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.

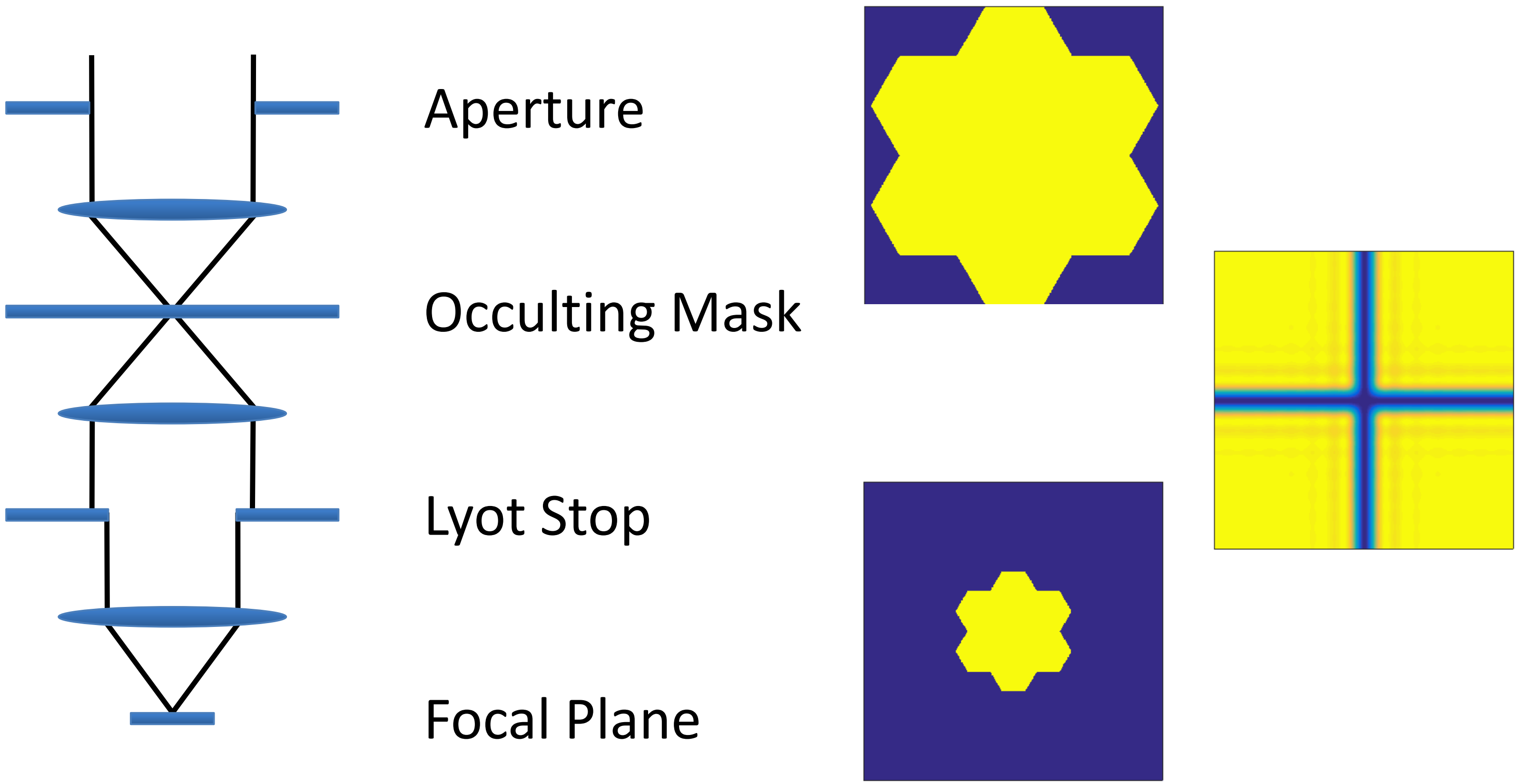
Caveats

- 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 $\{1\text{-sinc}^2(x) \times \text{sinc}^2(y)\}$or radial $\{1\text{-sinc}^2(r)\}$ or coronagraph provided by STScI or others.



