Phase Retrieval Implementation for the WFIRST Coronagraph Development Testbed

David Marx and Brian Kern

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91009

David.S.Marx@jpl.nasa.gov

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Outline

- 1. Describe the coronagraph
- 2. purpose of phase retrieval
- 3. algorithm of phase retrieval
- 4. results – examples
- 5. conclusion, acknowledgement

WFIRST Mission Objectives

WFIRST = **W**ide-**F**ield **I**nfrared **S**urvey **T**elescope

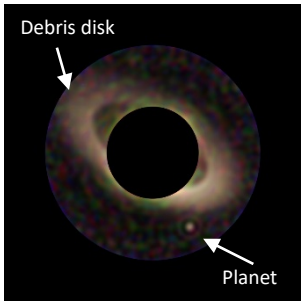
Science Objectives:

Precursor science for Exoplanet Missions

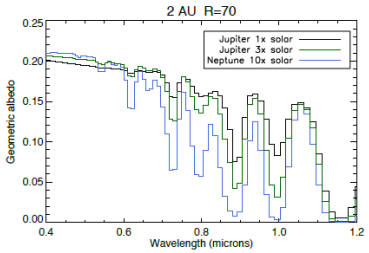
- Characterize the history of cosmic acceleration and structure growth
- Understand how planetary systems form and evolve and determine the prevalence of planets in the colder outer regions
- Demonstrate technology for characterization of atmospheres down to Jupiters around nearby stars
- Characterize debris disks around nearby stars

The Instrument

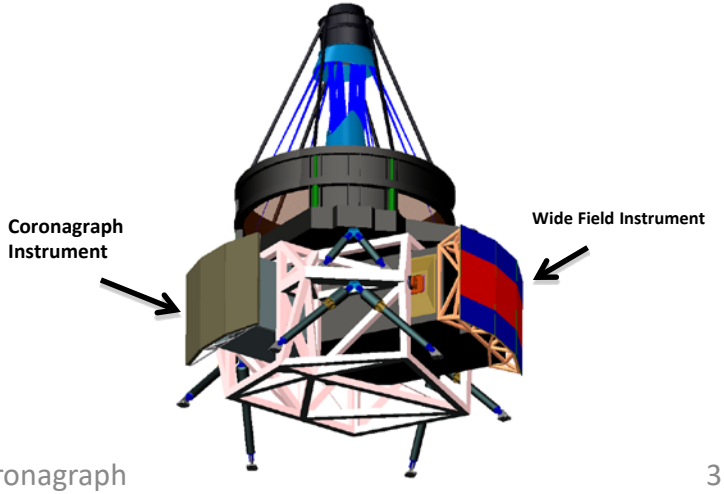
- CGI advances a number of new technologies:
  - Novel coronagraph masks (shaped pupil coronagraph and hybrid Lyot coronagraph)
  - Precision wavefront sensing and control with 2 deformable mirrors (Xinetics)
  - Ultra-low noise detector



