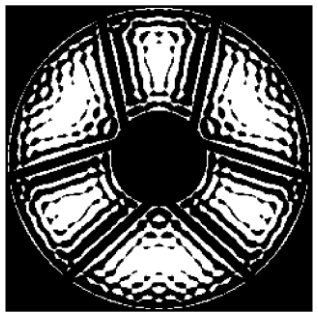
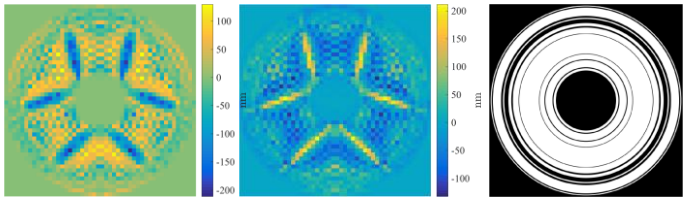
Jet Propulsion Laboratory
California Institute of Technology

Numerical Coronagraph Design for Shaped Pupils, Hybrid Lyots, and Beyond

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Garreth Ruane (California Institute of Technology)
Carl Coker (Jet Propulsion Laboratory, California Institute of Technology)

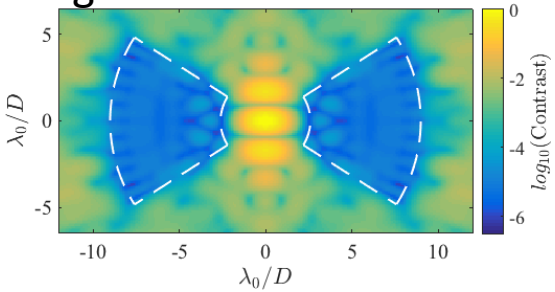
September 26, 2017

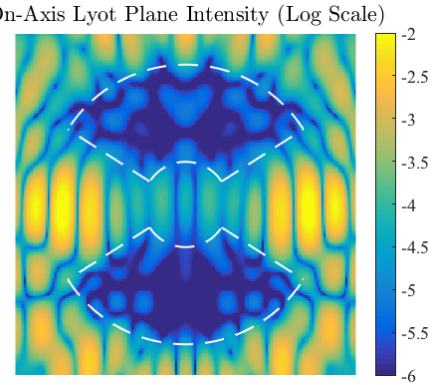
WFIRST SPLC (IFS) Design (**July 2017**)

Simultaneous Goals:

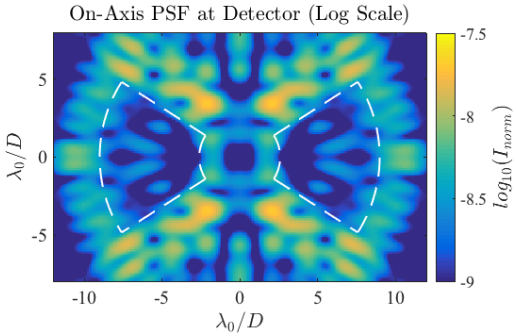
- Minimize starlight
- Maximize off-axis light

