Proximity Glare Suppression for Astronomical Coronagraphy (S2.01) and Precision Deployable Optical Structures and Metrology (S2.02)

Mirror Tech Days 2016
Greenbelt, MD

Nov 1, 2016

Stuart Shaklan

Jet Propulsion Laboratory

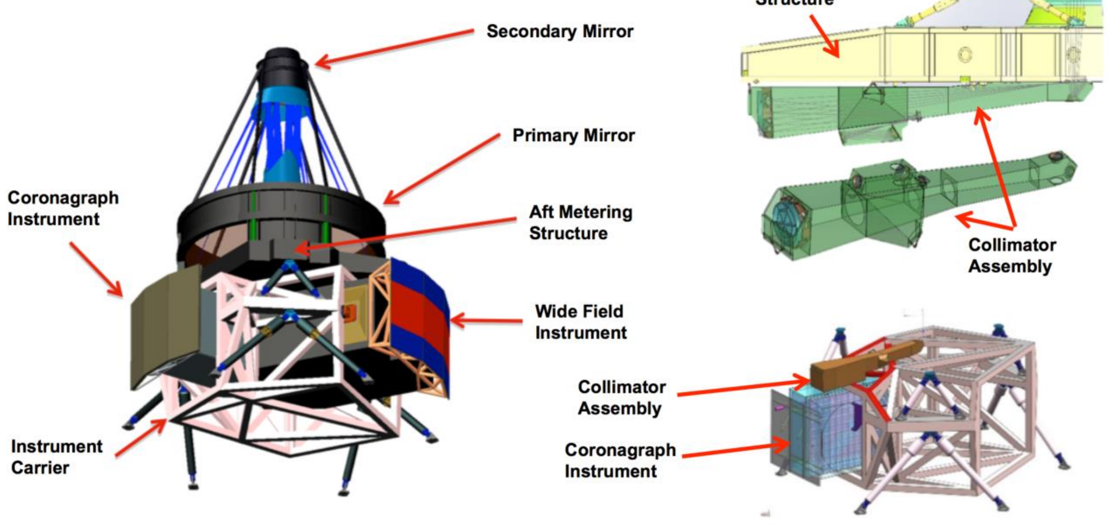
California Institute of Technology

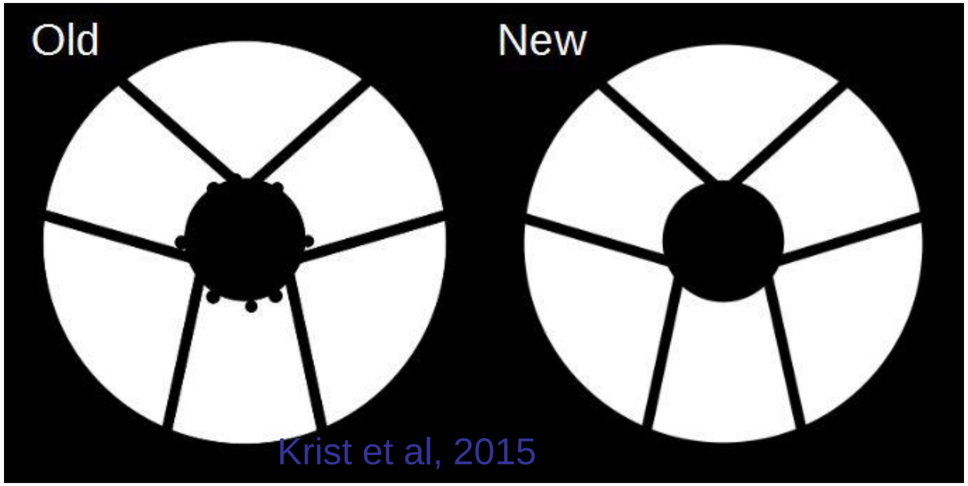
Overview

- High Contrast Imaging
  - State of the Art: coronagraphs and starshades
- S2.01 Subtopic Proximity Glare Suppression
  - Subtopic call
  - Subtopic Proposals
- S2.02: Precision Deployable Optical Structures and Metrology
  - Subtopic call
  - Subtopic Proposals