Integrated Model – Pupil Function

Pupil Function models the telescope

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

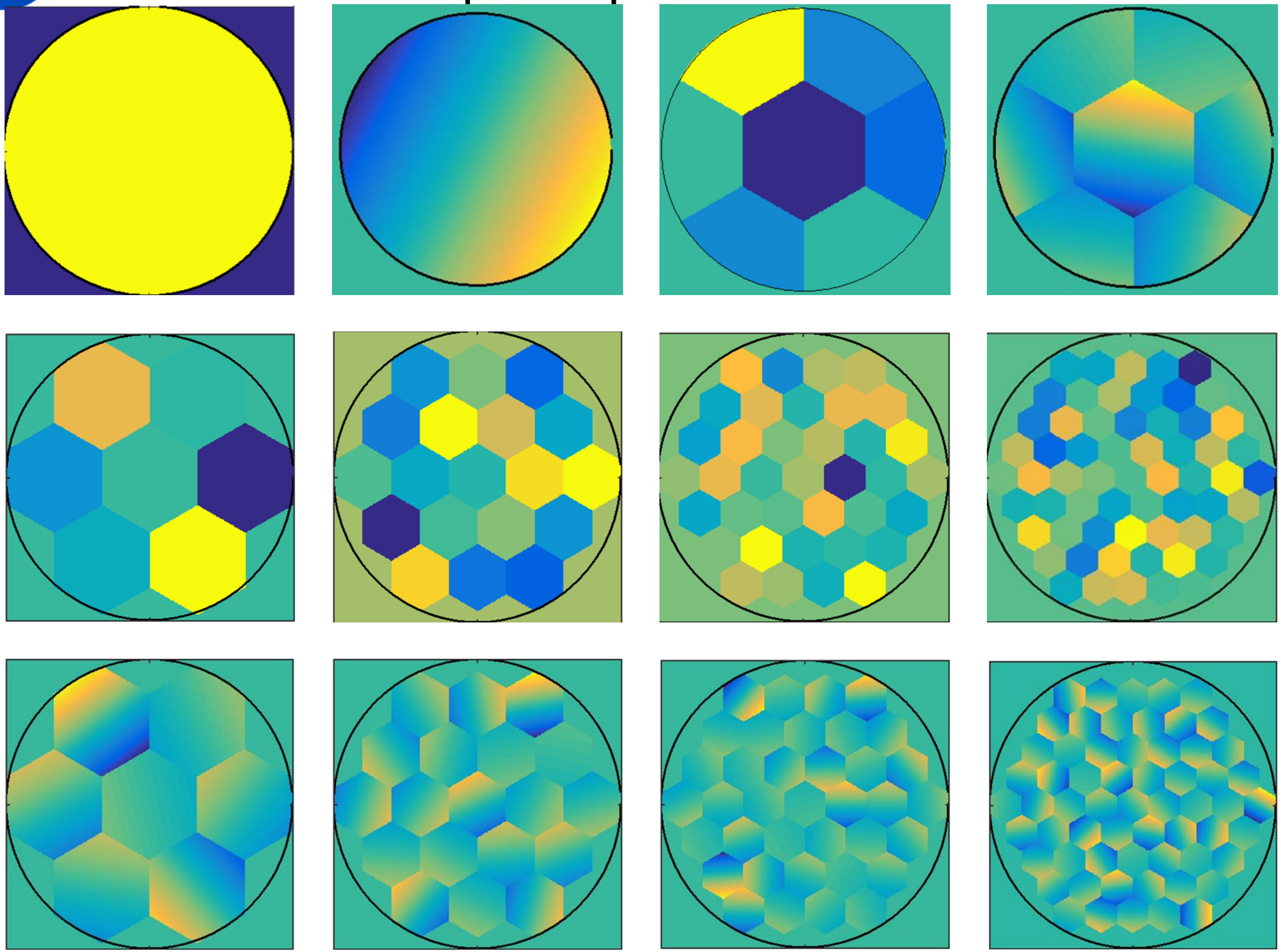
Aperture Mask

- 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

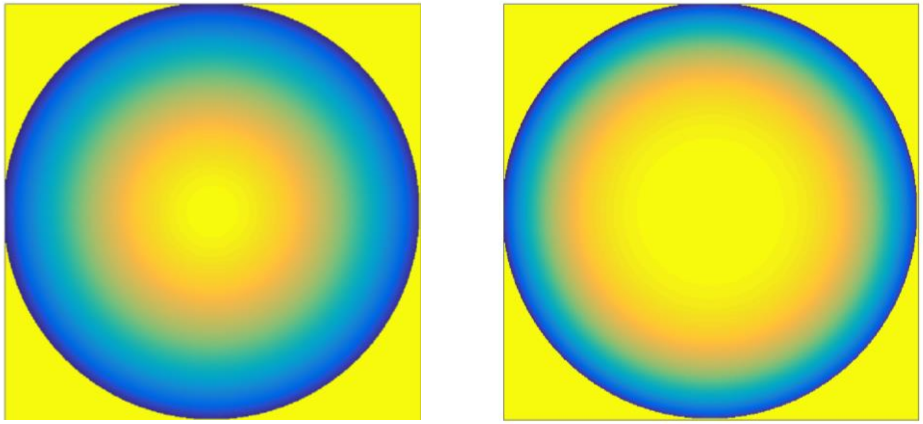
Phase defines telescope Wavefront Error

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

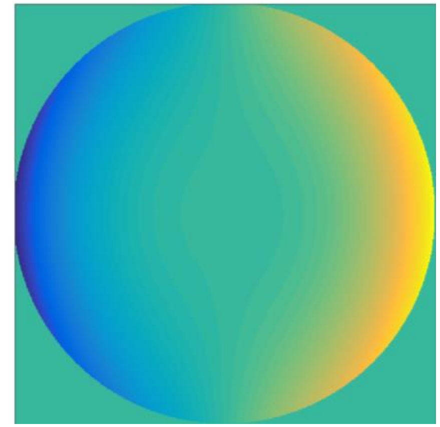
Input Pupil Functions



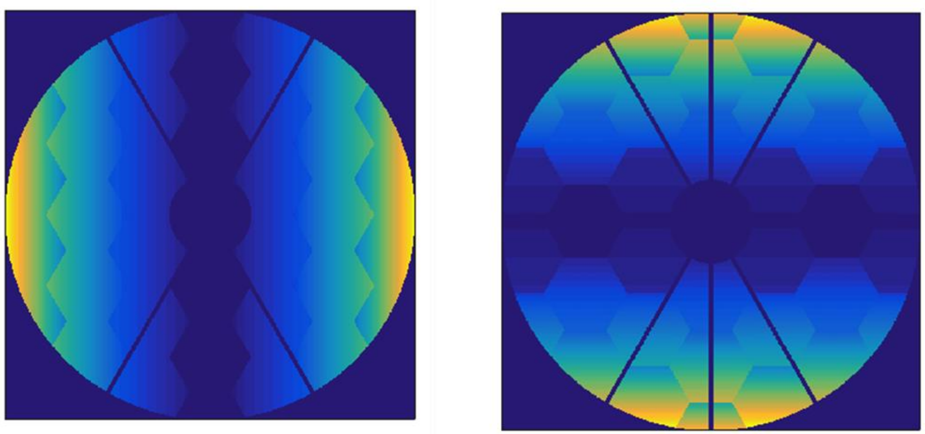
Input Phase Functions: Global Errors



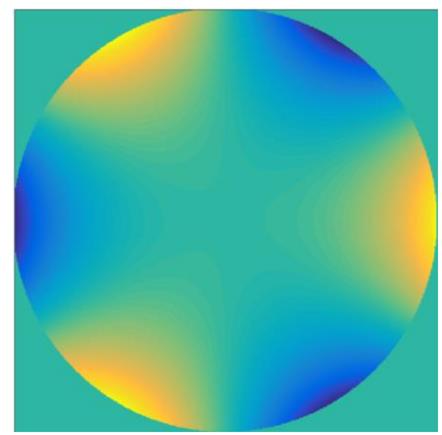
PM to SM Despace: Power and Spherical



PM to SM Decenter: Coma & Tilt

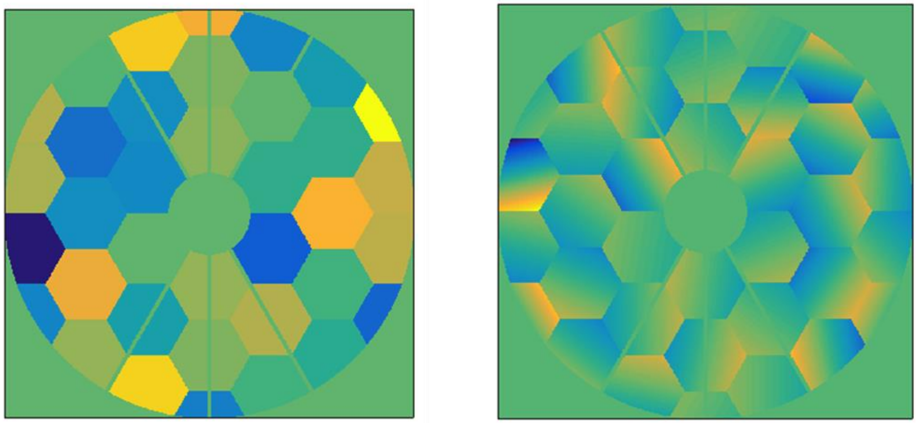


PM Backplane bending

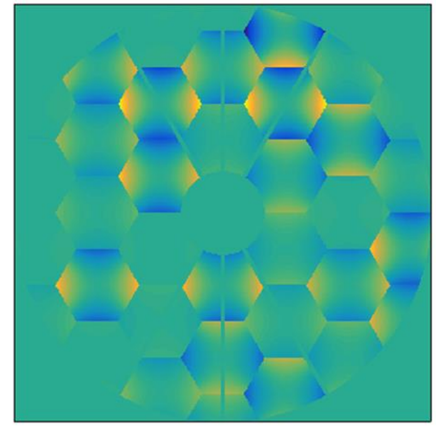


