Contrast Leakage as Function of Telescope Motion

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Executive Summary

- Improving model methodology to investigate radial and azimuthal contrast leakage associated with telescope Wavefront Error (WFE) Stability.

Wavefront Change over Time

- Goal is to develop methodology for deriving specification.

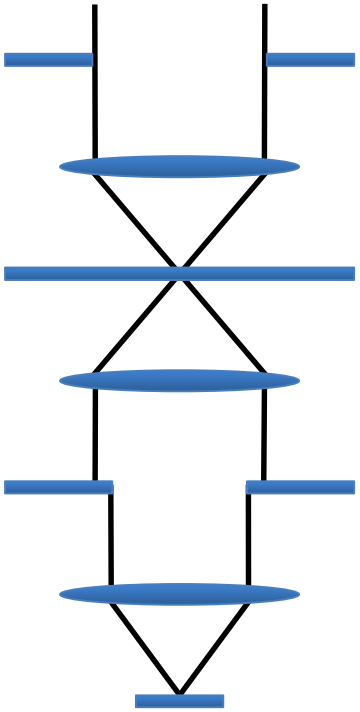
Caveats

- Monochromatic
- Simple model
- Band limited 4^{th} order Sinc^2 mask

Matlab Model

Simplified integrated model:

- Telescope Aperture: can be monolithic or segmented
- Single Stage Coronagraph: can be linear {1-sinc^2(x) × sinc^2(y)}or radial {1-sinc^2(r)} or coronagraph provided by STScI or others.

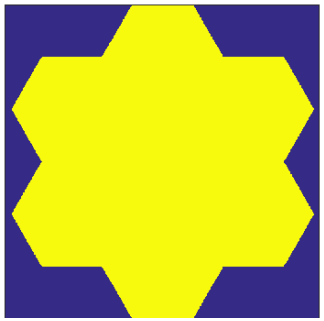


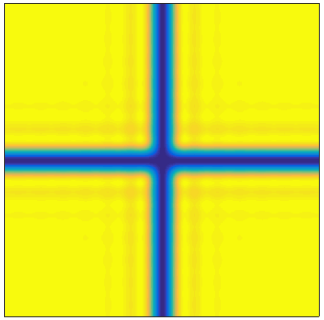
Aperture

Occulting Mask

Lyot Stop

Focal Plane





Integrated Model – Pupil Function

Pupil Function models the telescope

$$\text{Pupil}(x,y) = \text{Aper}(x,y) * \text{Phase}(x,y) = A(x,y)e^{-i\Phi(x,y)}$$