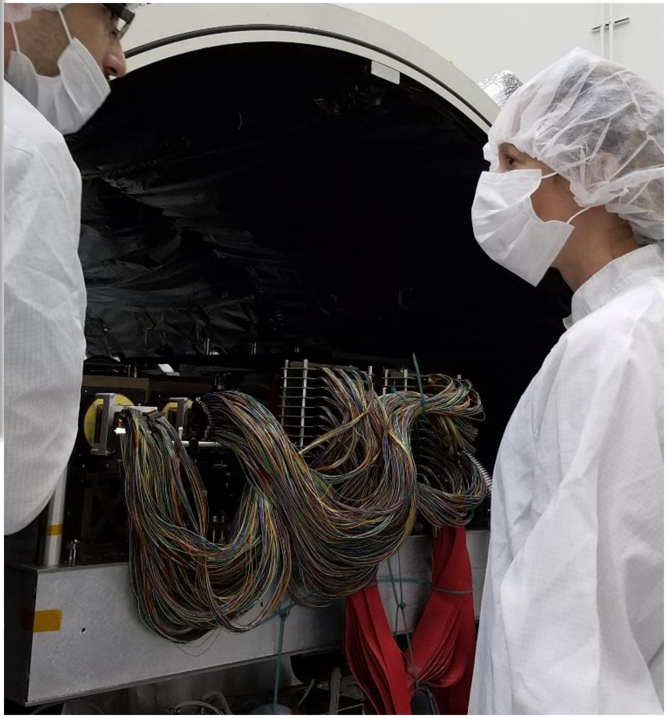
WFIRST/AFTA Coronagraph

Demers et al, 2015

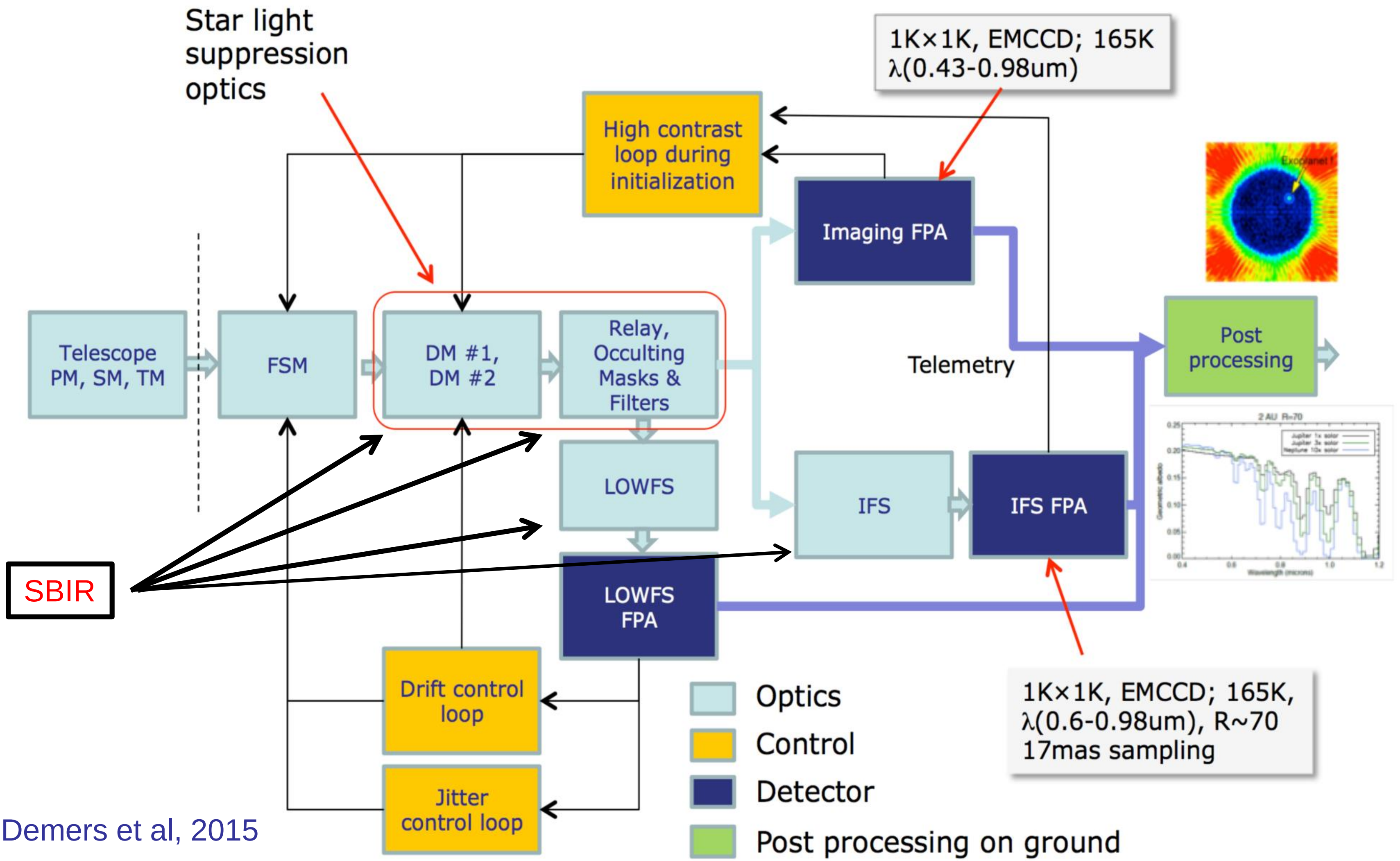




Krist et al, 2015



WFIRST/AFTA Coronagraph Schematic



Demers et al, 2015

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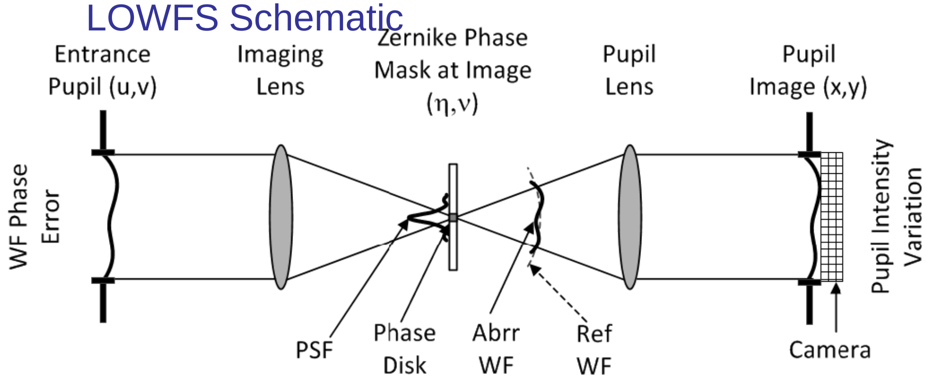
Low Order Wavefront Sensor

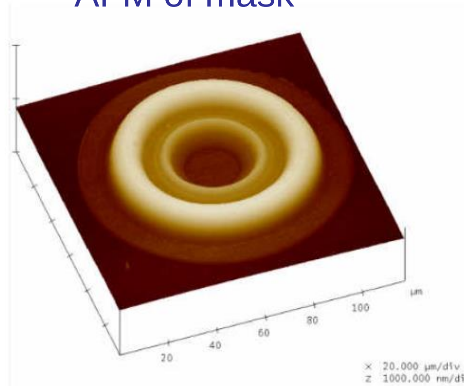
WFIRST Coronagraph **Milestone 6**

Low Order Wavefront Sensing and Control (LOWFS/C) subsystem provides pointing jitter sensing better than 0.4 mas rms per axis and meets pointing and low order wavefront drift control requirements.

