Jet Propulsion Laboratory
California Institute of Technology

Shaped Pupil Coronagraph Design Updates for the WFIRST CGI

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Outline

Previous Findings (March 2017):

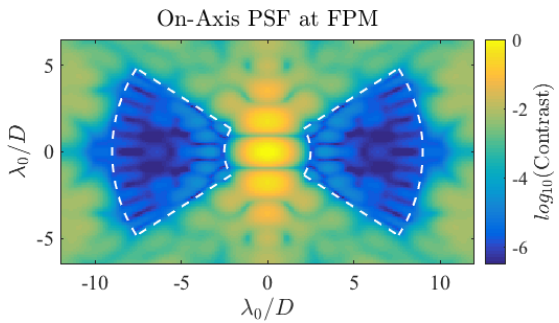
- Tried different **FPMs** (occulting bowtie or spot)
  - Higher throughput
  - Terrible tip/tilt sensitivities → *Kept old design*

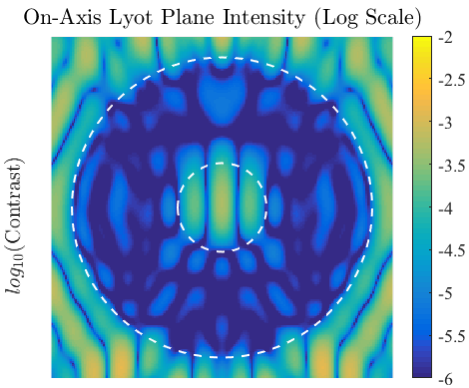
SPC-IFS Design Developments (April-June 2017):

1. Better **Lyot stop** shape → higher throughput and contrast
2. Better low-order **aberration sensitivities** (esp. tip/tilt)
3. Have to block outer 1% of telescope diameter
4. Made a design pipeline

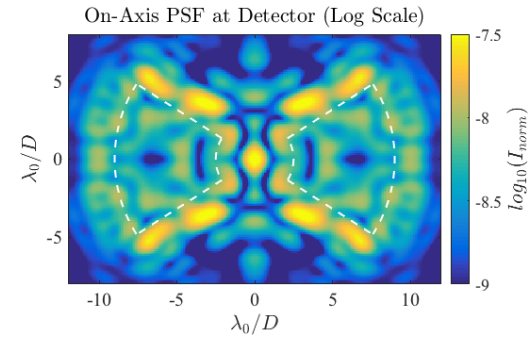
SPC-IFS Design (2015-2016)