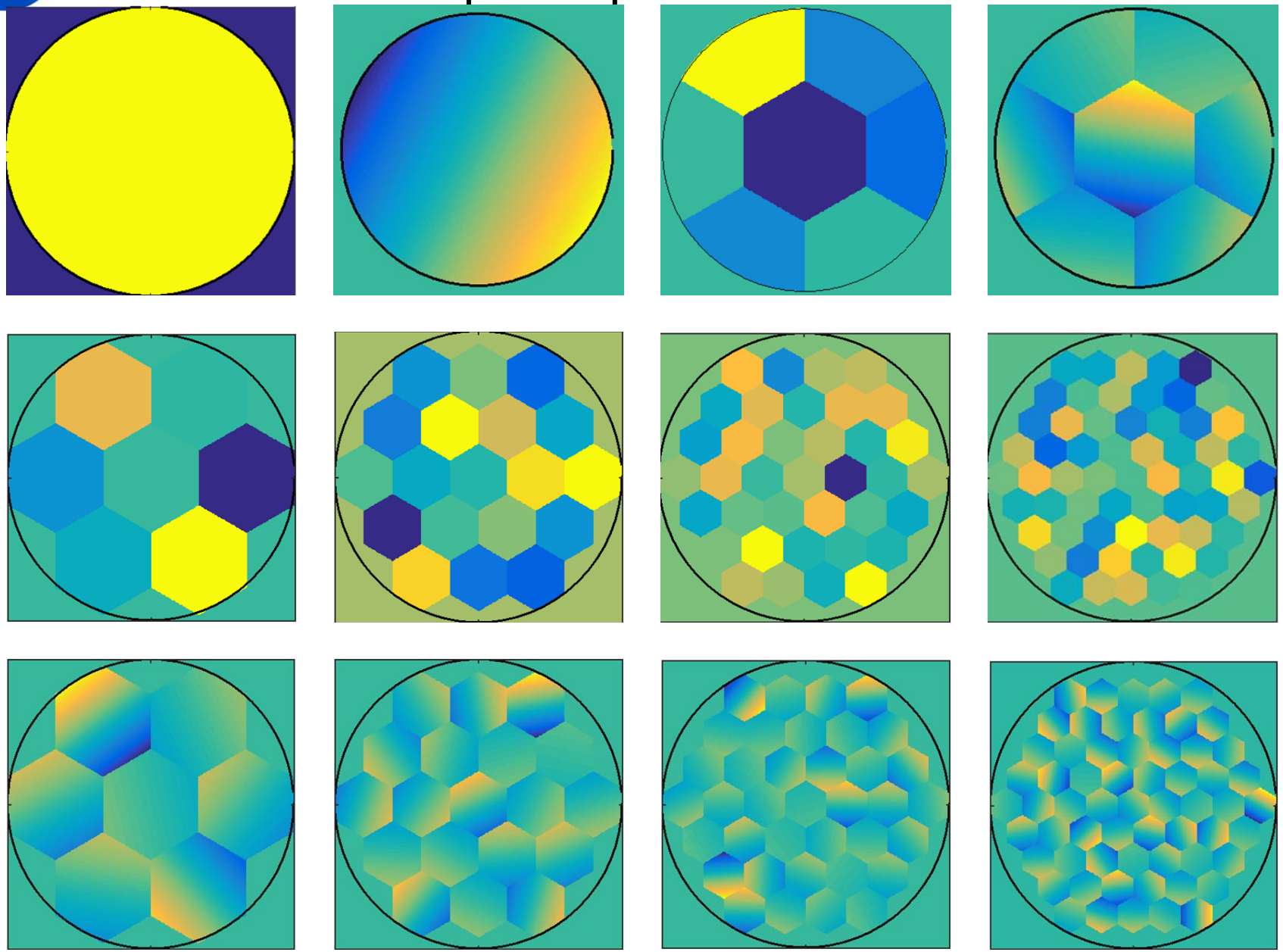
Aperture Mask

- Can model Monolithic or Segmented Aperture
- Segments are Hexagonal
- Outer Aperture can be Hex Segment Boundary or Circle
- Hex segmentation pattern is 1, 2, … to 6 Rings.
- Can also do Central Circular Obscuration and ‘cross’ spiders

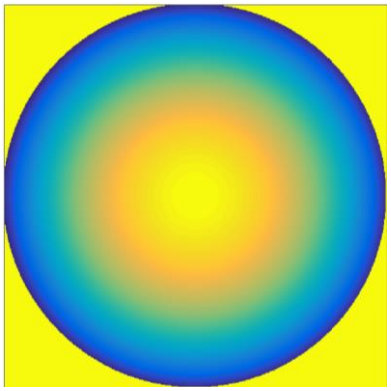
Phase defines telescope Wavefront Error

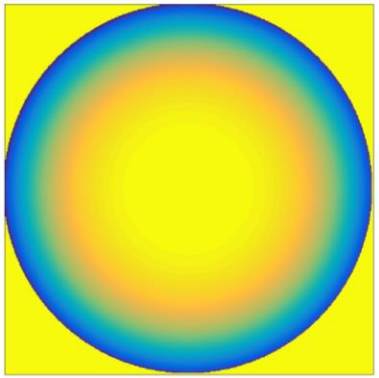
- Global Alignment: Despace (Power and Spherical), Decenter (Coma), Backplane Bending, Mount Errors, etc.
- Segment Rigid Body: Piston, Tip/Tilt