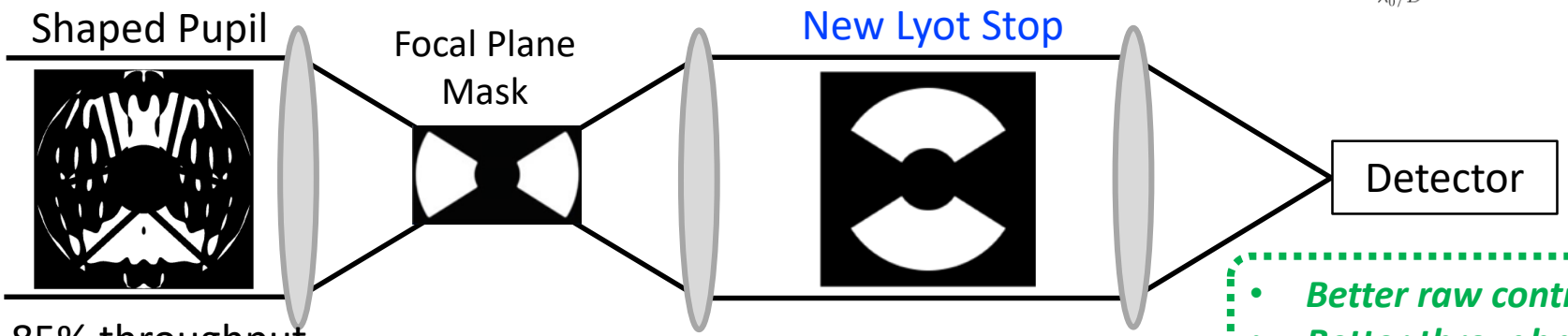
On-Axis Starlight





2 x 10^{-9} raw contrast

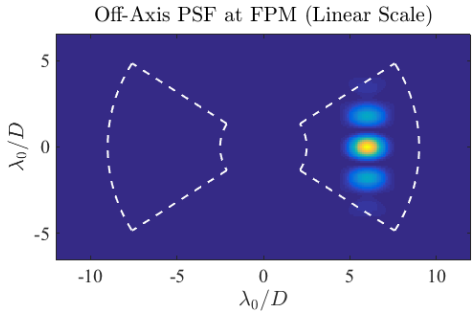


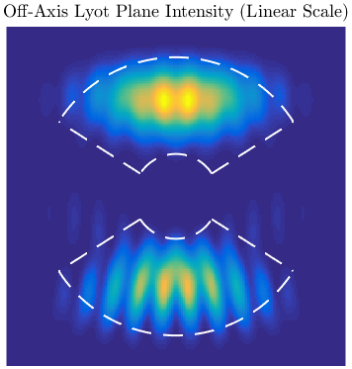


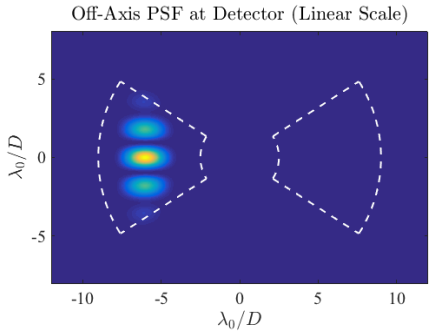
3.85% throughput

- ***Better raw contrast***
- ***Better throughput***

Off-Axis Planet Light





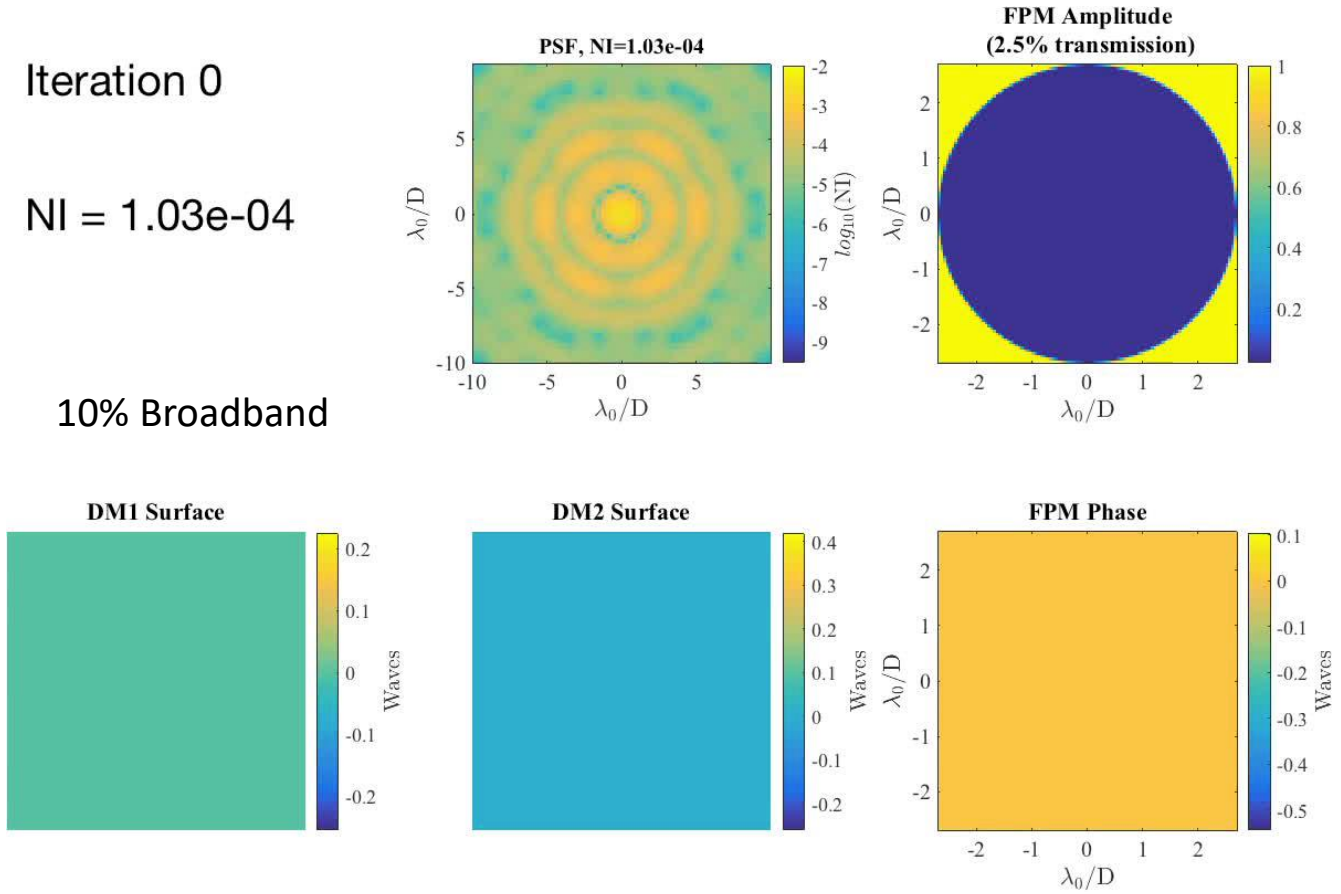


- Linear programs + grid searches
- Optimize tip/tilt sensitivity as well

DMLCs & HLCs

- The future of coronagraph design is **numerical optimization**.
- Need a **fast code** for design surveys
  - Rapid re-linearization of DM Jacobians takes only minutes

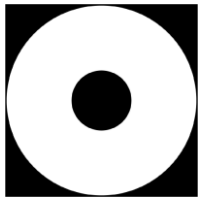
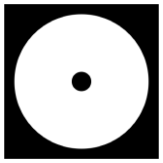
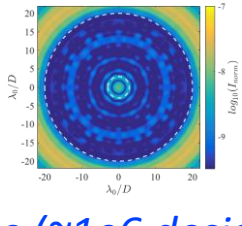
FALCO:
FAst
Linearized
Coronagraph
Optimizer



Gary Ruane, Carl Coker, and I are writing on a master code of this for most Lyot coronagraphs:

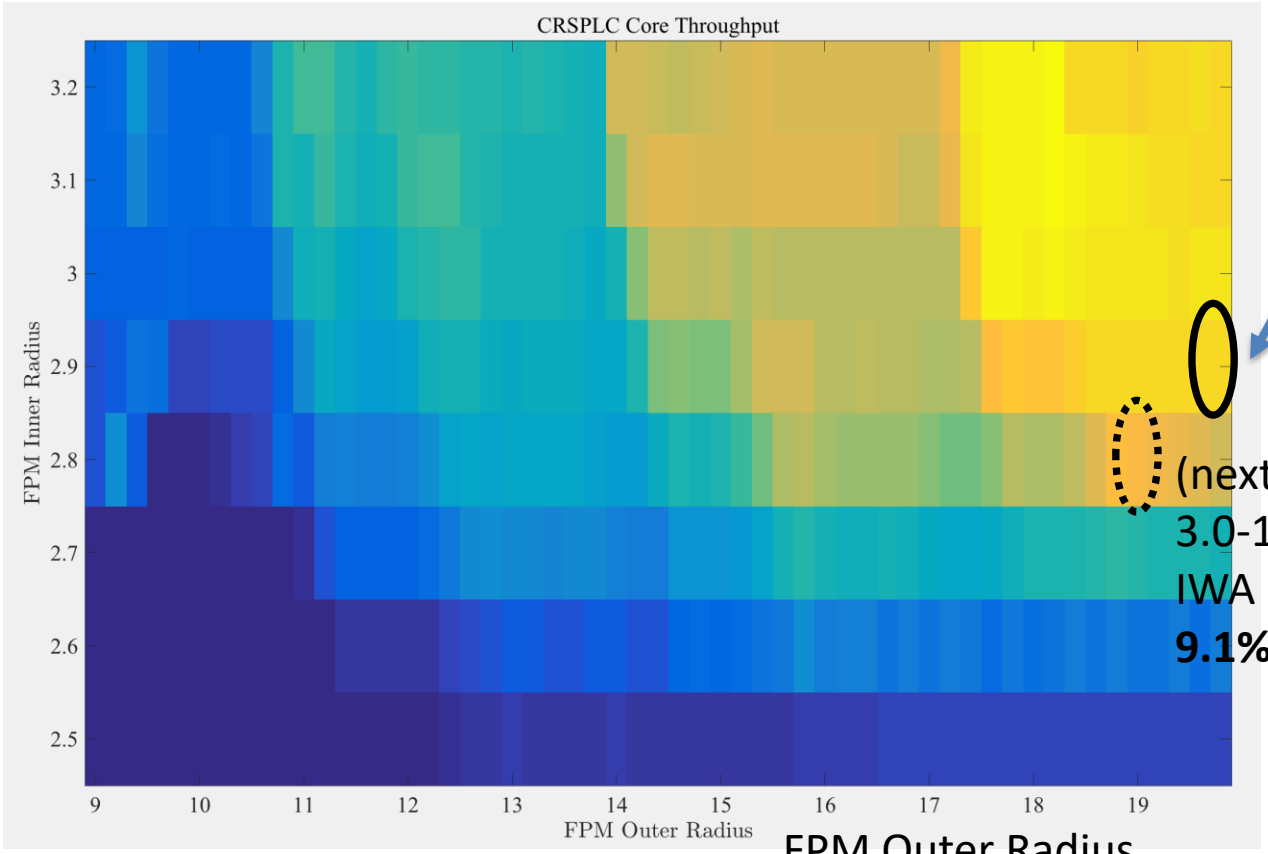
- DM(A)VC, DMSPLC, DM(AP)LC, HLC

1-D SPLC

Pupil	DM1	DM2	Shaped Pupil	FPM	Lyot Stop	PSF
	flat	flat				

4 x 10^{-10} contrast
9.6% throughput
IWA=3.1
OWA=19.7

First step: Perform extensive grid search of 1-D optimizations (~1e6 designs)

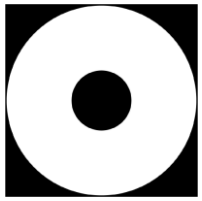
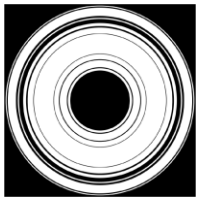
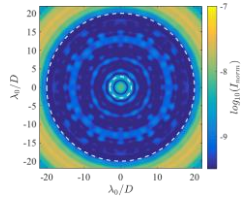


FPM Inner Radius

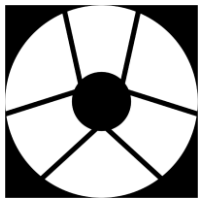
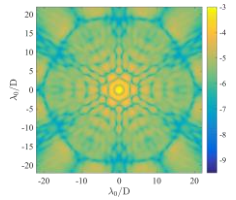
FPM Outer Radius

(next design to try:
3.0-18.5 lambda/D
IWA & OWA,
9.1% core throughput)

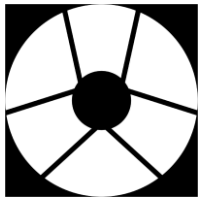
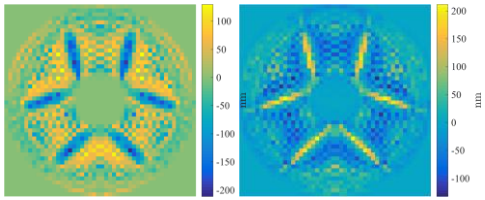
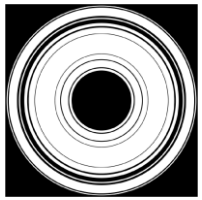
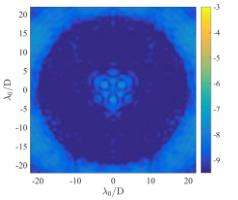
DM-SPLC for WFIRST