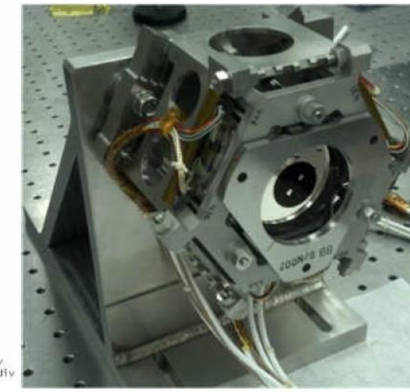
LOWFS Schematic



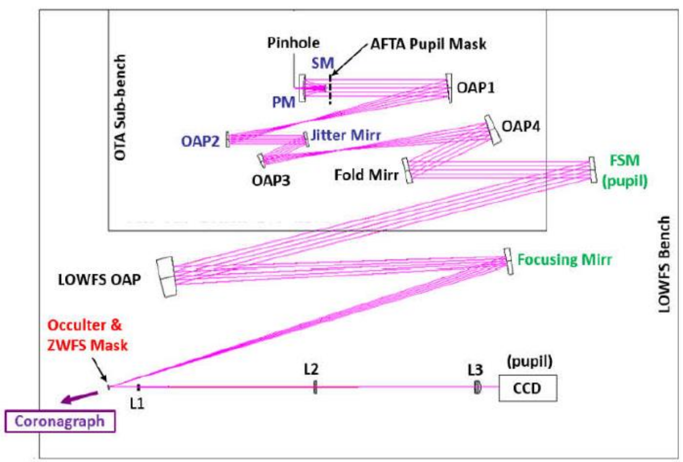
AFM of mask



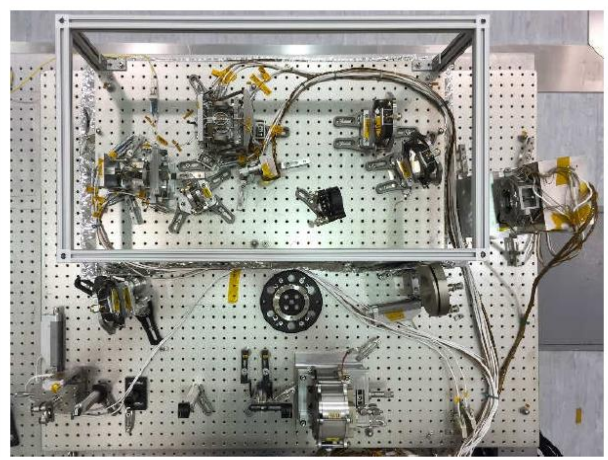
Tip-tlt mirror



LOWFS Layout



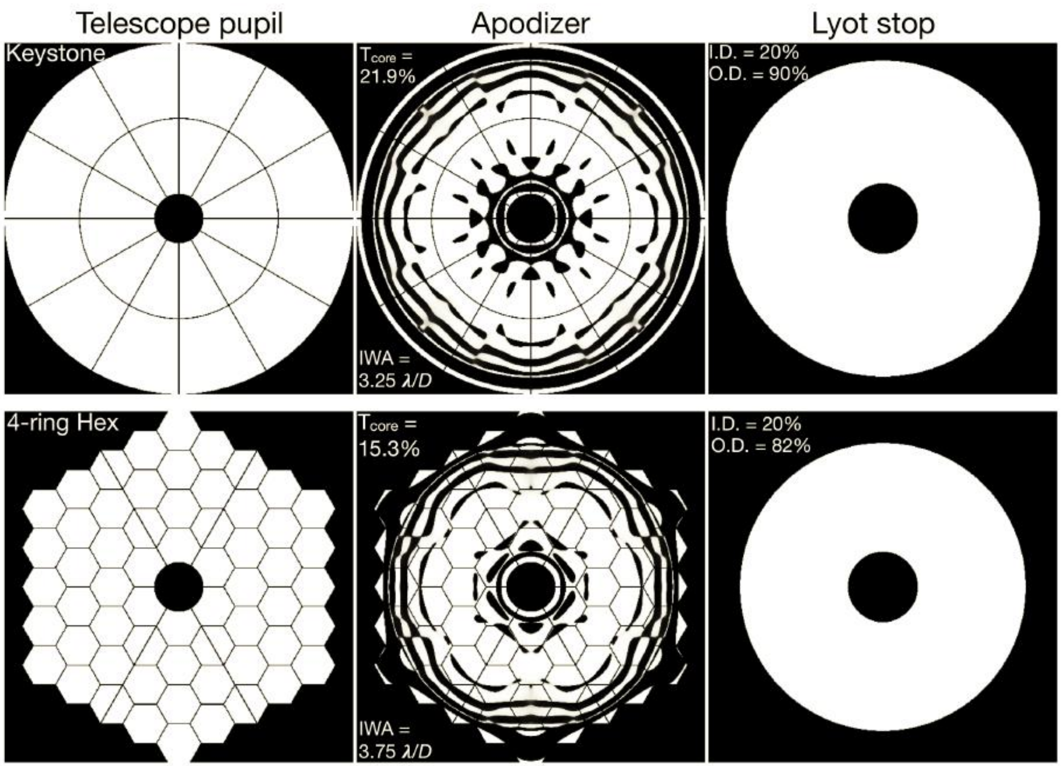
LOWFS Experiment

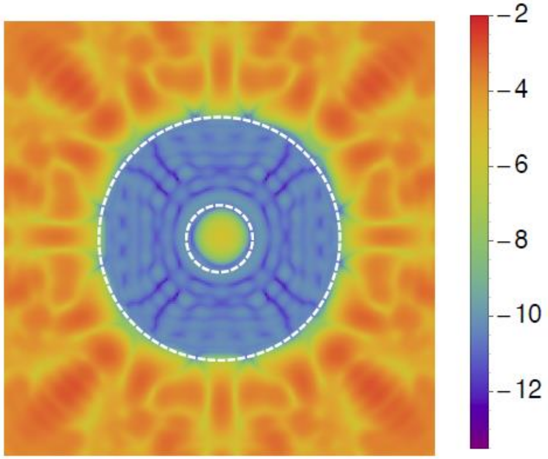


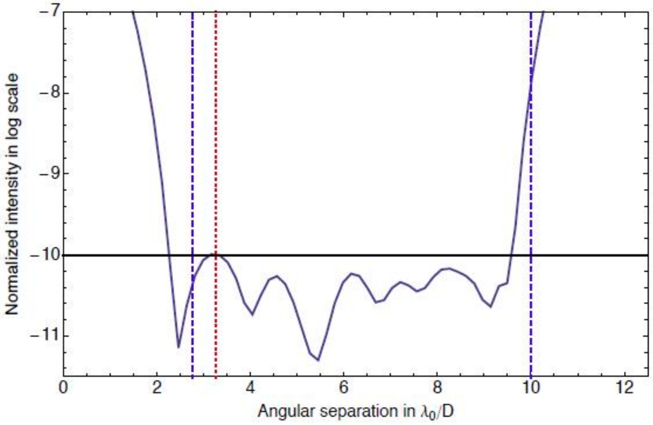