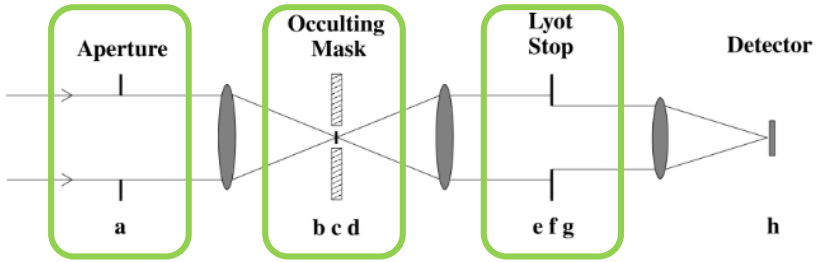
Exo-planet
Direct imaging



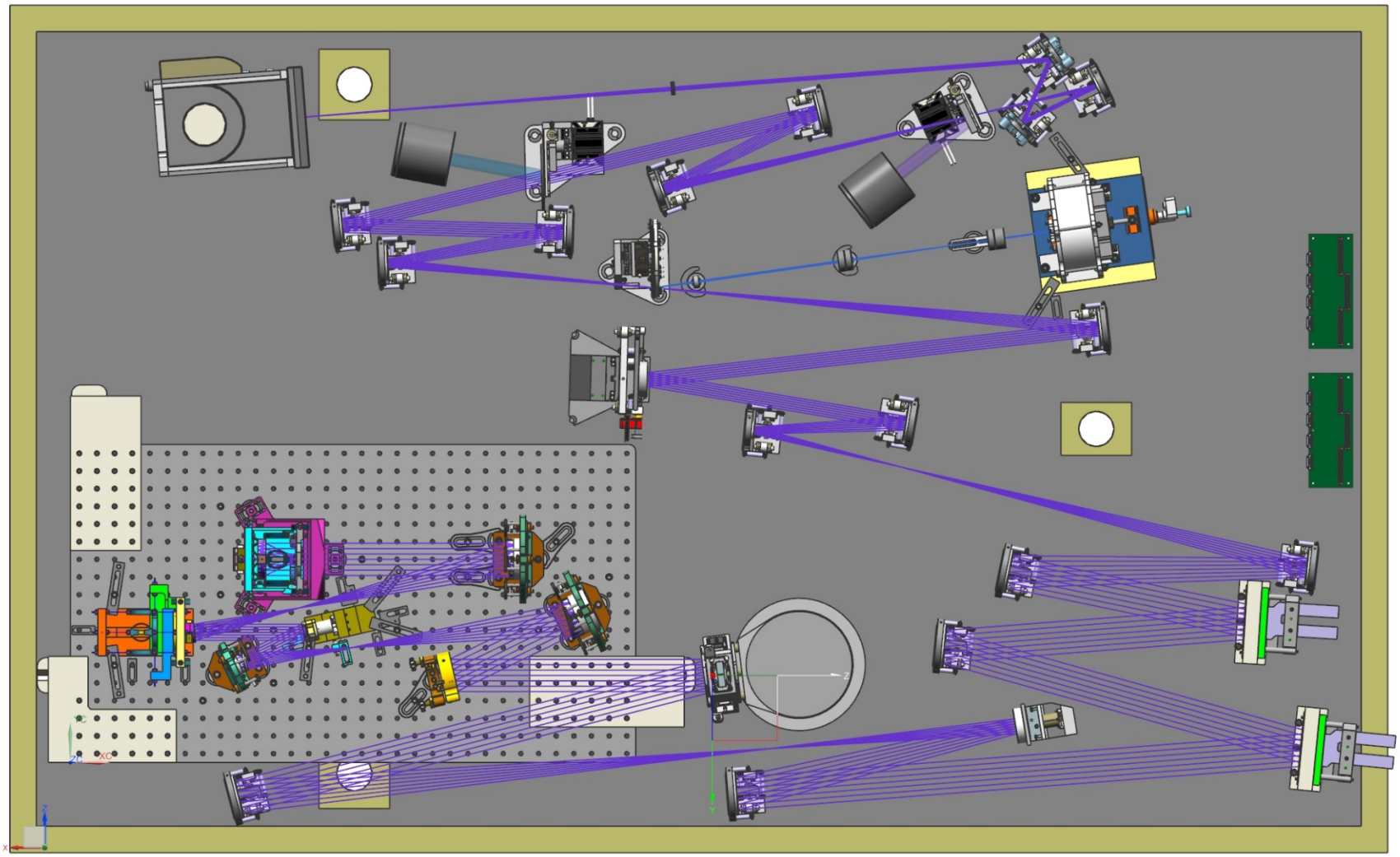
Exo-planet
Spectroscopy



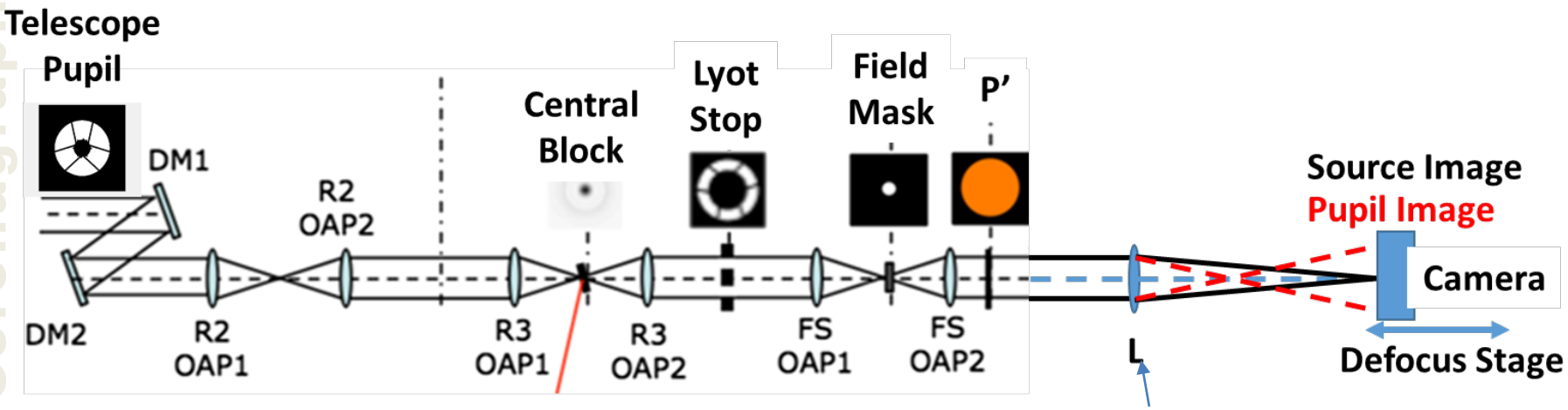
Canonical Coronagraph



Coronagraph Testbed



Model Layout for Phase Retrieval



Motorized Swap:

- Lens to Image Source
- Lens to Image Pupil

Purpose of Phase Retrieval

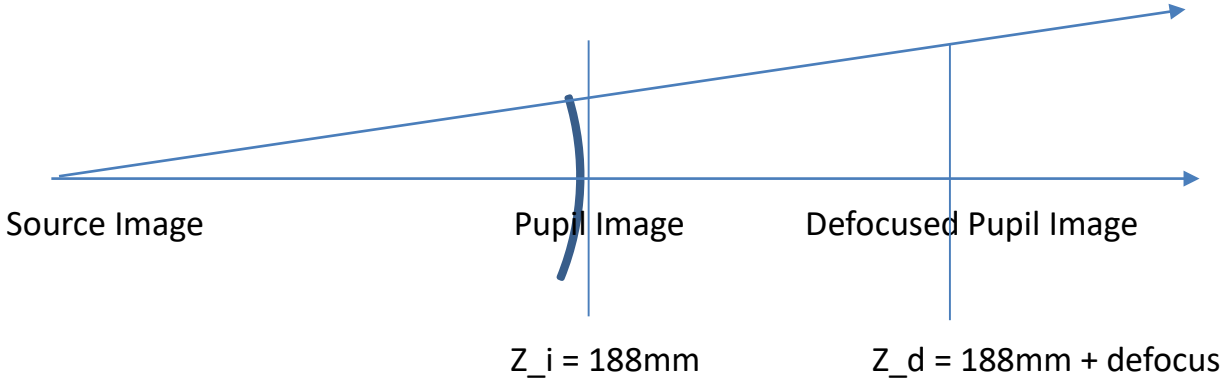
Uses of Phase Retrieval:

- Evaluate Pupil Wavefront Error
- Evaluate Deformable Mirror Operation
  - Gain
  - Actuator Registration
- Alignment of:
  - Telescope Pupil
  - Deformable Mirror
  - Lyot Stop
- Initial Deformable Mirror Settings

Algorithm

- 1. Load Pupil Images, Subtract Dark, Select Best Focus Pupil Image
  - Scaled and Flipped Pupil Image => Pupil Amplitude Reference
- 2. Load Source Images, Subtract Dark, Center & Crop
- 3. Select Best Focus Source Image
- 4. Parametric Fit of Propagated Pupil Reference * Phase(Zernikes)
  to Best Focus Source Image
  - Done in several steps of increasing Zernike Order
- 5. Select Several Source Images, Starting with Fit Pupil, Iterate Propagation to Each Source Image, Enforcing Amplitude Constraint