Input Pupil Functions

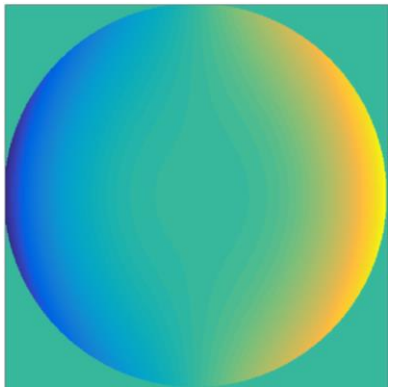


Input Phase Functions: Global Errors

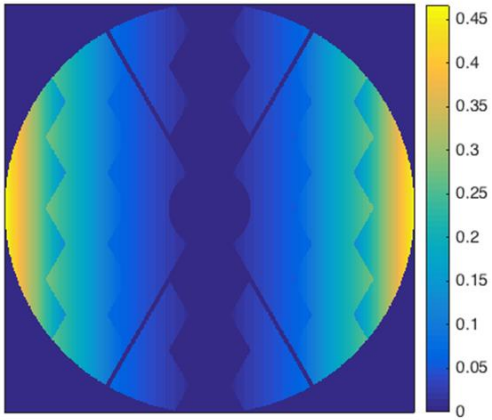


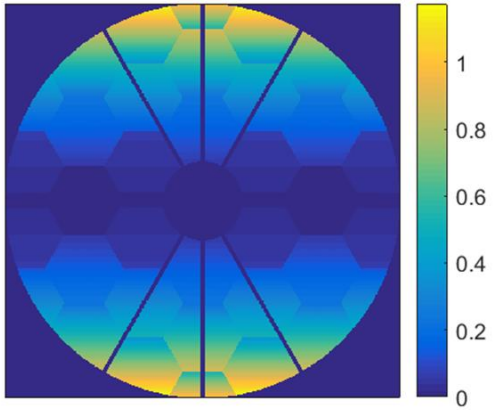


PM to SM Despace: Power and Spherical

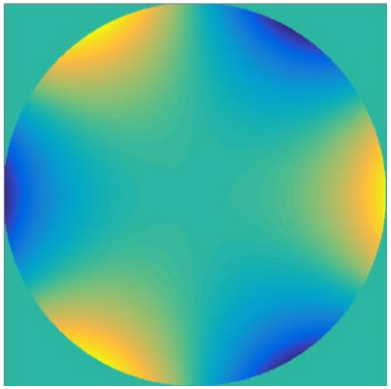


PM to SM Decenter: Coma & Tilt



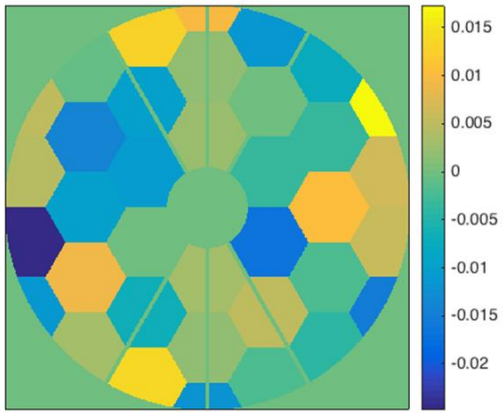


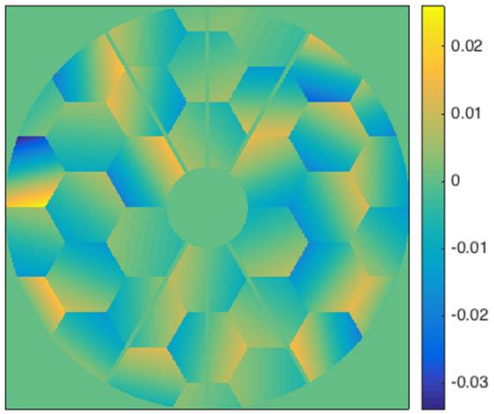
PM Backplane bending



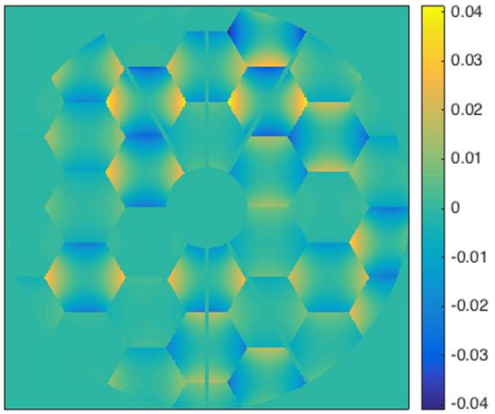
PM Mount: Trefoil

Input Phase Functions: Segment Errors

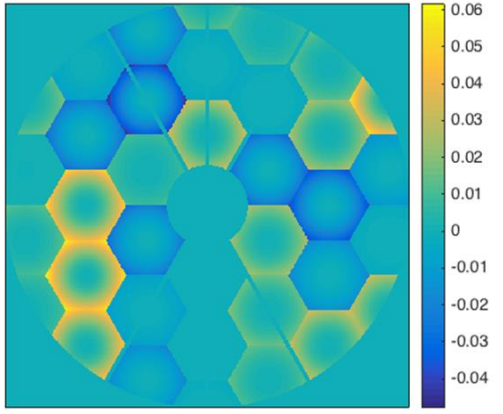




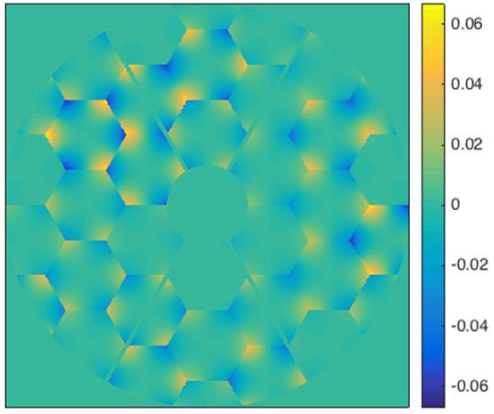
Segment Rigid Body Motion: Pistion and Tip/Tilt



Segment Decenter or Bending: Astigmatism



Segment Thermal Drift: Power



Segment Mount: Trefoil