- F. Shi et al, "WFIRST Coronagraph Milestone 6 Final Report: Low Order Wavefront Sensing and Control."
  - http://wfirst.gsfc.nasa.gov/science/sdt_public/wps/references/WFIRST_CGI_Milestone6_Final_Report.pdf

Segmented Coronagraph Studies

Apodized Pupil Lyot Coronagraph



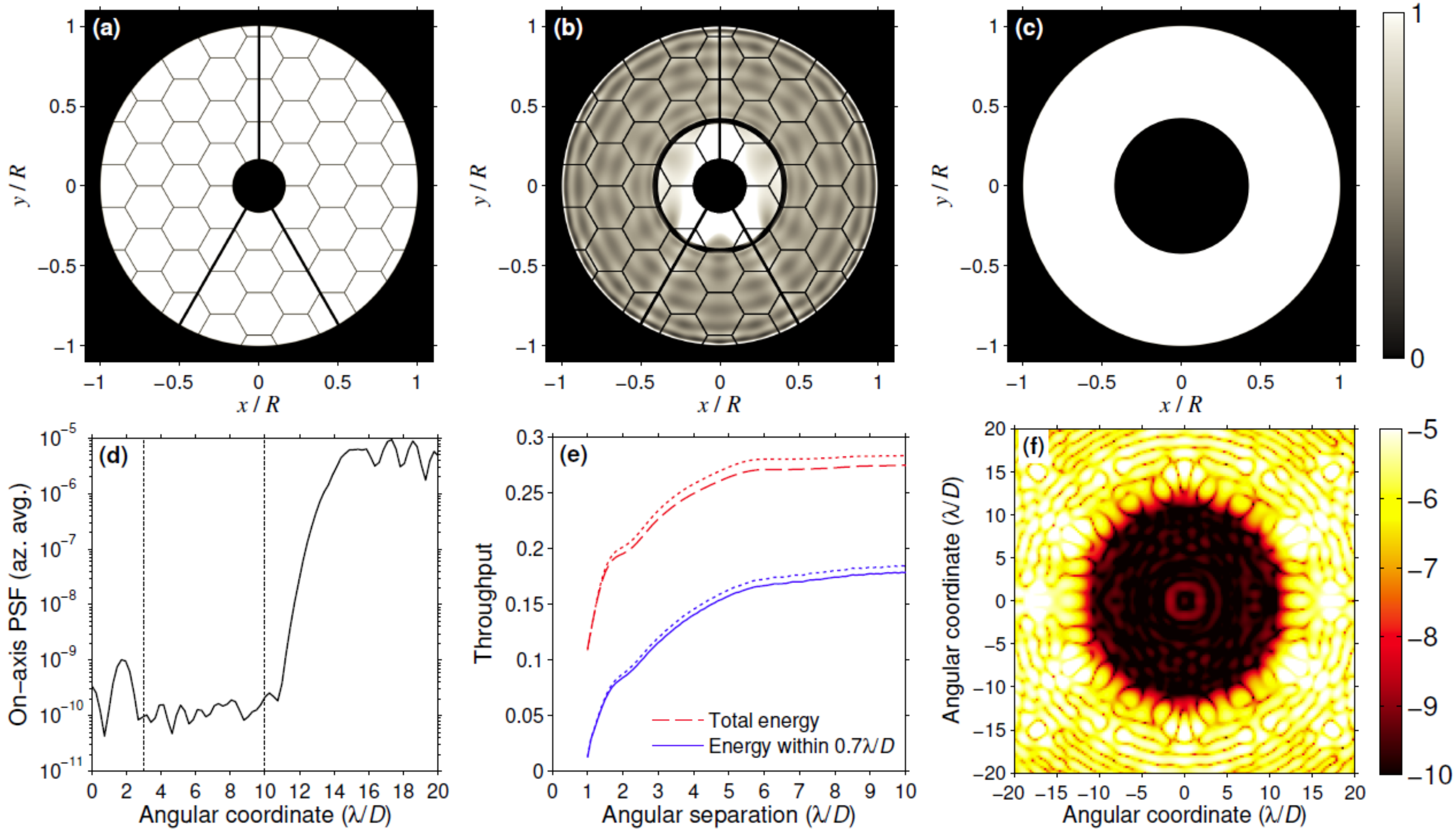




Zimmermann et al. (2016)