Pupil Image Propagation

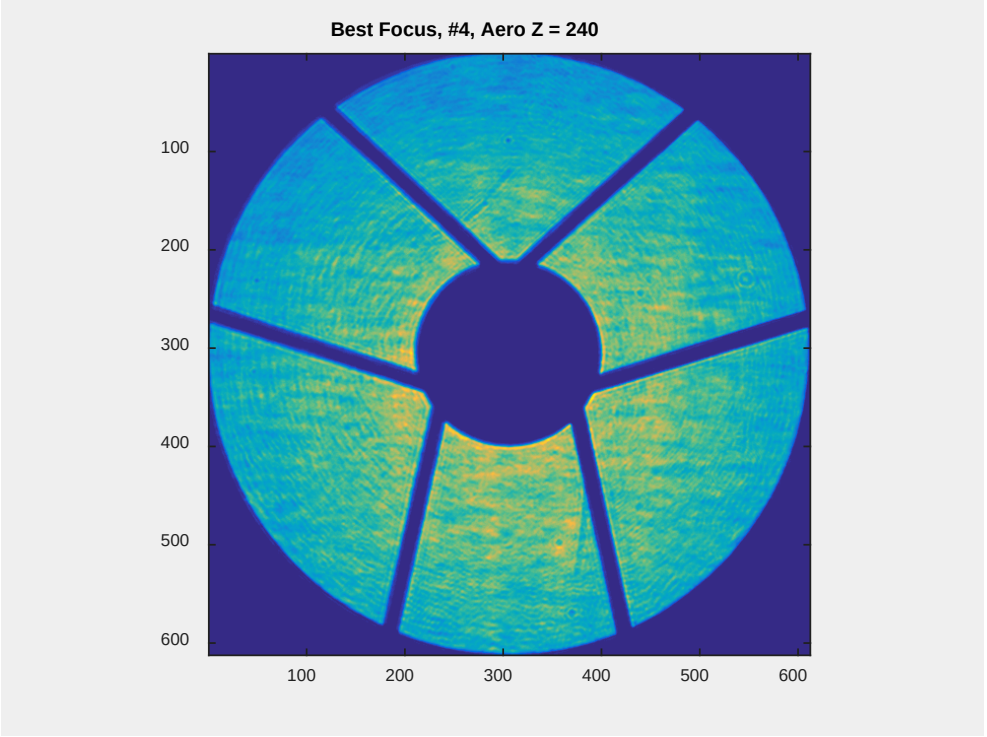


Fresnel Propagation from Pupil Image to Defocused Pupil Image:

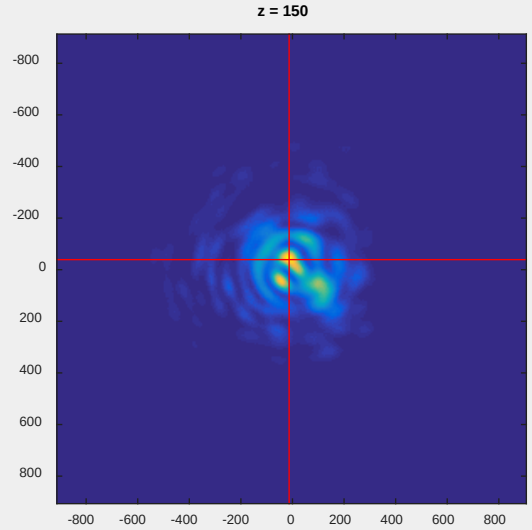
$$E(z_d) = Fr\left\{e^{-j\frac{\pi}{\lambda z_i}r^2}\ E(z_i);\ z_{defocus}\right\} e^{j\frac{\pi}{\lambda z_d}r^2}$$