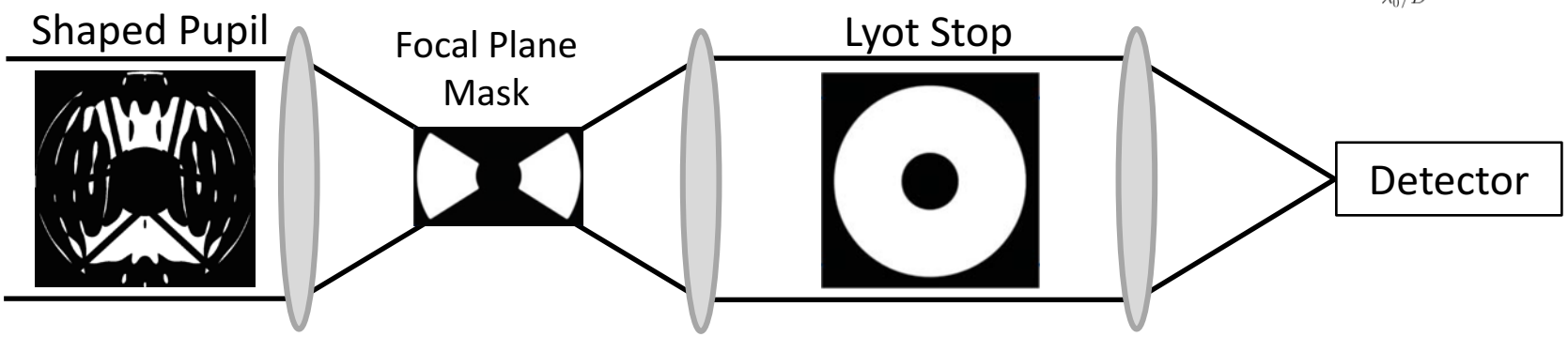
On-Axis Starlight *(Log Scale)*





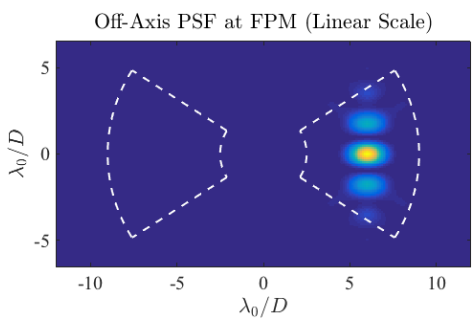
5 x 10^{-9} raw contrast

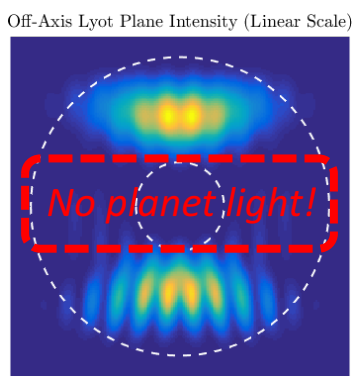


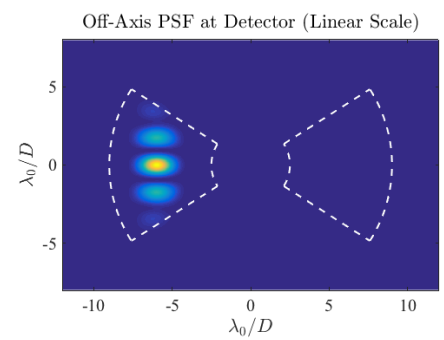


3.6% core throughput

Off-Axis Planet Light *(Linear Scale)*



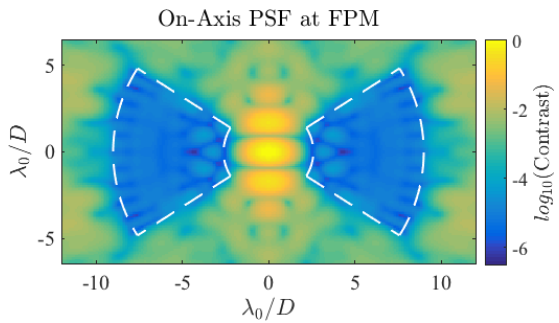


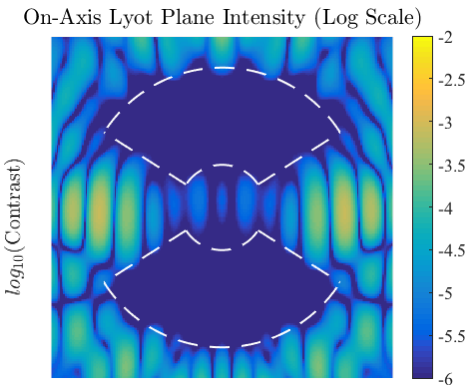


Zimmerman, Riggs, et al. 2016

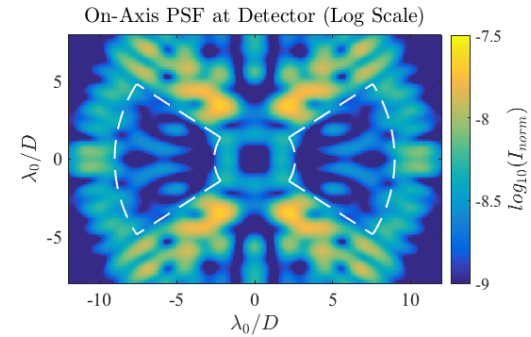
SPC-IFS Design (June 2017)