Segmented Coronagraph Studies

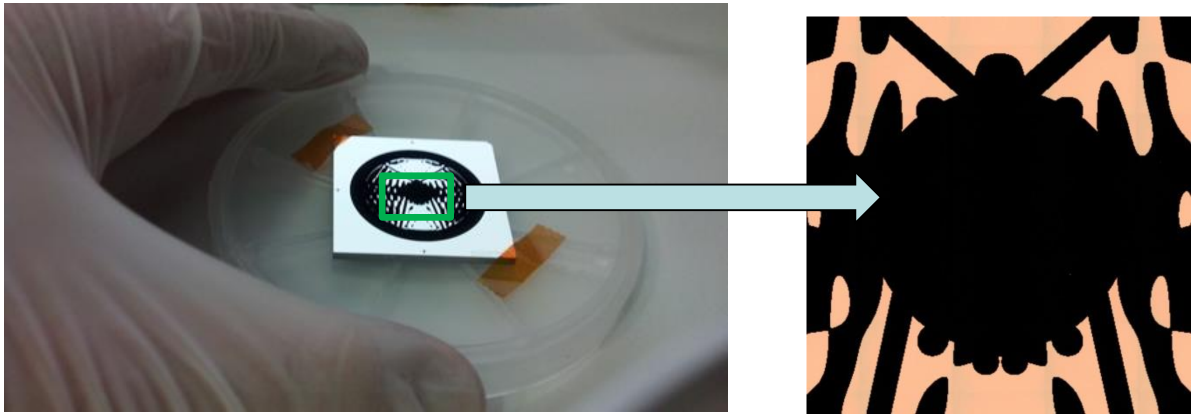
Vortex Coronagraph



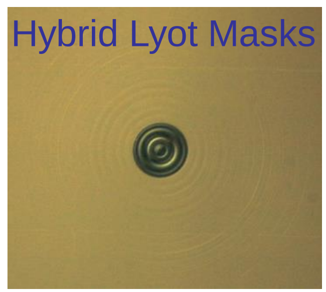
Ruane et al. (2016)

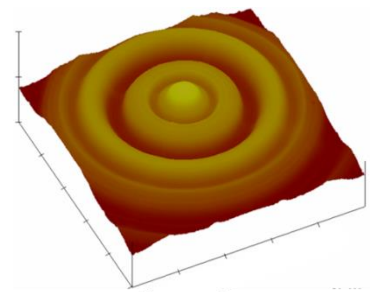
WFIRST/AFTA Coronagraph Technologies

Reflective Shaped Pupil Masks with Black Silicon AR surface

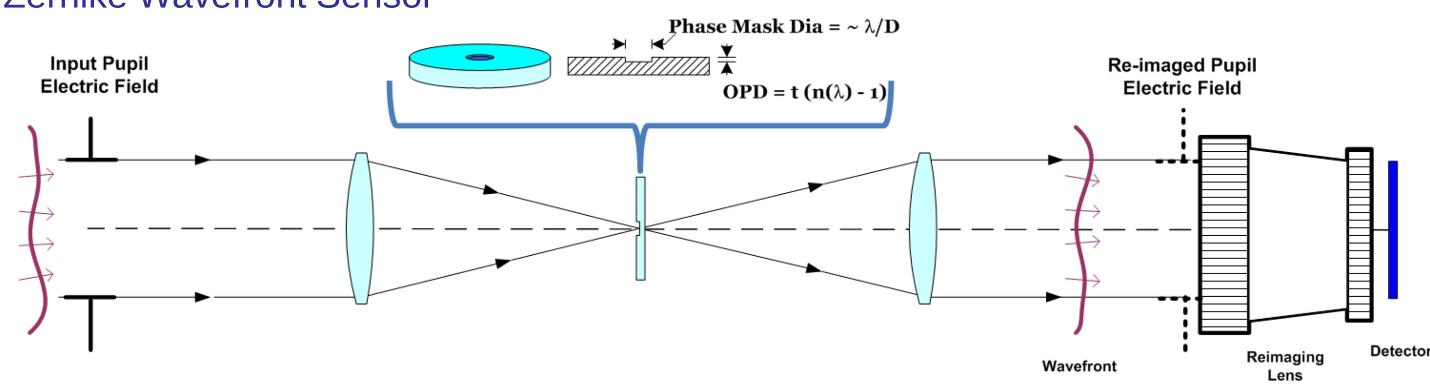


Hybrid Lyot Masks





Zernike Wavefront Sensor



WFIRST Telescope Joined by a Starshade

"WFIRST Rendezvous Mission" Complements Coronagraph, with sensitivity to discover Exo-Earths in the Habitable Zone

WFIRST will launch in the mid 2020's and will make high-resolution infrared images over 100x the field of HST.