PM Mount: Trefoil

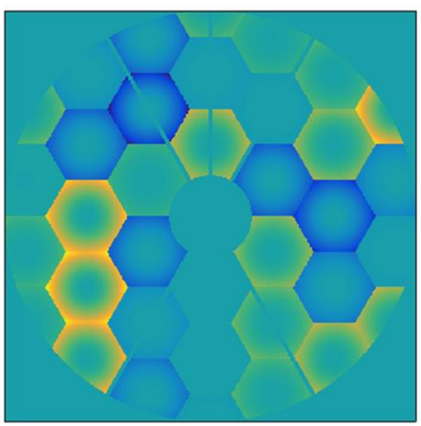
Input Phase Functions: Segment Errors



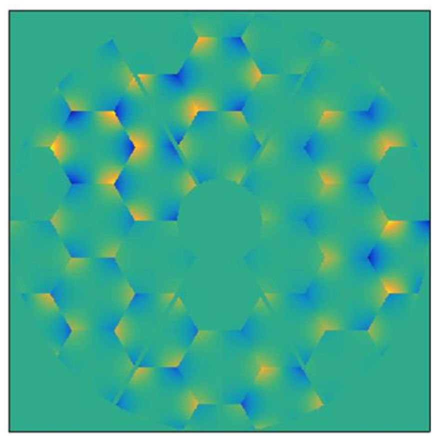
Segment Rigid Body Motion:
Piston and Tip/Tilt



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

NOTE: Segment level static and periodic errors are correlated.

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

Previous model versions calculated average raw contrast leakage over a region of interest (square or annular).

We are now decomposing the leakage into radial and azimuthal components.

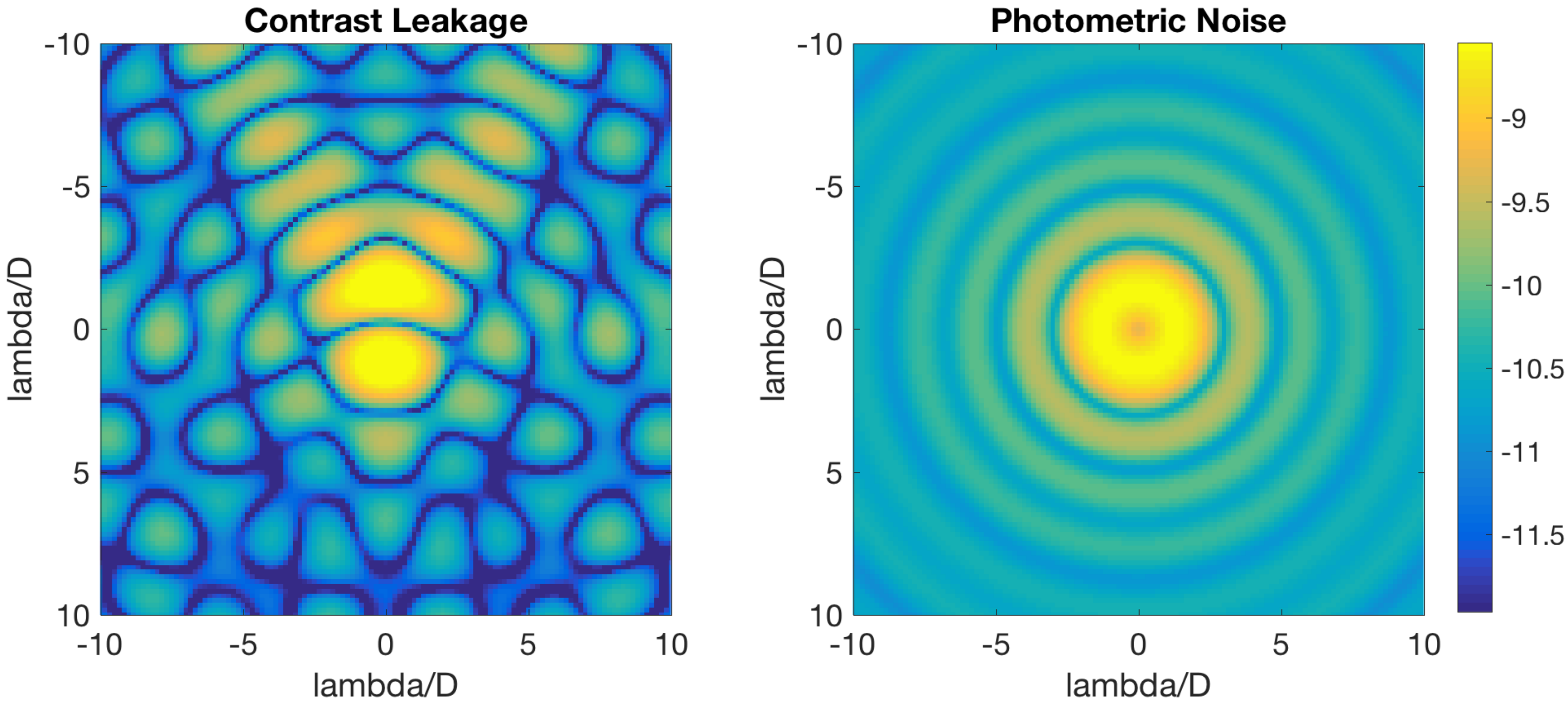
- Photometric Noise – time and spatial averaged radial
- Systematic Noise – azimuthal varying error

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.