Phase Function Perturbations

Three temporal Phase Function cases are modeled:

- Static
- Periodic
- Random

Static models contrast leakage for a fix amplitude of each wavefront error.

Periodic models contrast leakage for a wavefront error that varies sinusoidally between +/- peak amplitude values. This case represents periodic vibration such as rocking mode of a secondary mirror tower or of a primary mirror segment that is uncorrected (either no active control of active control is slow).

Random models motion that is not corrected by an assumed active control system.

Model Output

The model calculates Contrast Leakage:

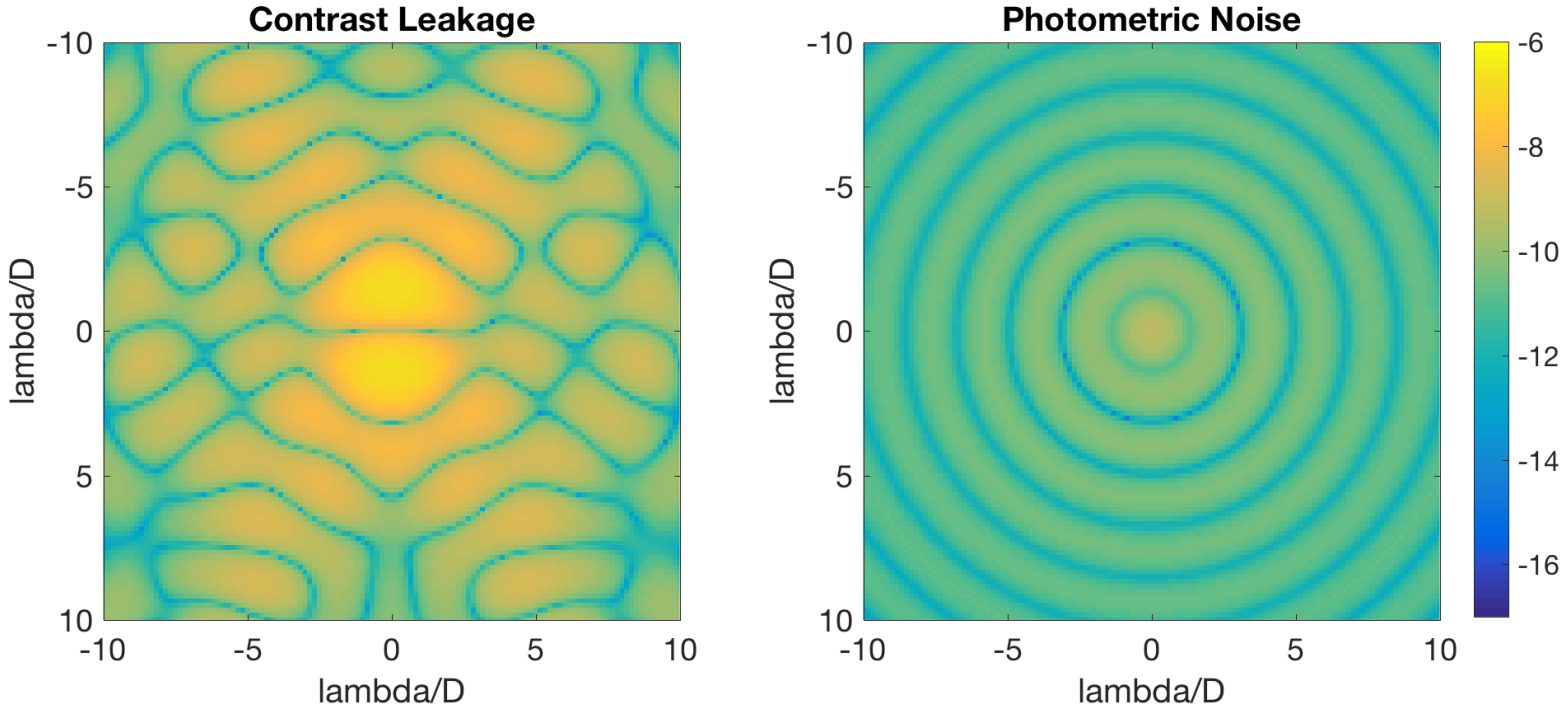
- Photometric Noise – time and spatial averaged radial
- Systematic Noise – azimuthal varying error