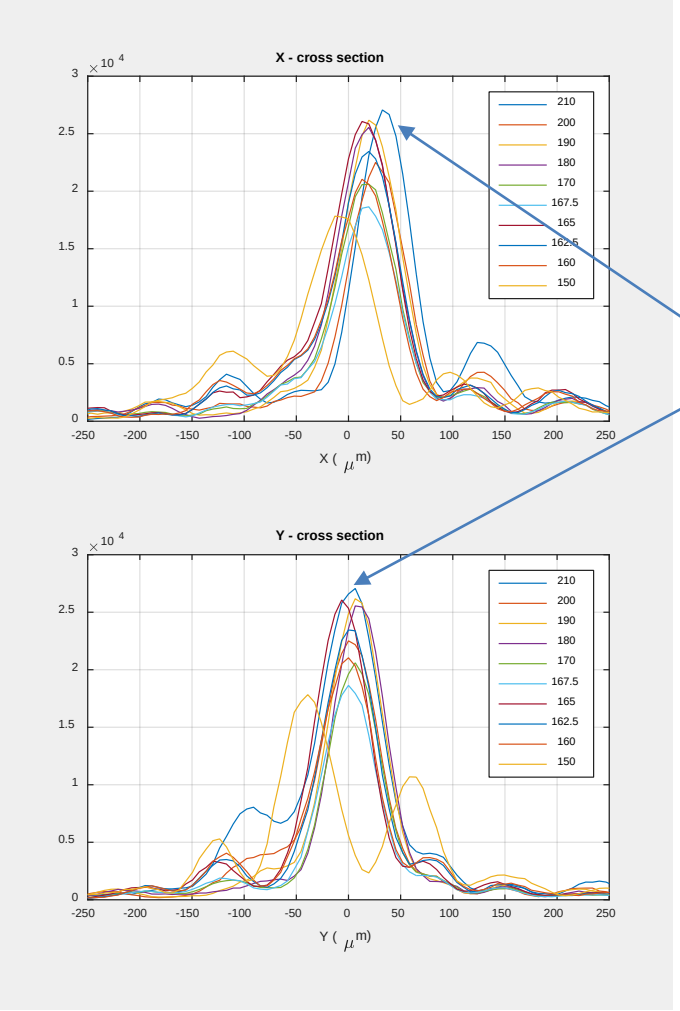
Parametric Fitting of Source Images

- Reference Pupil is Scaled & Flipped Image of Pupil:



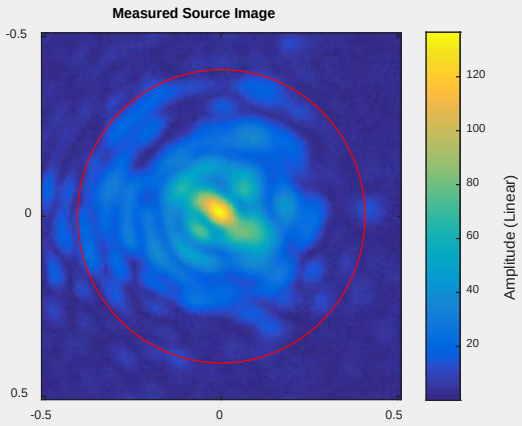
- Crop and Center Source Image

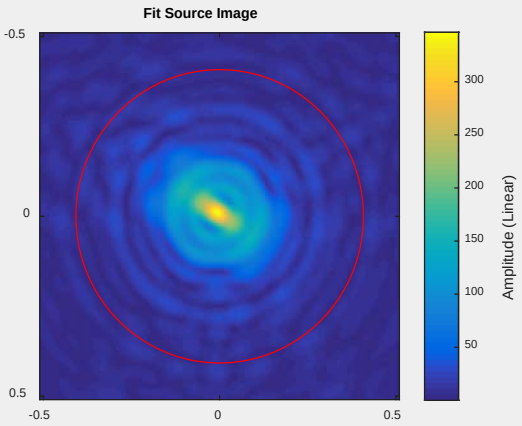


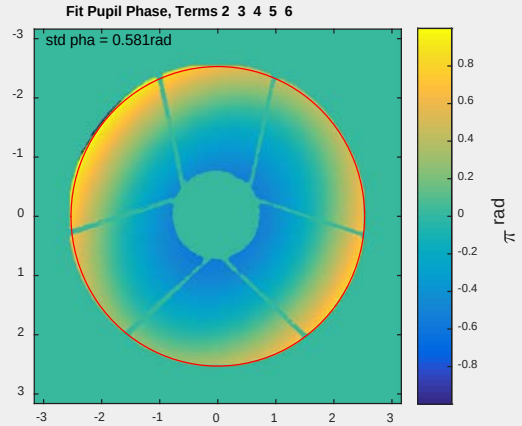


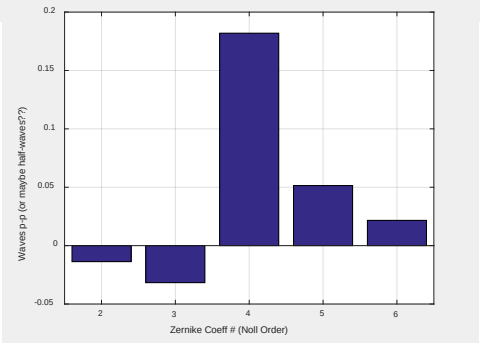
Best Focus:
Z = 167.5

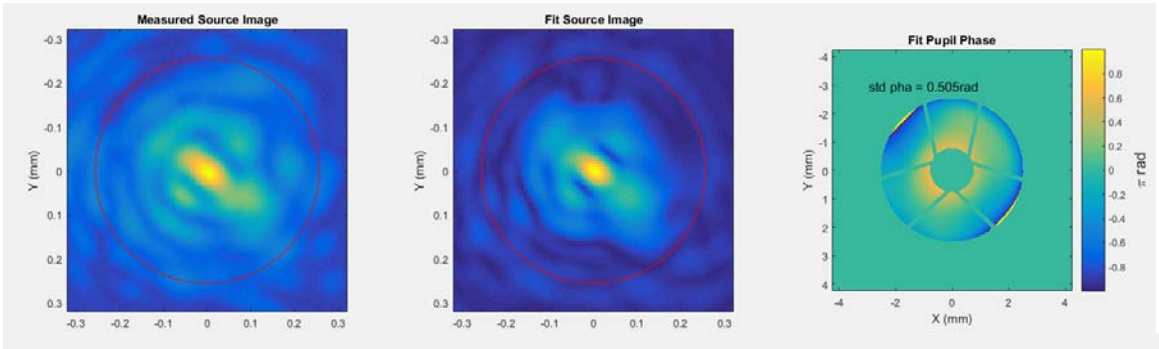
- Fit Low Order Zernike Pupil Phase to Match Calculated and Measured Source Image

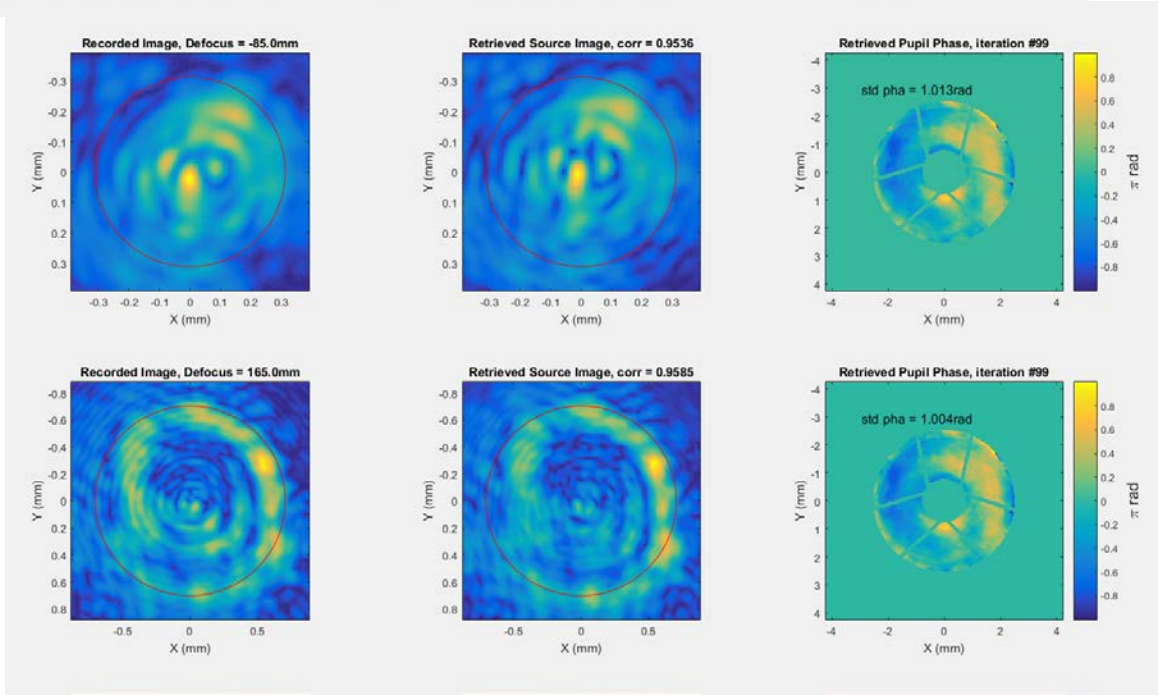









Measured Source Image
Fit Source Image
Fit Pupil Phase
std pha = 0.505rad
Y (mm)
X (mm)
π rad


Recorded Image, Defocus = -85.0mm
Retrieved Source Image, corr = 0.9536
Retrieved Pupil Phase, iteration #99
std pha = 1.013rad
Recorded Image, Defocus = 165.0mm
Retrieved Source Image, corr = 0.9585
Retrieved Pupil Phase, iteration #99
std pha = 1.004rad
Y (mm)
X (mm)
π rad

Conclusions and Summary

- The WFIRST Coronagraph Testbed Design Produces Images of the Source and the Pupil.
- Defocused Images Were Used for Phase Retrieval.
- Phase Retrieval Accurately Measured Wavefront Error at the Pupil of the Coronagraph.