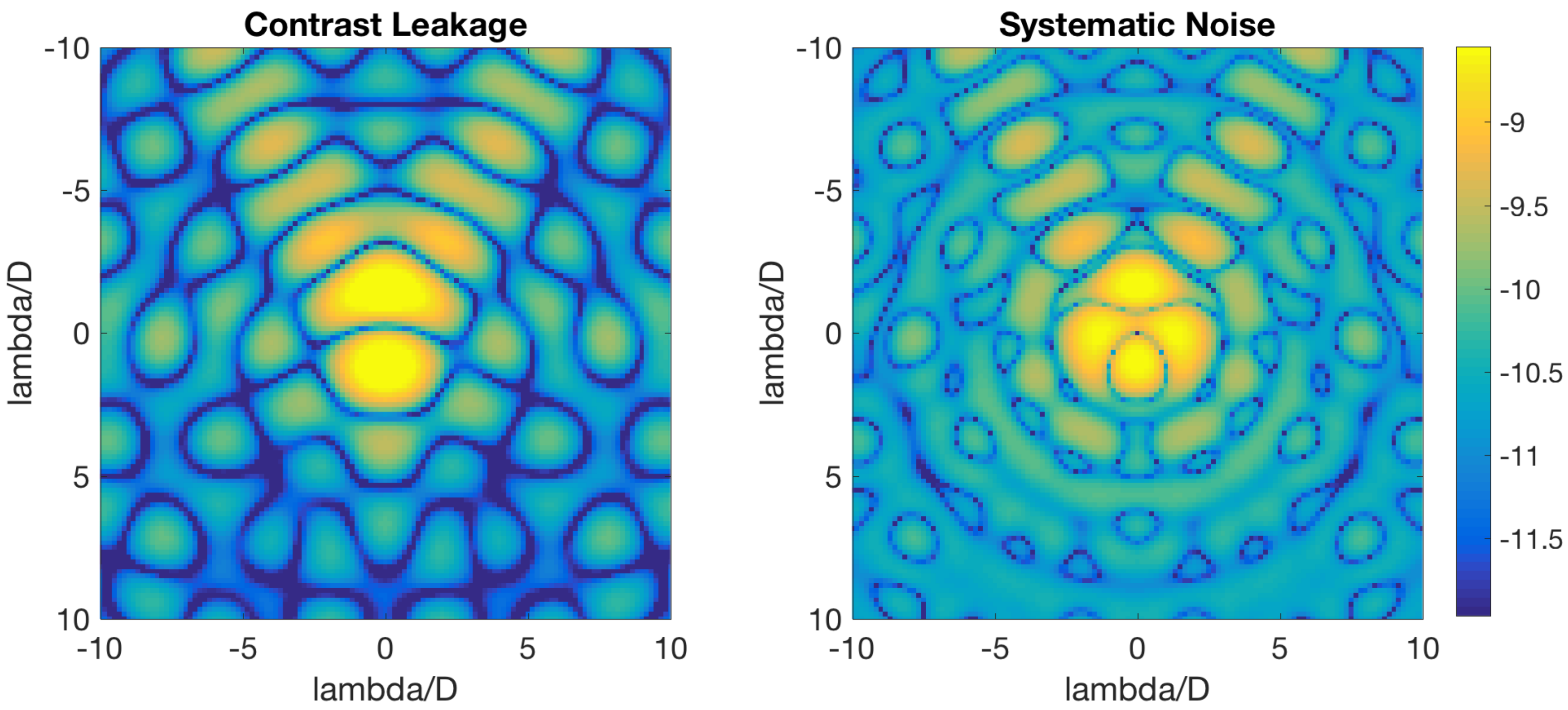
Photometric Noise

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 10^{-10} contrast, Photometric Noise Contrast Leakage may be as large as 10^{-10} contrast for a SNR = 1.

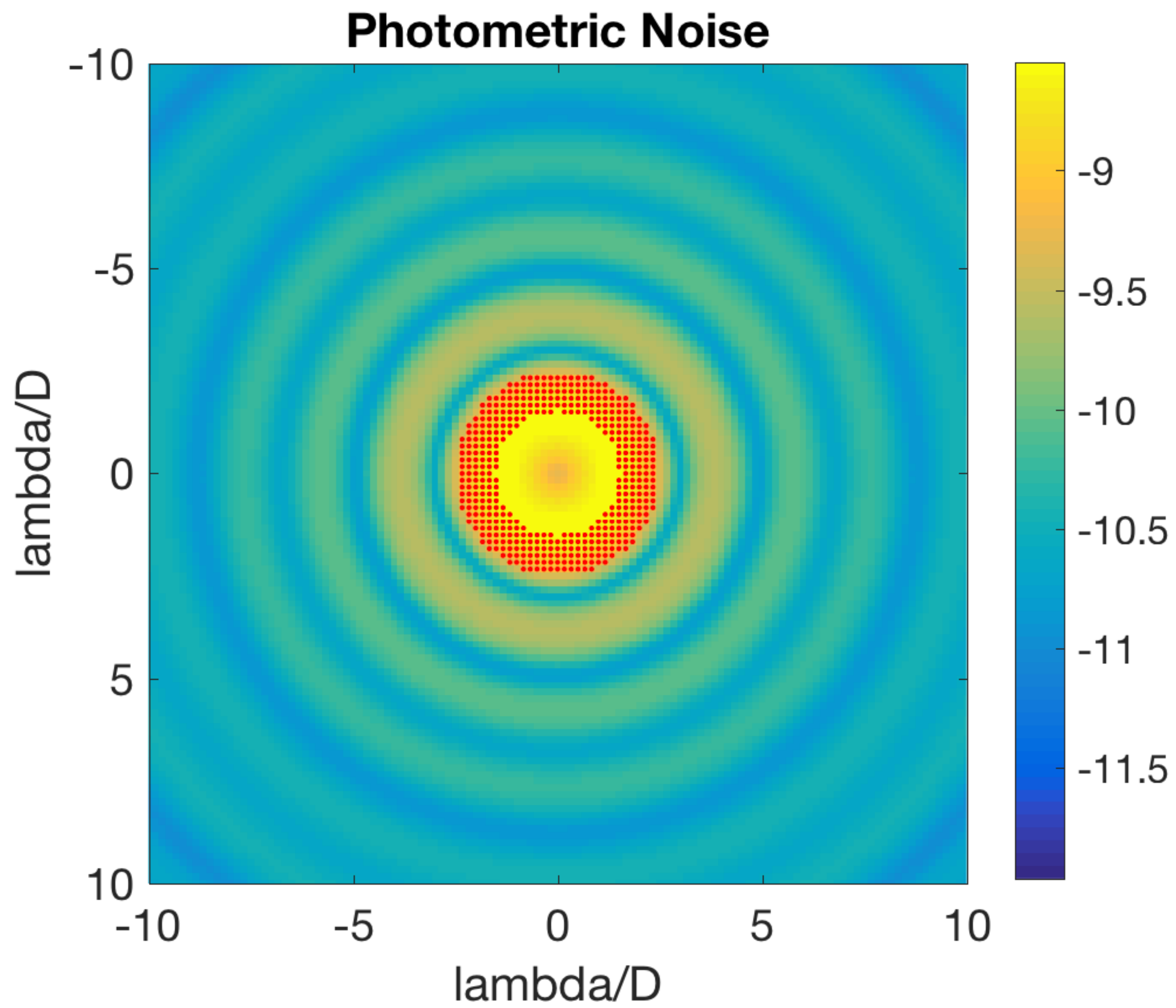


Systematic Noise

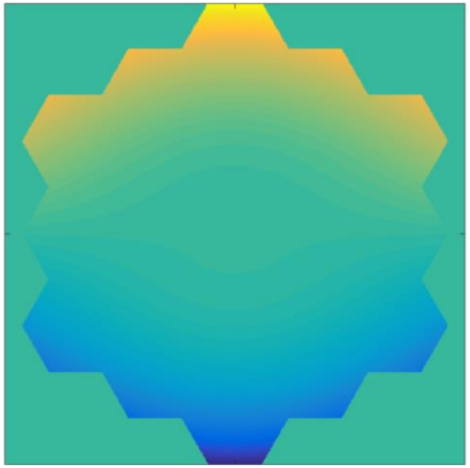
Systematic Noise is the component of the dark hole speckles that varies spatially after subtraction of the time-averaged radial component. This noise component can be confused for a planet. For a planet with 10^{-10} contrast, systematic noise should be no larger than 2×10^{-11} contrast.