We are following the definitions and methodology published by:

Stuart B. Shaklan, Luis Marchen, John Krist and Mayer Rud, “Stability error budget for an aggressive coronagraph on a 3.8m telescope”, SPIE Proceedings 8151, 2011.

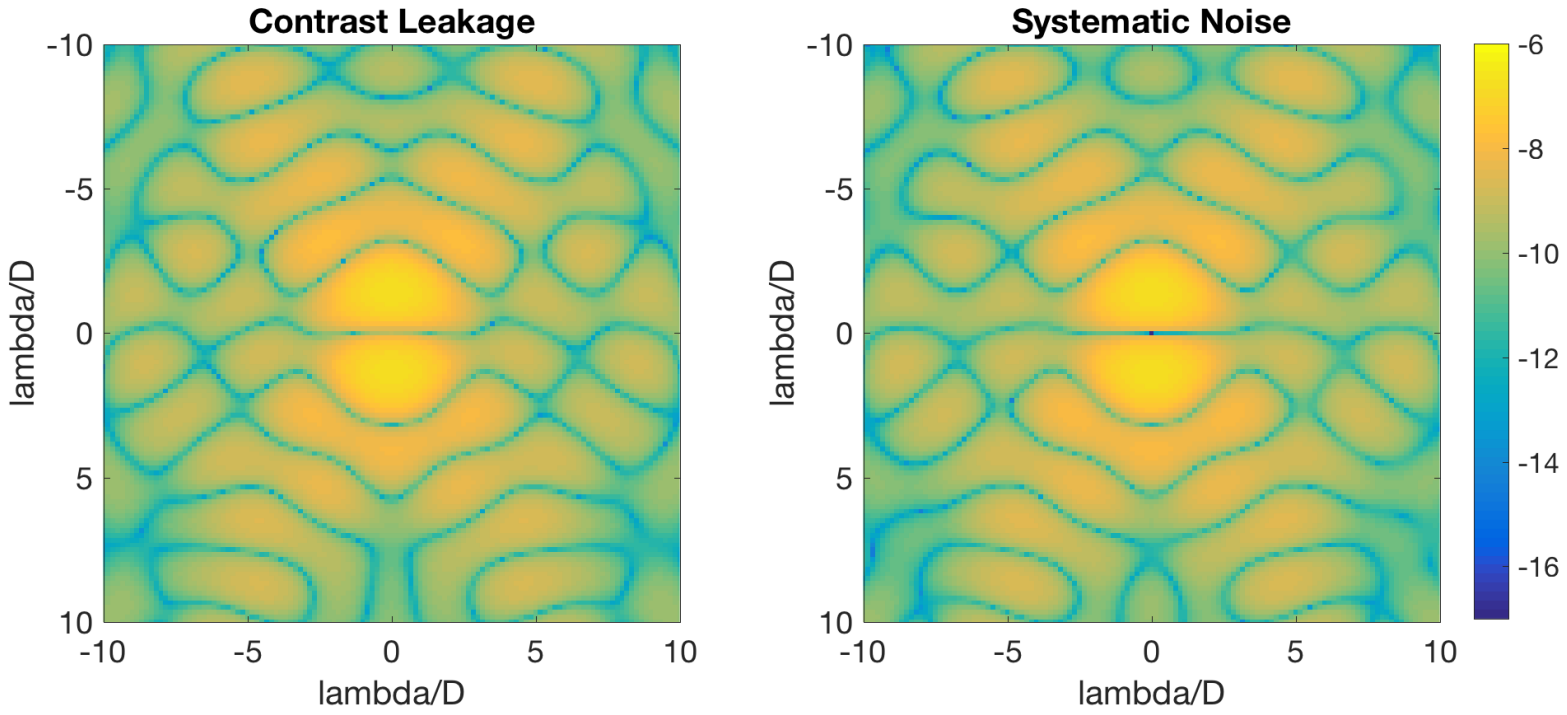
Photometric Noise

Photometric Noise is the time and spatial averaged radial component of the dark hole speckles. Photometric Noise is rotationally symmetric and cannot be confused for a planet. Assuming that the planet is 10E-10 contrast, Photometric Noise Contrast Leakage may be as large as 10E-10 contrast for a SNR = 1.

