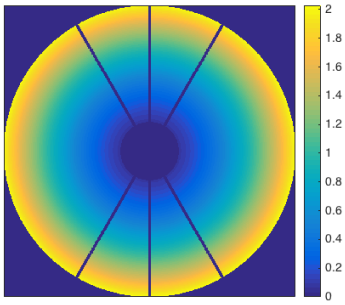
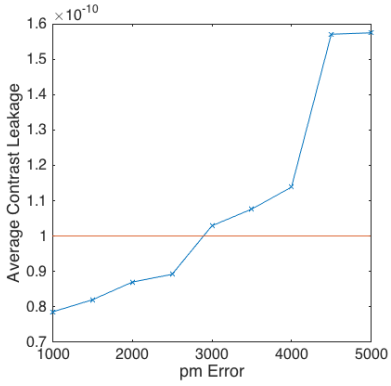
Global Power – 3000 pm

Single Random WFE



Average Contrast Leakage of 50 WFEs



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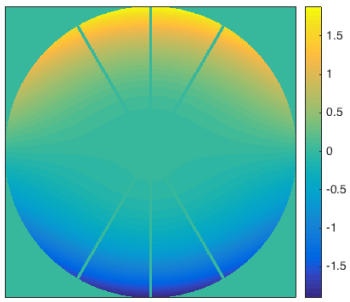
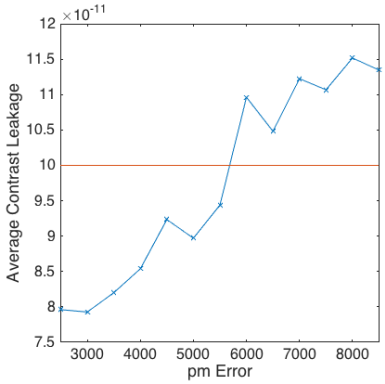
Global Coma – 5800 pm

Single Random WFE



Average Contrast Leakage of 50 WFEs



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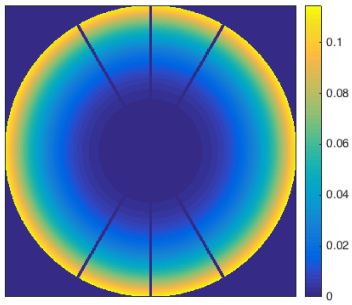
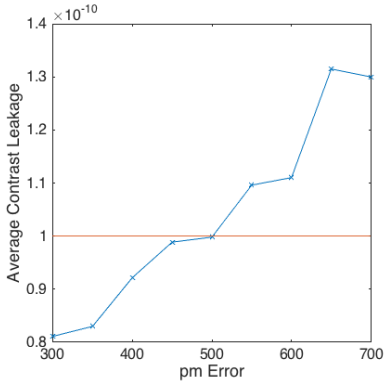
Global Spherical – 500 pm

Single Random WFE



Average Contrast Leakage of 50 WFEs



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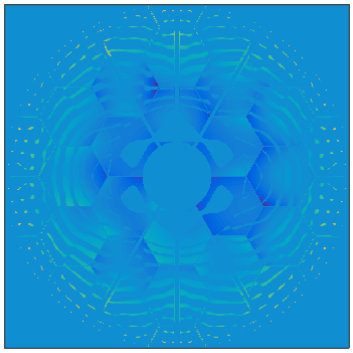
Summary

Segments		WFE (pm)
	Piston	10
	Tip / Tilt	20
	Power	30
	Astigmatism	35
	Trefoil	65
Global		
	Power	3000
	Coma	5800
	Spherical	500
Back Plane		
	Bend About X	500
	Bend About Y	120



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Conclusion

Have developed a tool and methodology to investigate the effect of telescope dynamic modes on coronagraph contrast leakage.

If you give us a coronagraph model, we will use it in this tool.

Future enhancements:

- Look at contrast leakage over smaller ROI at different λ/D
- Spectral bandwidth

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