2.4 m telescope

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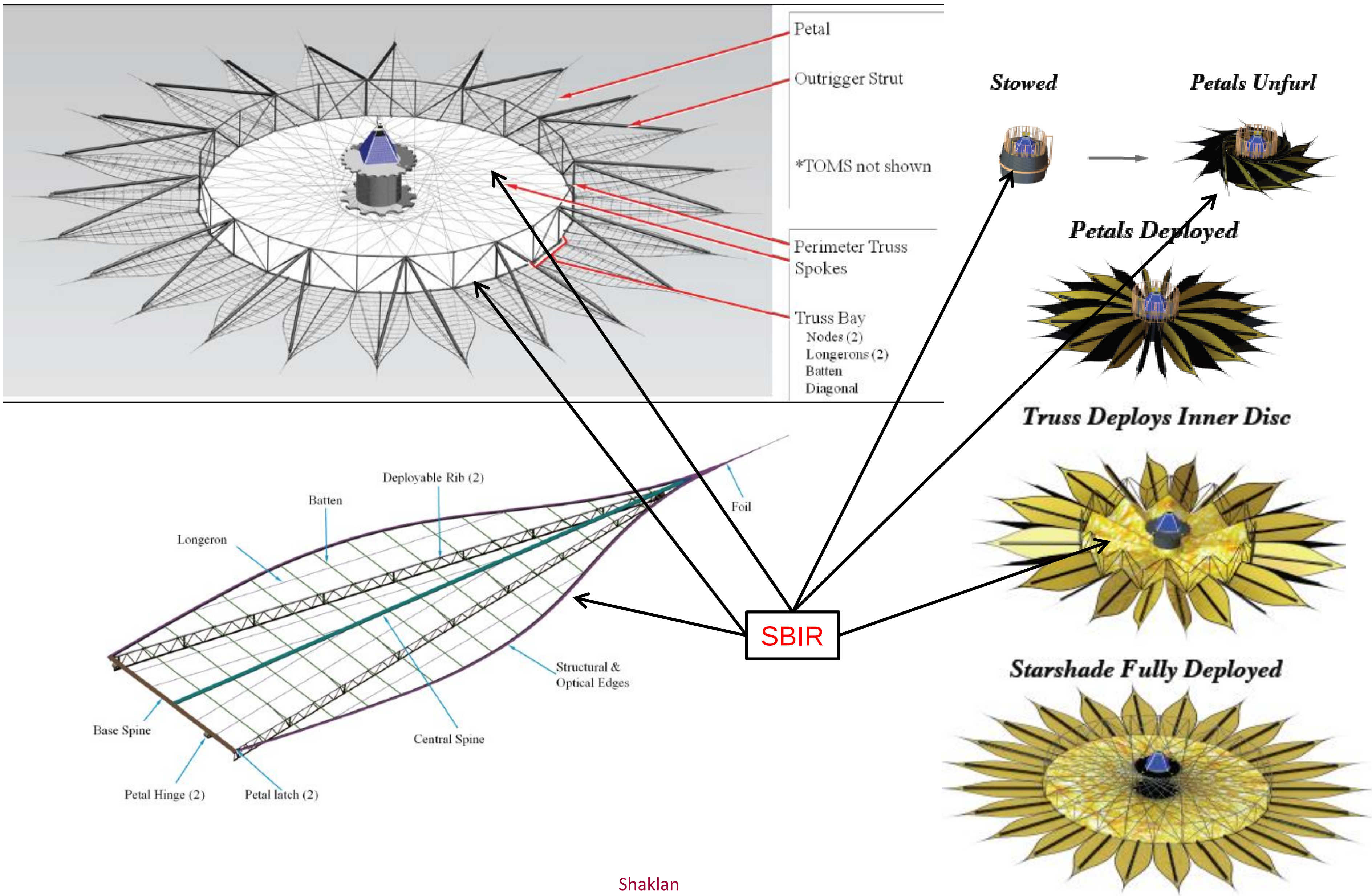
Starshade Construction and Deployment



Precision Full Scale Petals

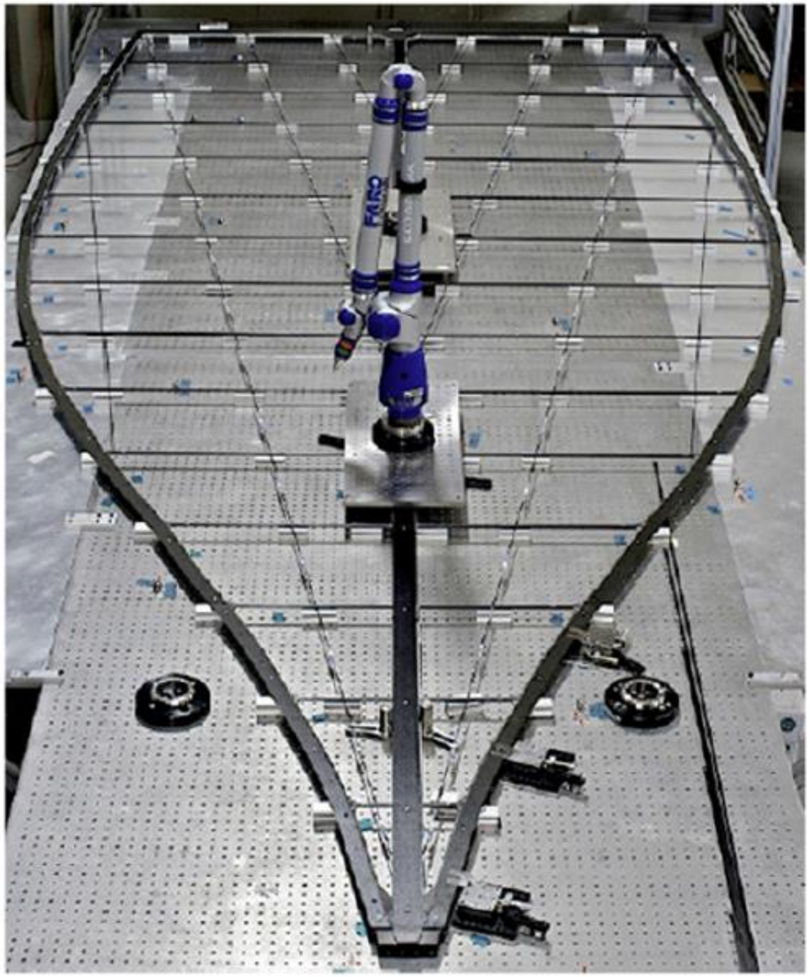


Figure 9.4-1. TDEM-09 petal prototype used to demonstrate manufacturing tolerance on petal width profile. Micrometer stages for positioning edge segments shown at bottom right.