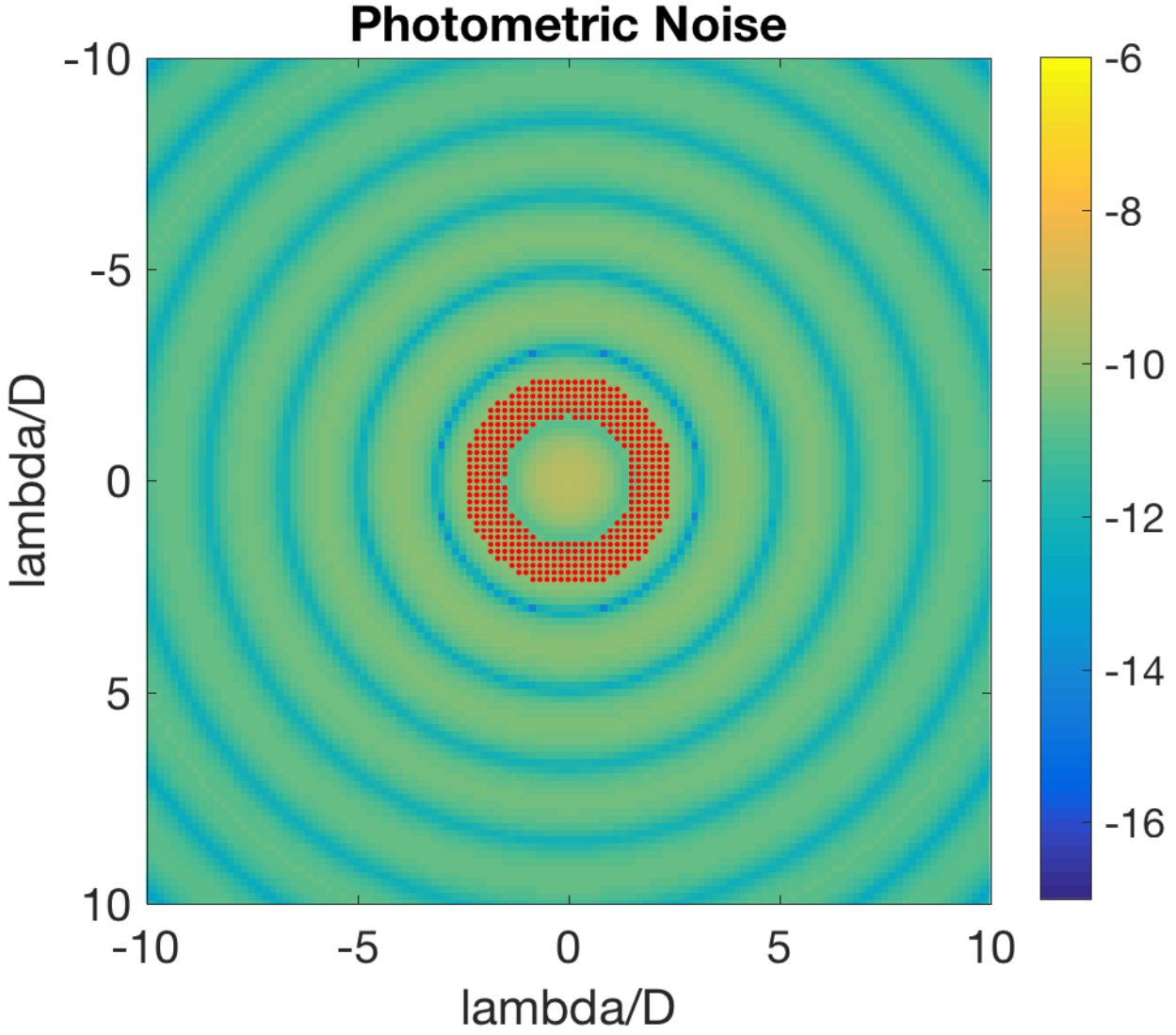


Systematic Noise

Systematic Noise is the component of the dark hole speckles that varies spatially after subtraction of the time-averaged radial component. This noise component can be confused for a planet. For a planet with 10E-10 contrast, systematic noise should be no larger than 20E-11 contrast.