Annular ROI from 1.5 to 2.5 λ/D



Sensitivity Analysis

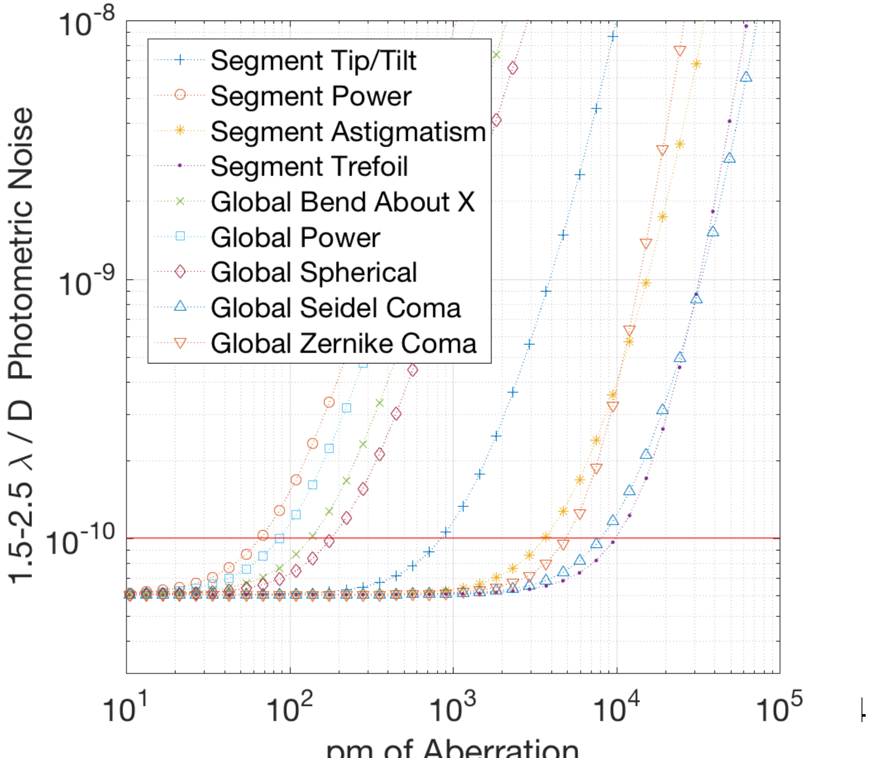


Input pupil WFE:

- Single Static Realization
- Average 20 Sinusoidal Realizations
  - Mechanical movement
- Average 50 Random Realizations
  - Thermal drift