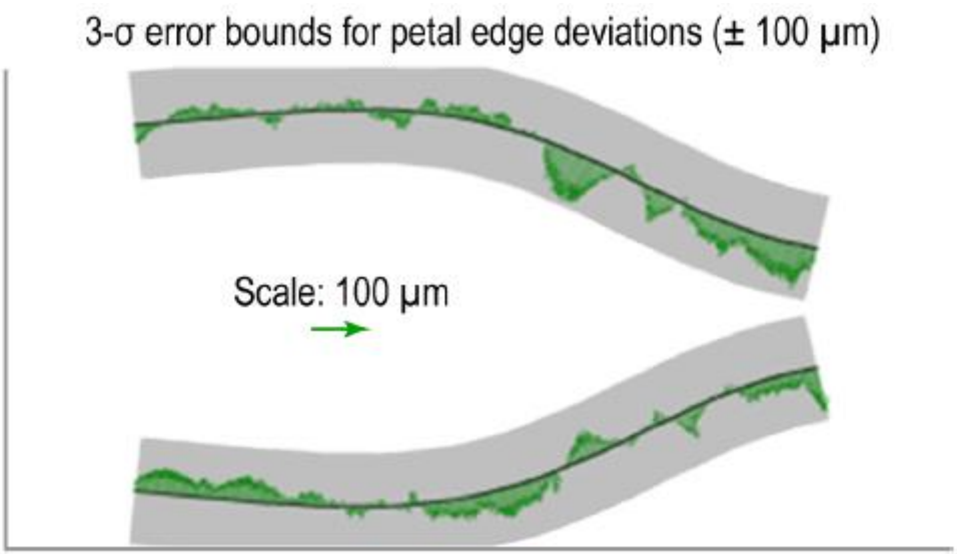


Figure 9.4-2. Measured petal shape error (green arrows) vs. 100 μm tolerance for 1×10^{-10} imaging (gray band) shows full compliance with the allocated tolerance.

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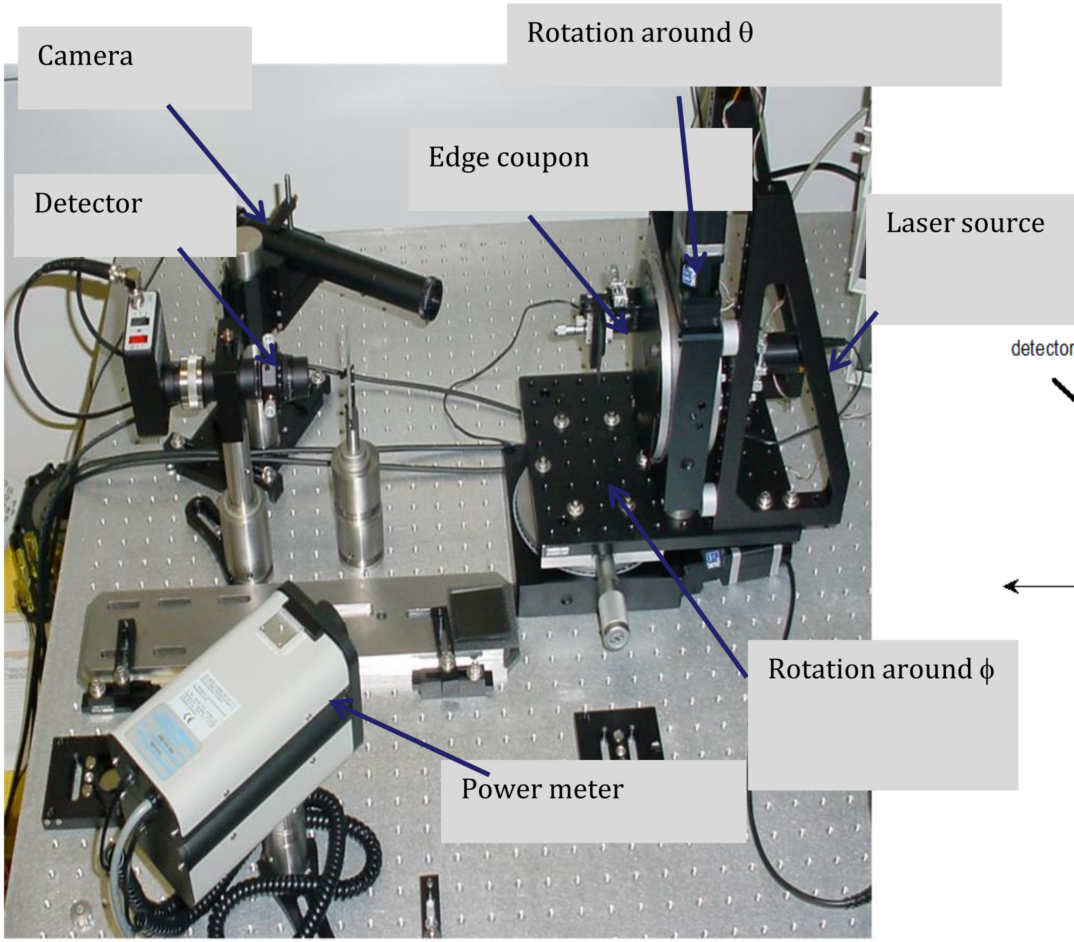
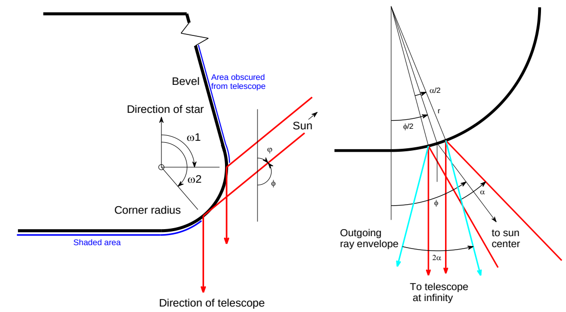
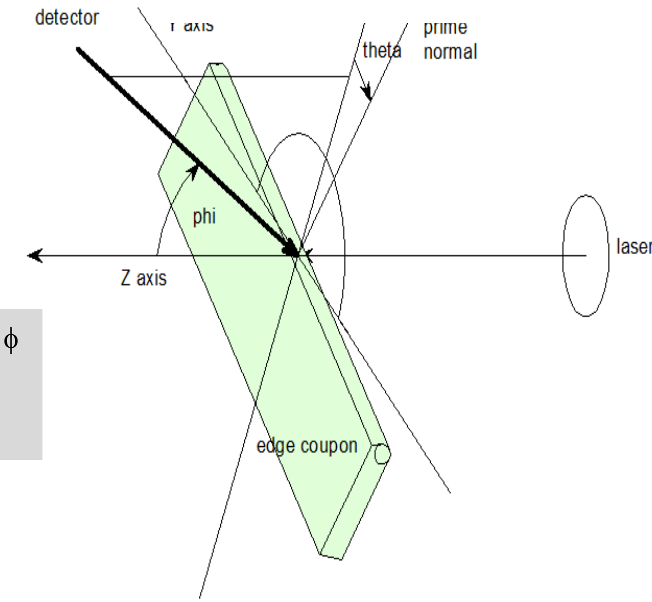
Scatterometer for Characterizing Starshade Edges