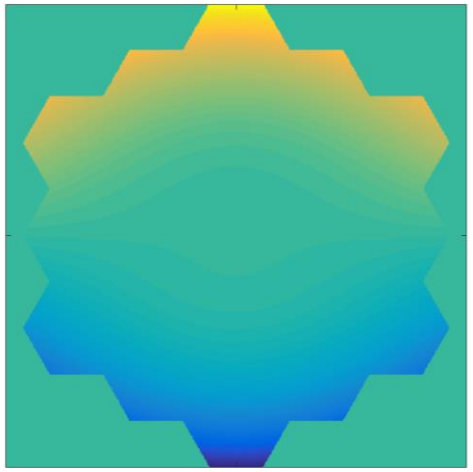
Annular ROI from 1.5 to 2.5 λ/D



Sensitivity Analysis

Input pupil WFE:

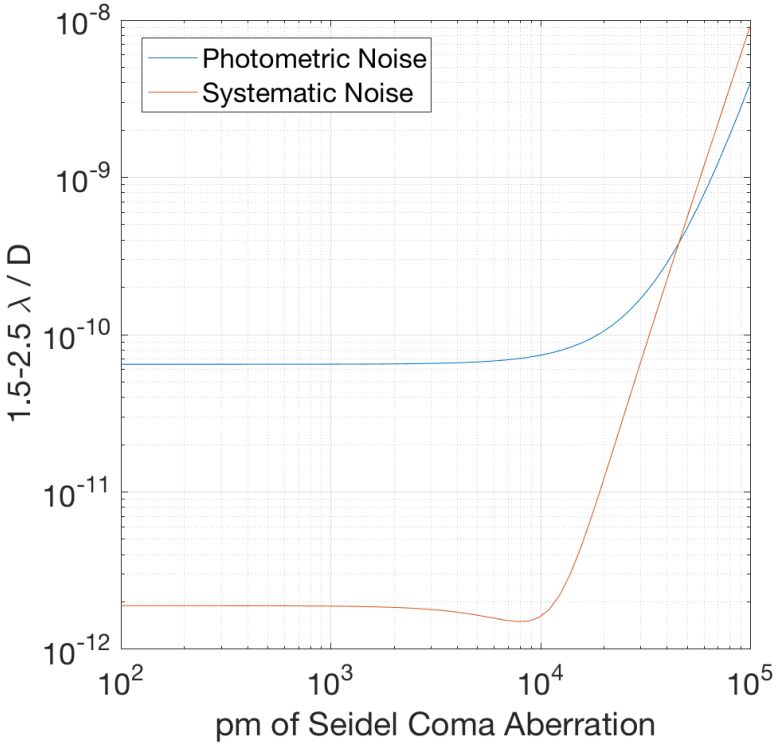
- Single Static Realization
- Average 50 Sinusoidal Realizations
- Average 50 Random Realizations



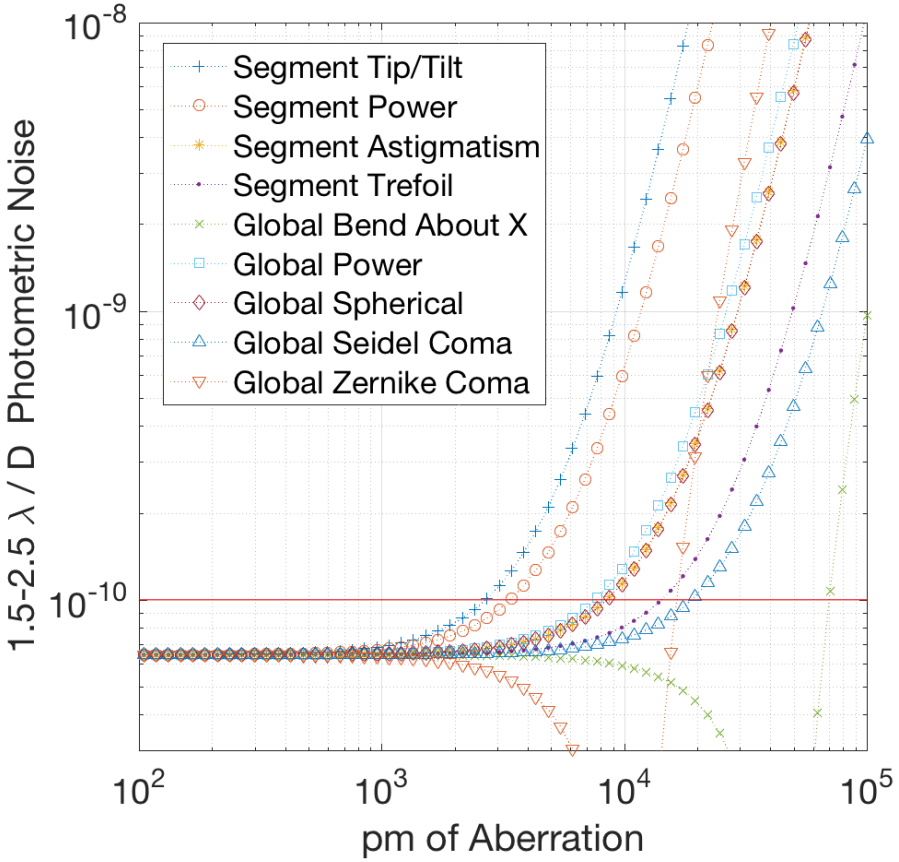
Quantify Contrast Leakage over ROI:

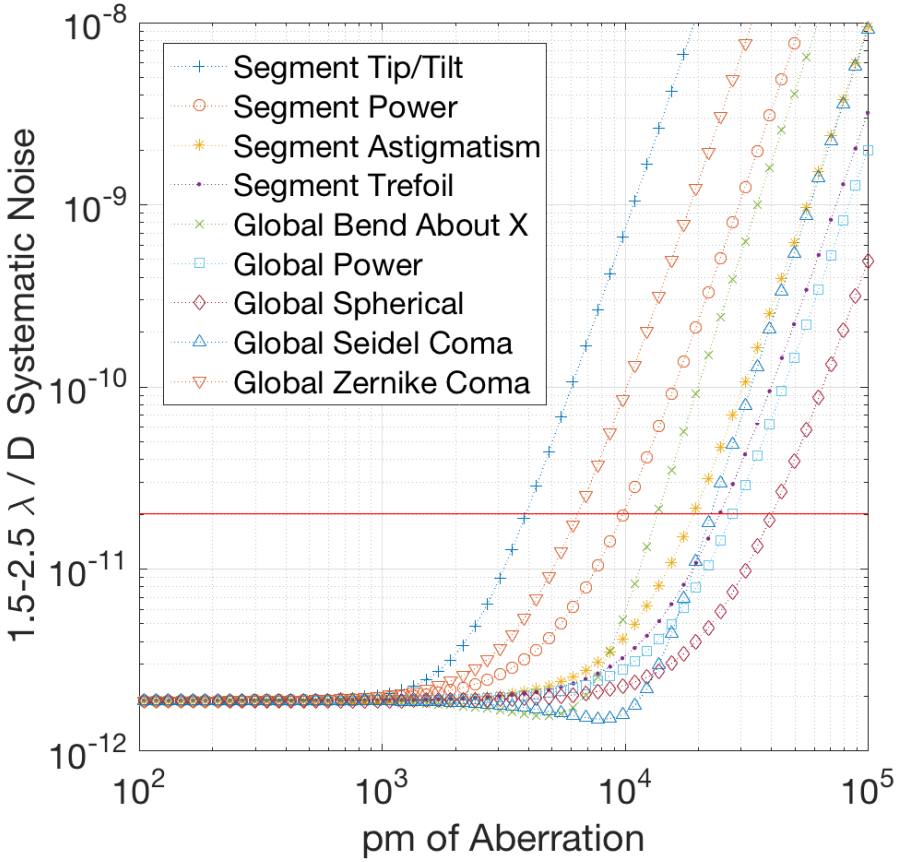
- Average Radial
- Azimuthal

Plot Contrast Leakage vs. Aberration Amplitude



Periodic Noise in Segmented Telescope





Summary for Periodic Noise in Segmented Telescope

Segments	Aberration	WFE (nm) for 10E-10 Photometric Noise	WFE (nm) for 20E-11 Systematic Noise
	Tip / Tilt	2.5	4
	Power	3.5	10
	Astigmatism	9	20
	Trefoil	15	25
Global			
	Power	8	30
	Spherical	9	40
	Seidel Coma	20	20
	Zernike Coma	15	6
Back Plane/Mount			
	Bend About X	70	15

Conclusions

Developed methodology for calculating Photometric and Systematic Contrast Leakage Noise

Will use Leakage Sensitivity to define Telescope Mechanical Motion Tolerances.