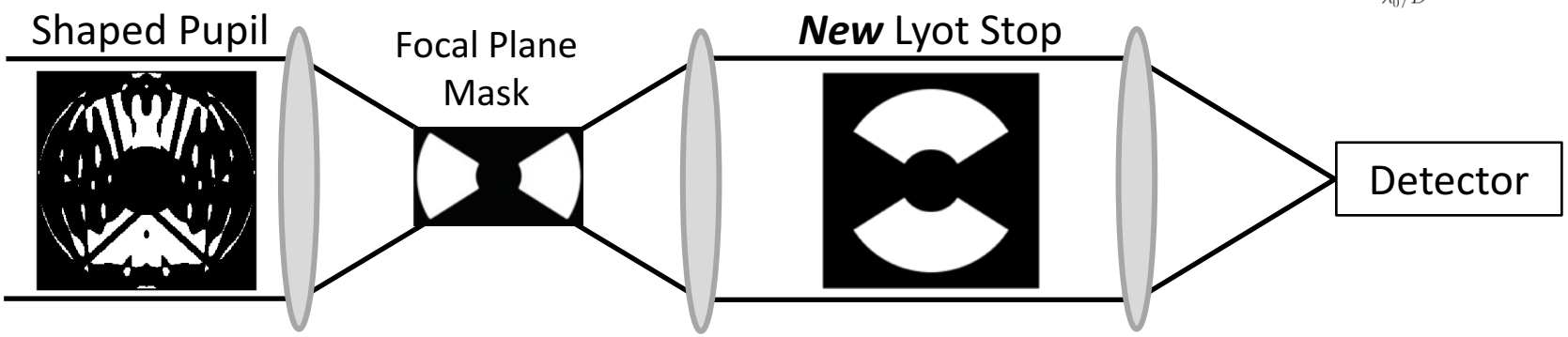
On-Axis Starlight *(Log Scale)*





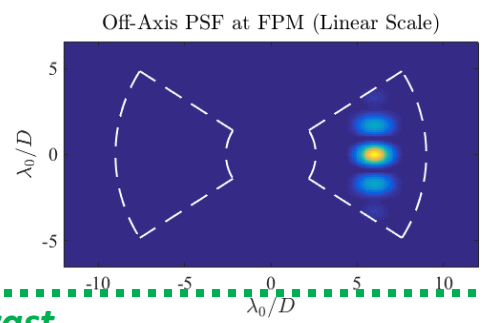
1 x 10^{-9} raw contrast

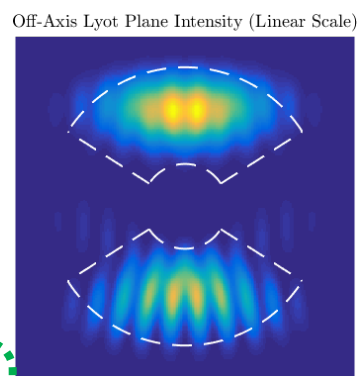


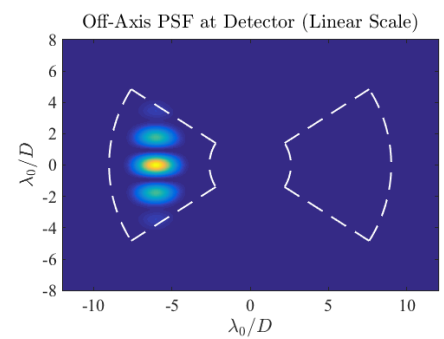


3.8% core throughput

Off-Axis Planet Light *(Linear Scale)*







- ***Better raw contrast***
- ***Better throughput***
- ***Same/Better low-order aberration sensitivities***

Choosing the Best Design

We now have flexibility with design parameters.

Q: How do we choose best balance of

- raw contrast
- throughput
- low-order aberration sensitivities?

→ **Design survey** to **maximize science yield**

SPC-IFS Design Pipeline

1) SPLC-IFS Optimization Code

Grid search over design variables.

Python wrapper

AMPL base code

Masks from each design

2) Rapid Optical Simulator (MATLAB)

Simulate effects of:

1) **Tip/tilt**: jitter and stellar size
2) **Polarization** aberrations (Phase A model).
3) [*Soon*] Realistic **Fresnel** model. **Monte Carlo**:
   1) Unknown **misalignments**
   2) **PSD aberration maps** for each optic

Tables: Raw contrast, throughput, core area

3) Bijan's RV Planet Exposure Time Calculator (MATLAB)

Vary input assumptions.

Exposure times & # of Spectra

4) Human Review

- Look for highest yield designs.
  - Robust to different assumptions.
- Adjust strategy to get spectra that are missed.