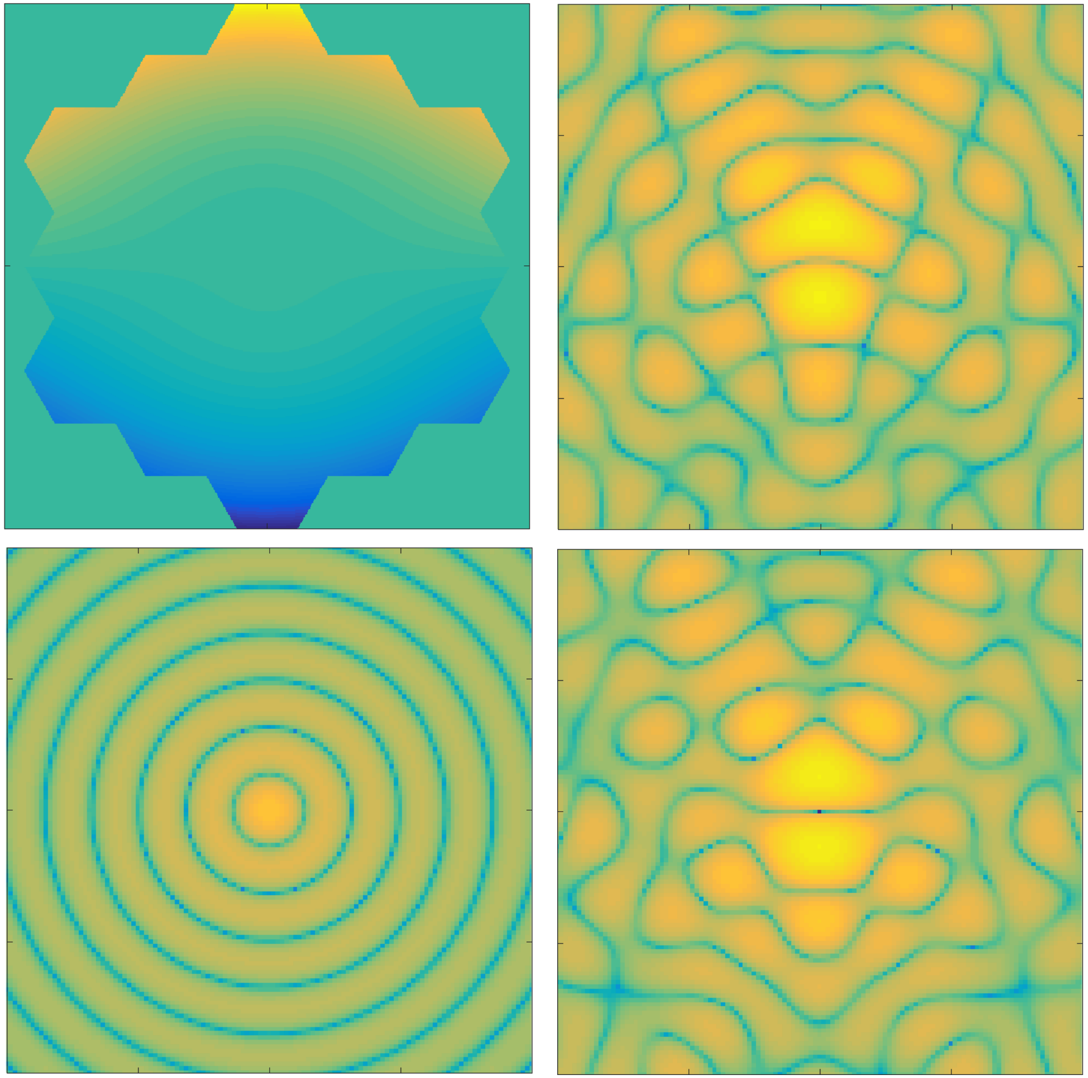
Quantify contrast leakage over RO

- Photometric Noise
- Systematic Noise

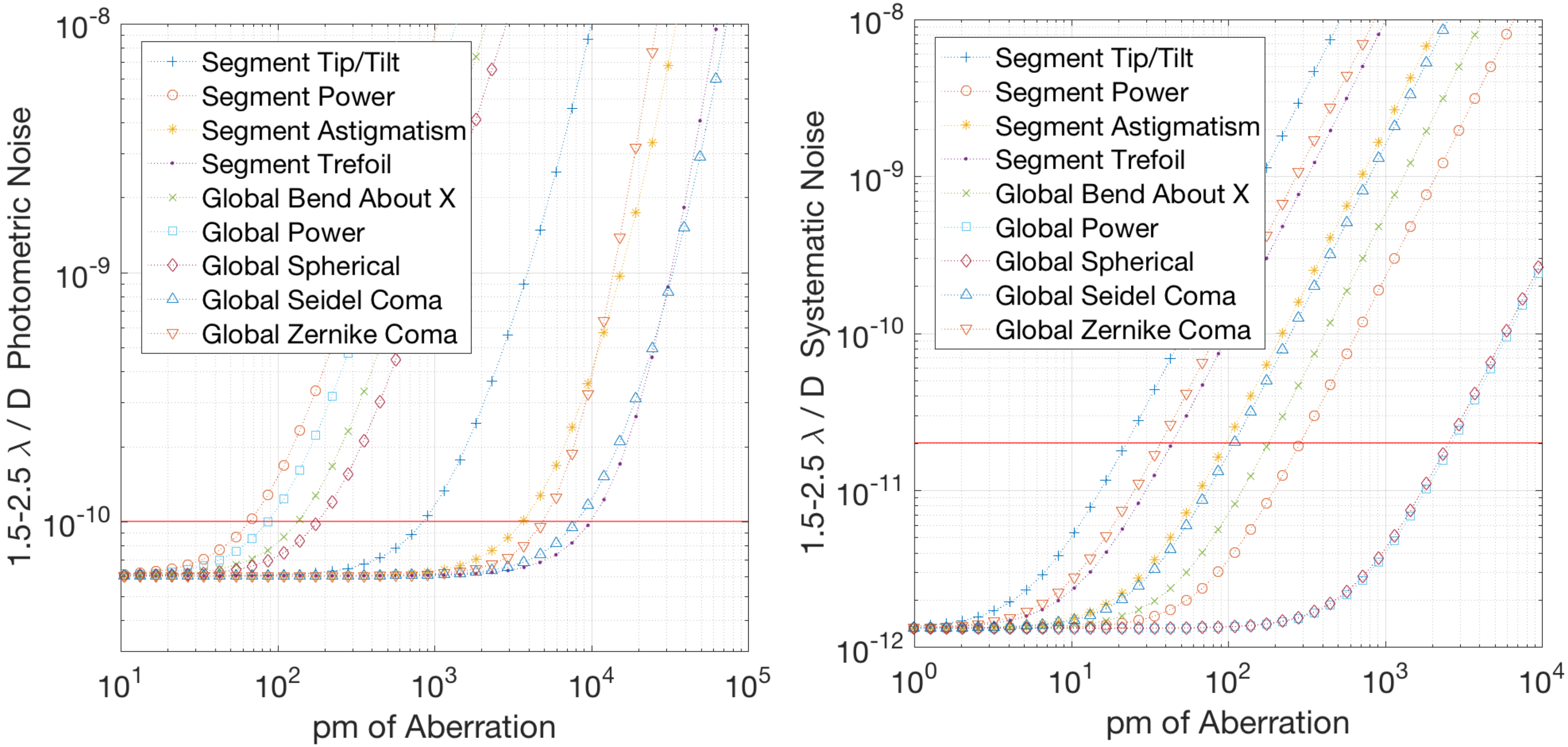


Plot Contrast Leakage vs. Aberration Amplitude

Hex (N2) Segmented Telescope



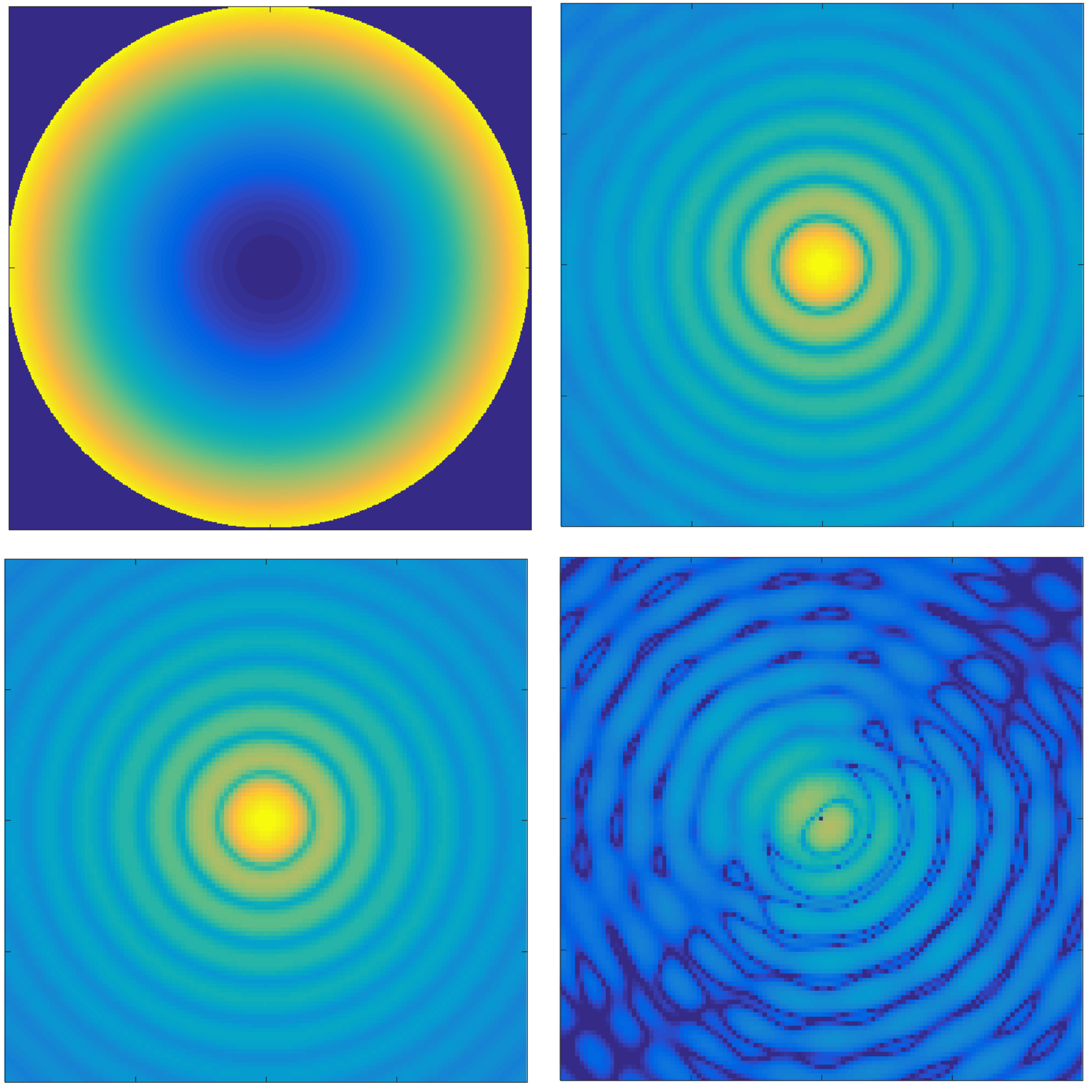
Static Noise in Hex Segmented Telescope



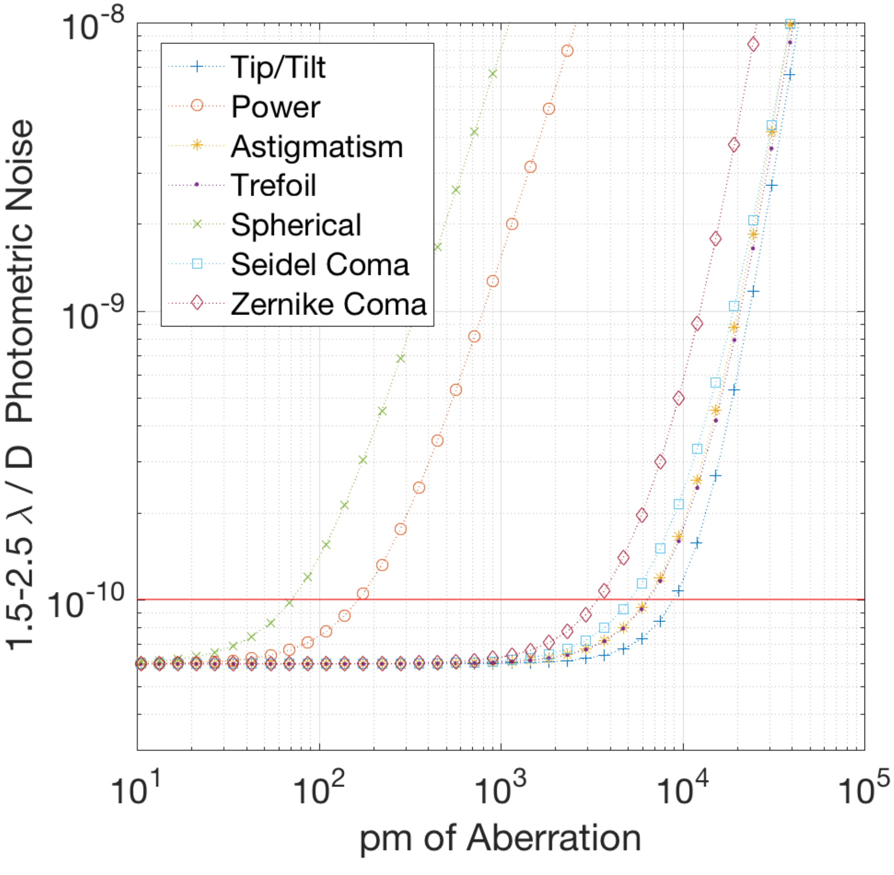
Static Noise in Hex Segmented Telescope

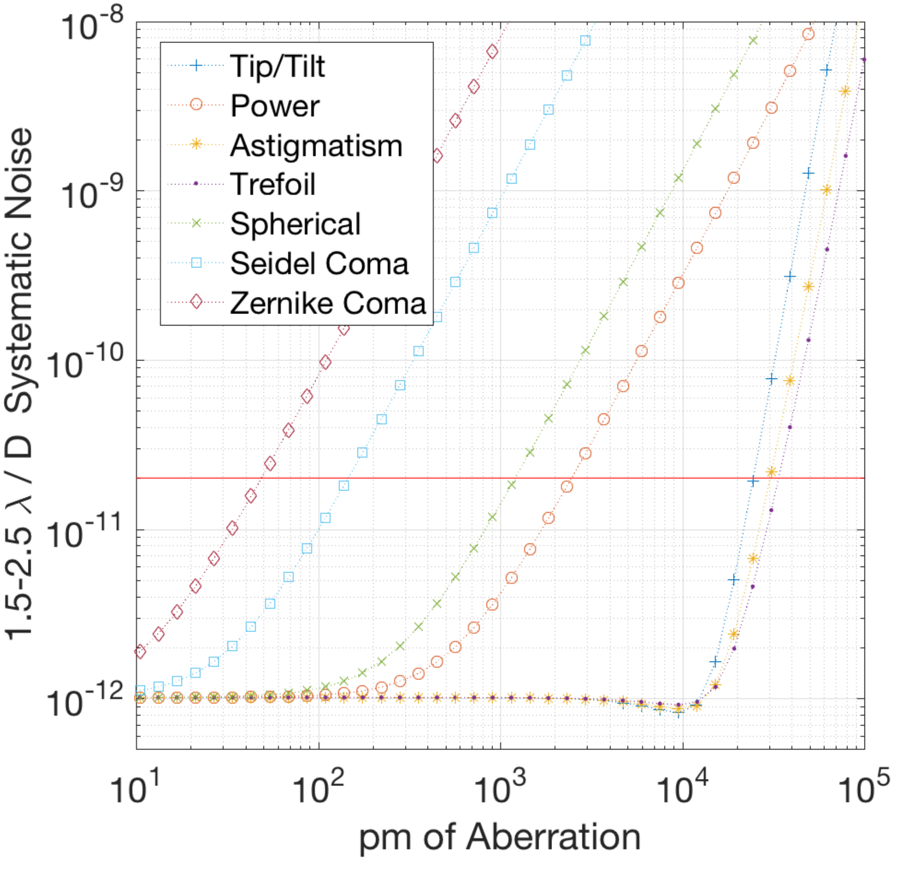
1.5-2.5 λ/D Segments	Aberration	WFE (pm) for 1x10^{-10} Photometric Noise	WFE (pm) for 2x10^{-11} Systematic Noise
	Tip / Tilt	900	22
	Power	70	200
	Astigmatism	2,500	95