Pupil	DM1	DM2	Shaped Pupil	FPM	Lyot Stop	PSF	
	flat	flat					4 x 10^{-10} contrast **9.6% throughput** IWA=3.1 OWA=19.7

First step: Perform extensive grid search of 1-D optimizations.

	flat	flat					5 x 10^{-6} contrast **7.5% throughput**

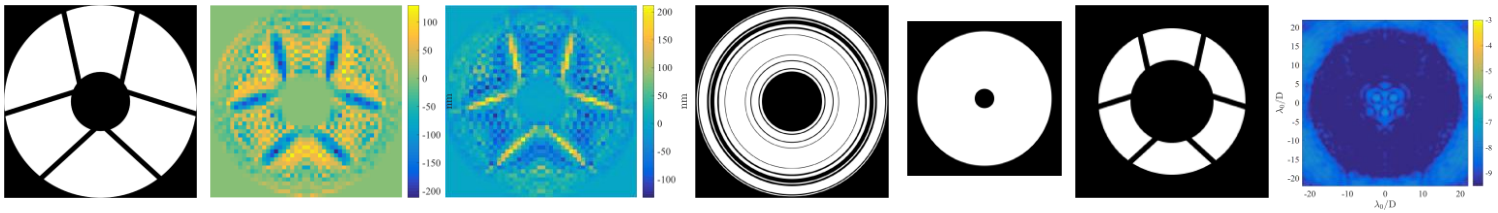
Second step: Include struts in pupil and add to Lyot stop.

 							4 x 10^{-10} contrast **5-6% throughput** IWA=3.1 OWA=19.7

Third step: Use DMs to suppress diffraction from struts.

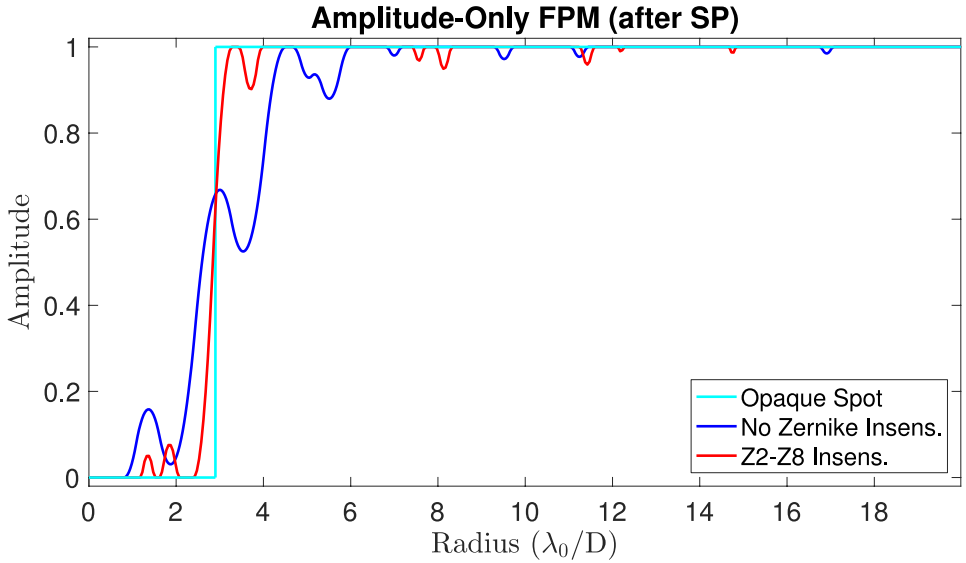
DMs apodize the struts more efficiently than the shaped pupil mask
- ➢ Better achievable throughput, IWA, and/or contrast

Designing in Sequential, Small Steps



4×10^{-10} contrast
4-6% throughput
IWA=3.1
OWA=19.7

Next Step: FPM Optimization



<u>1-D Optimizations:</u>

- Optimize apodizer and FPM simultaneously.
- Numerically constrain contrast while including low-order Zernike aberrations.
- Fast surveys.

Summary

- Apodizers need to be very robust to alignment error
  - Use apodizer only for primary and secondary mirrors
  - Use DMs to handle struts and segment gaps
- Break big nonlinear problem into (small, linear, or 1-D) problems.
- Very fast relinearization is critical for DM-integrated coronagraph designs

Backup Slides