Optimization code modifications

SPC-IFS Design Pipeline: Output

(Optimistic Case)

Assumptions: $\sigma_{T/T\ RMS}$ = **0.5** mas, D_{star} = 1.0 mas,
both polarizations, <=240 hours/spectrum/bandpass
f_{pp} = **0.1**

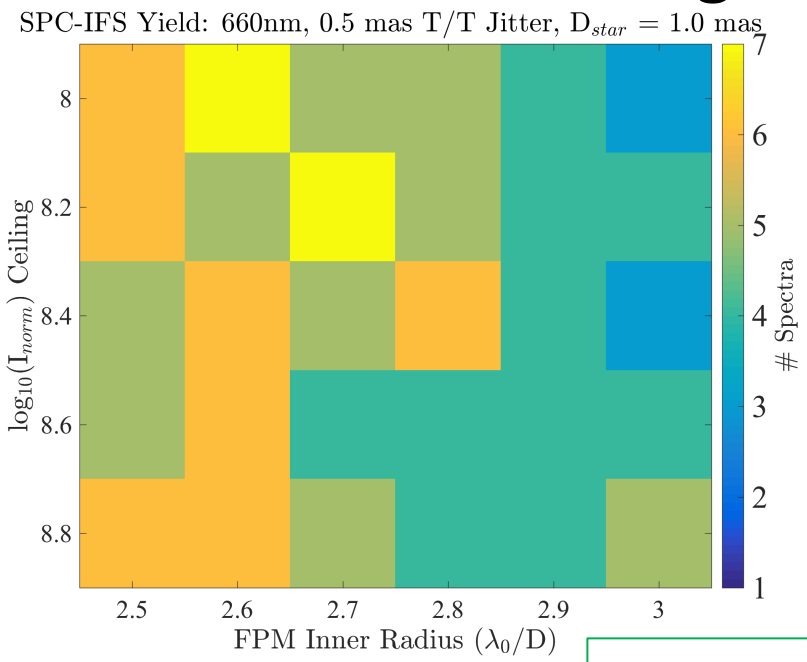
2016 Design (Annular Lyot Stop):

(Telescope OD not reduced)

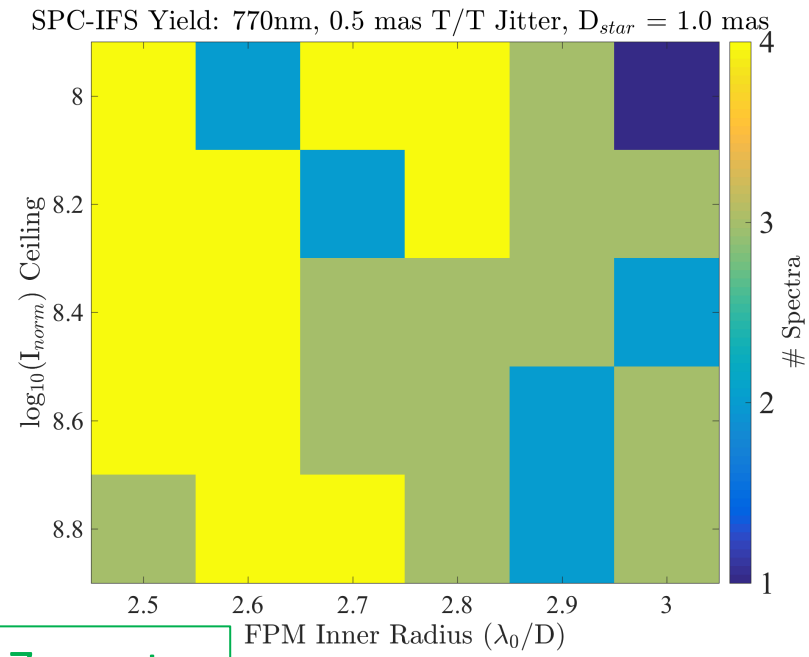
660 nm: <4 spectra
770 nm: <3 spectra

June 2017 Design Survey (Bowtie Lyot Stop):

(prop. to Contrast)



(~= IWA – 0.3)



660 nm: <=7 spectra
770 nm: <=4 spectra

SPC-IFS Design Pipeline: Output

Assumptions: $\sigma_{T/T\ RMS}$ = **1.5** mas, D_{star} = 1.0 mas,
both polarizations, <=240 hours/spectrum/bandpass
f_{pp} = **0.2**

(**Pessimistic** Case)