	Trefoil	10,000	42
Global			
	Power	90	2,500
	Spherical	180	2,500
	Seidel Coma	8,000	100
	Zernike Coma	5,000	35
Back Plane/Mount			
	Bend About X	150	180

Monolithic Telescope



Static Noise in Monolithic Telescope

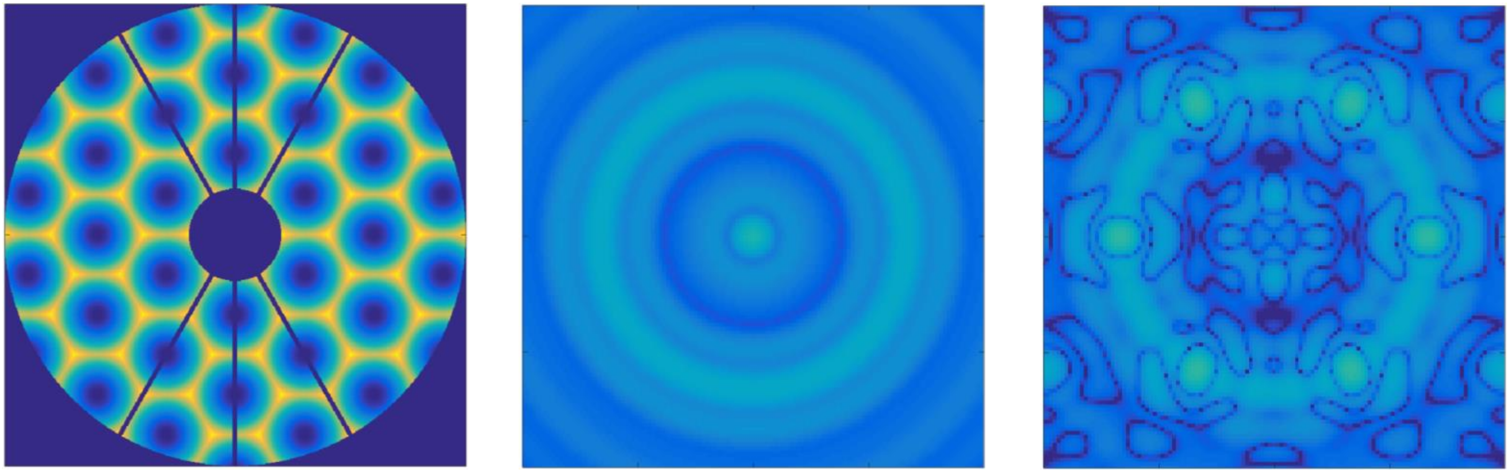




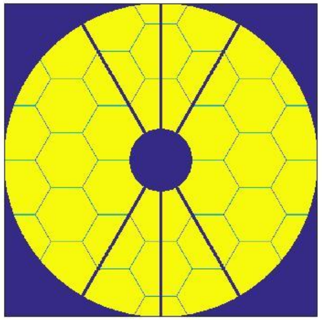
Static Noise in Monolithic Telescope

1.5-2.5 λ/D Aberration	WFE (pm) for $1x10^{-10}$ Photometric Noise	WFE (pm) for $2x10^{-11}$ Systematic Noise
Tip / Tilt	9,000	25,000
Power	180	2,500
Astigmatism	6,500	30,000
Trefoil	6,500	35,000
Spherical	70	1,200
Seidel Coma	5,000	150
Zernike Coma	3,500	50

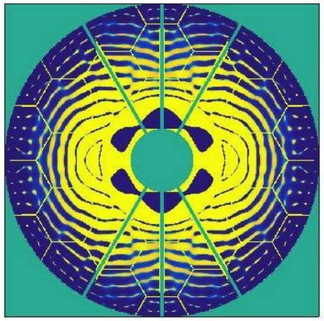
ATLAST Telescope



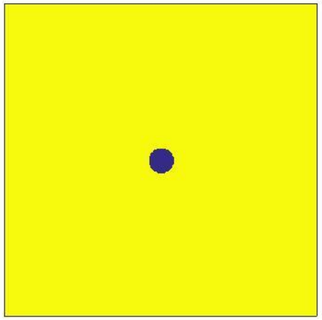
Aperture



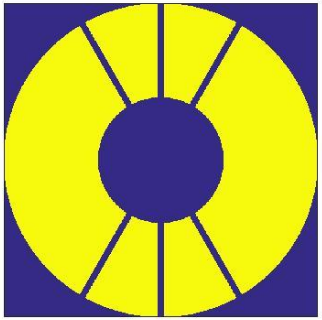
Apodization



FPM

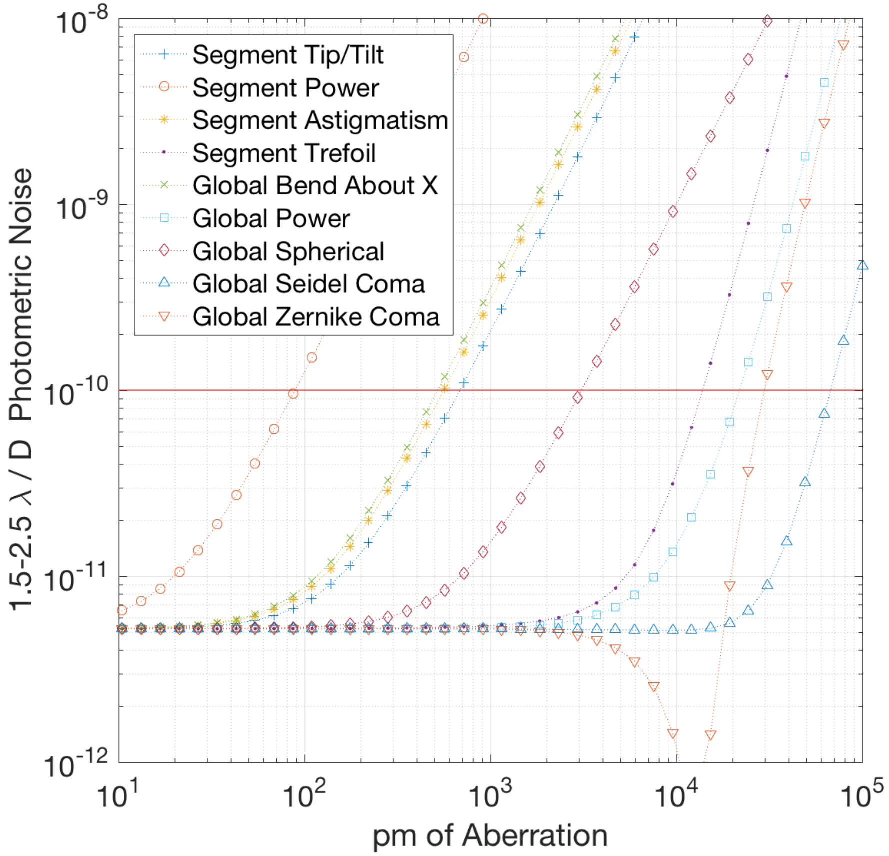


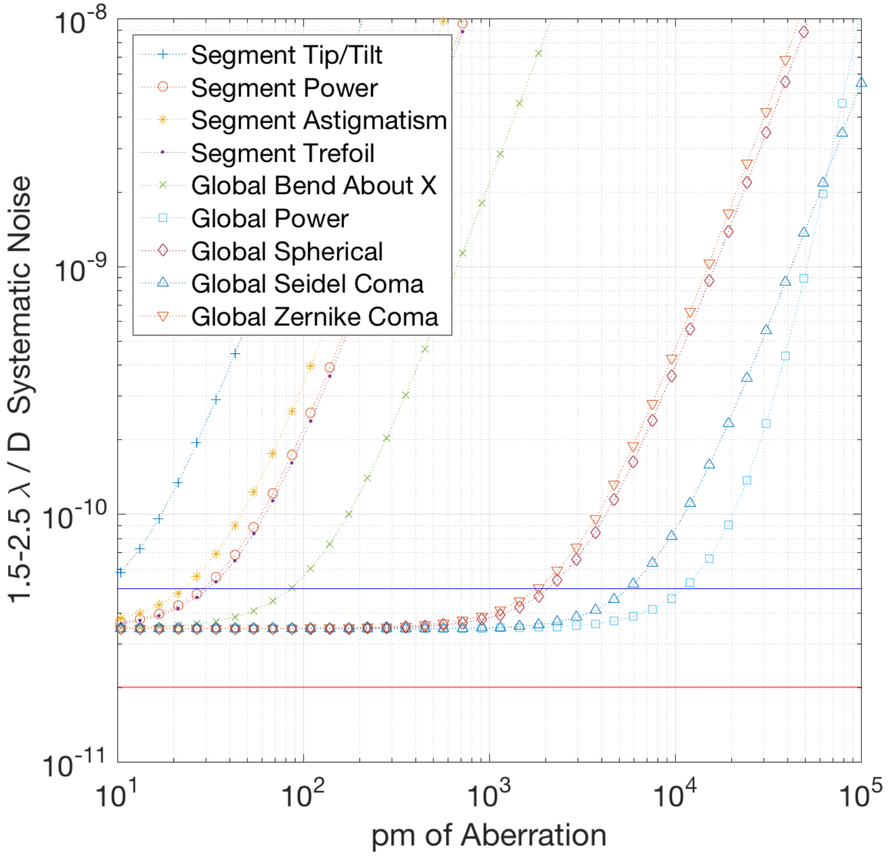
Lyot Stop



N’Diaye, et. al., “Apodized Pupil Lyot Coronagraphs for Arbitrary Apertures”, Astro-PH, 2016

Static Noise in ATLAST Telescope





Static Noise in ATLAST Telescope

4.5-5.5 λ/D Segments	Aberration	WFE (pm) for $1x10^{-10}$ Photometric Noise	WFE (pm) for $5x10^{-11}$ Systematic Noise
	Tip / Tilt	700	18
	Power	90	60
	Astigmatism	60	45
	Trefoil	15,000	60
Global			
	Power	20,000	20,000
	Spherical	3,000	4,200
	Seidel Coma	65,000	11,000
	Zernike Coma	20,000	3,900
Back Plane/Mount			
	Bend About X	50	190

Conclusions

Developed methodology for calculating Photometric and Systematic Contrast Leakage Noise

Will use Leakage Sensitivity to define Telescope Mechanical Motion Tolerances.