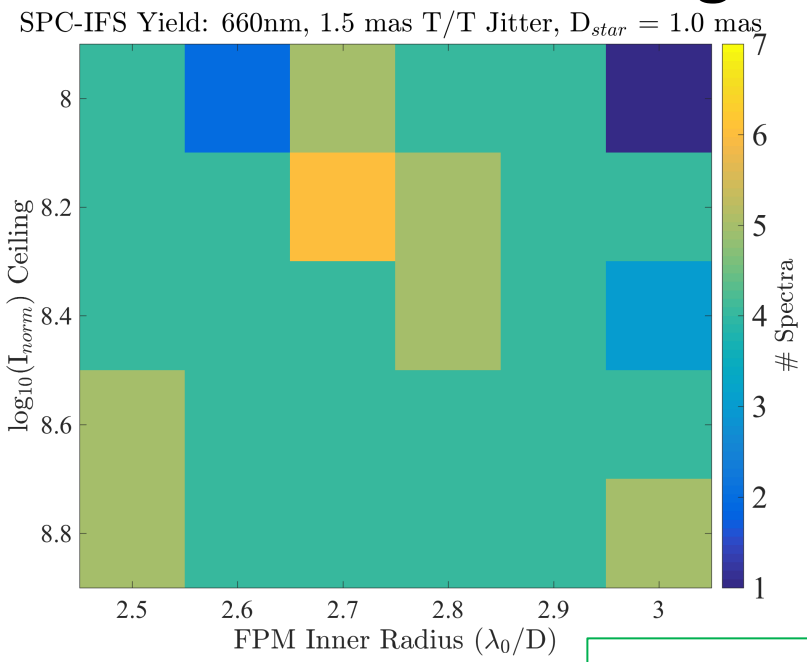
2016 Design (Annular Lyot Stop):

(Telescope OD not reduced)

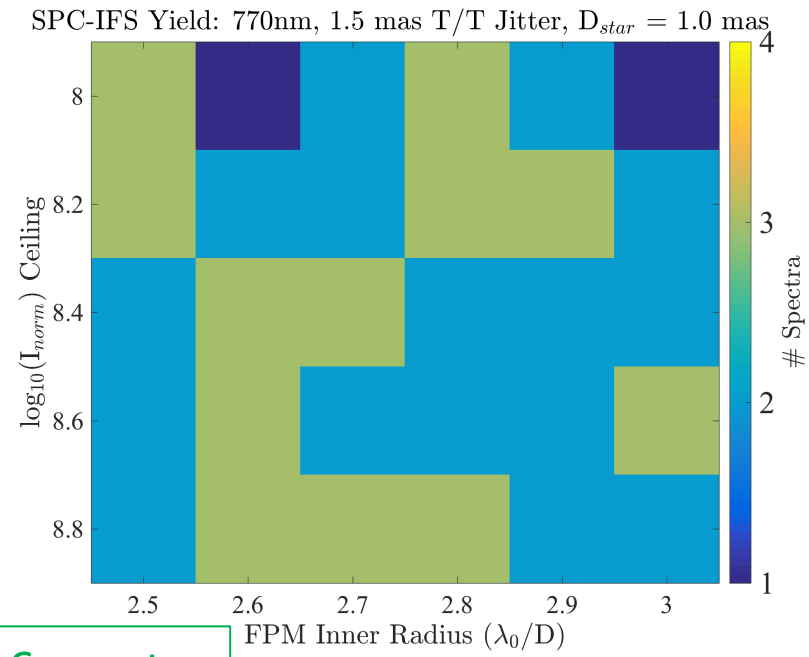
660 nm: <3 spectra
770 nm: <1 spectra

June 2017 Design Survey (Bowtie Lyot Stop):

(prop. to Contrast)



(~= IWA – 0.3)



660 nm: <=6 spectra
770 nm: <=3 spectra

Summary

1. **Same/Better** low-order aberration sensitivities
   - Now **directly suppressing tip/tilt** (T/T)
   - Direct tradeoff: throughput vs T/T insensitivity

2. **New Lyot Stop Shape**
   - **Better** throughput *(mostly negated by telescope OD being blocked)*
   - **Better** raw contrast

   - (Tentative) New Yield Estimate:
     - **~6** spectra @ 660nm
     - **~3** spectra @ 770nm

Next Steps

1. **Fine tune design pipeline**
   - Small improvements to AMPL optimization code
   - More thorough grid search
   - Vary exoplanet albedo assumptions

2. **Improve design pipeline fidelity**
   - Add Fresnel model & Monte Carlo to make pipeline more accurate

3. Explore **other, higher-performing design** options
   - Re-try higher throughput FPM designs from March
     - Include tip/tilt sensitivity in the optimization.
     - Put into same design pipeline.