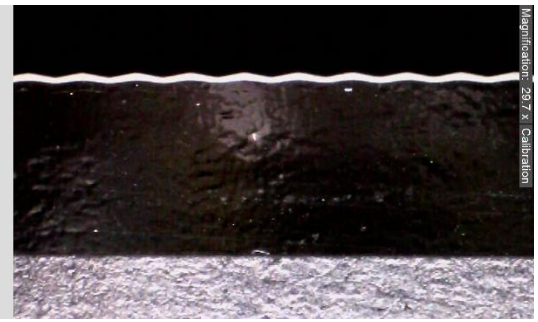
Scatterometer testbed showing the two axis stage used to rotate the edge coupon. A ccd camera was used to assist in setup and alignment and the laser source was attached to the rotation stages. The detector is in the effective optical position of the sun, while the laser is in the position of the telescope.

Martin et al 2013

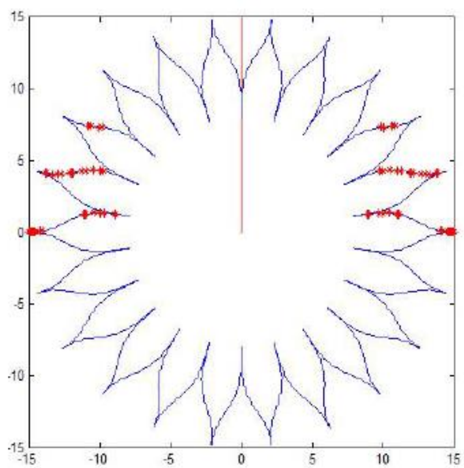
Starshade Optical Edges

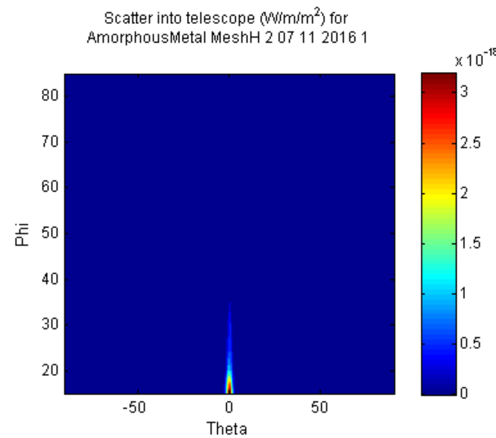
- New idea: “Stealth Edges”
- Using specular edges, introduce high frequency ripple that diffracts sunlight away from the telescope. It won’t affect diffraction of starlight.

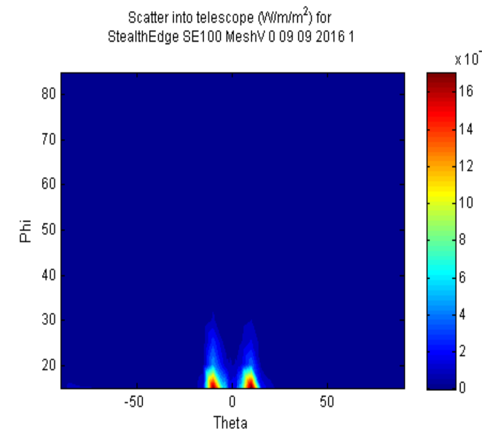
100 um amplitude, 1 mm period

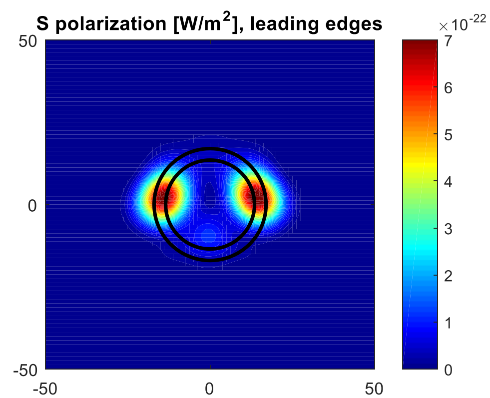


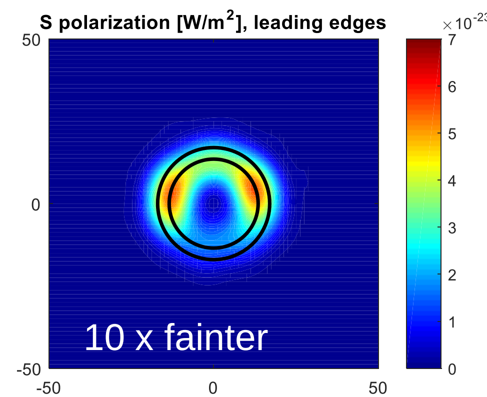
Etched amorphous metal.
Edge RoC ~ 1 um.





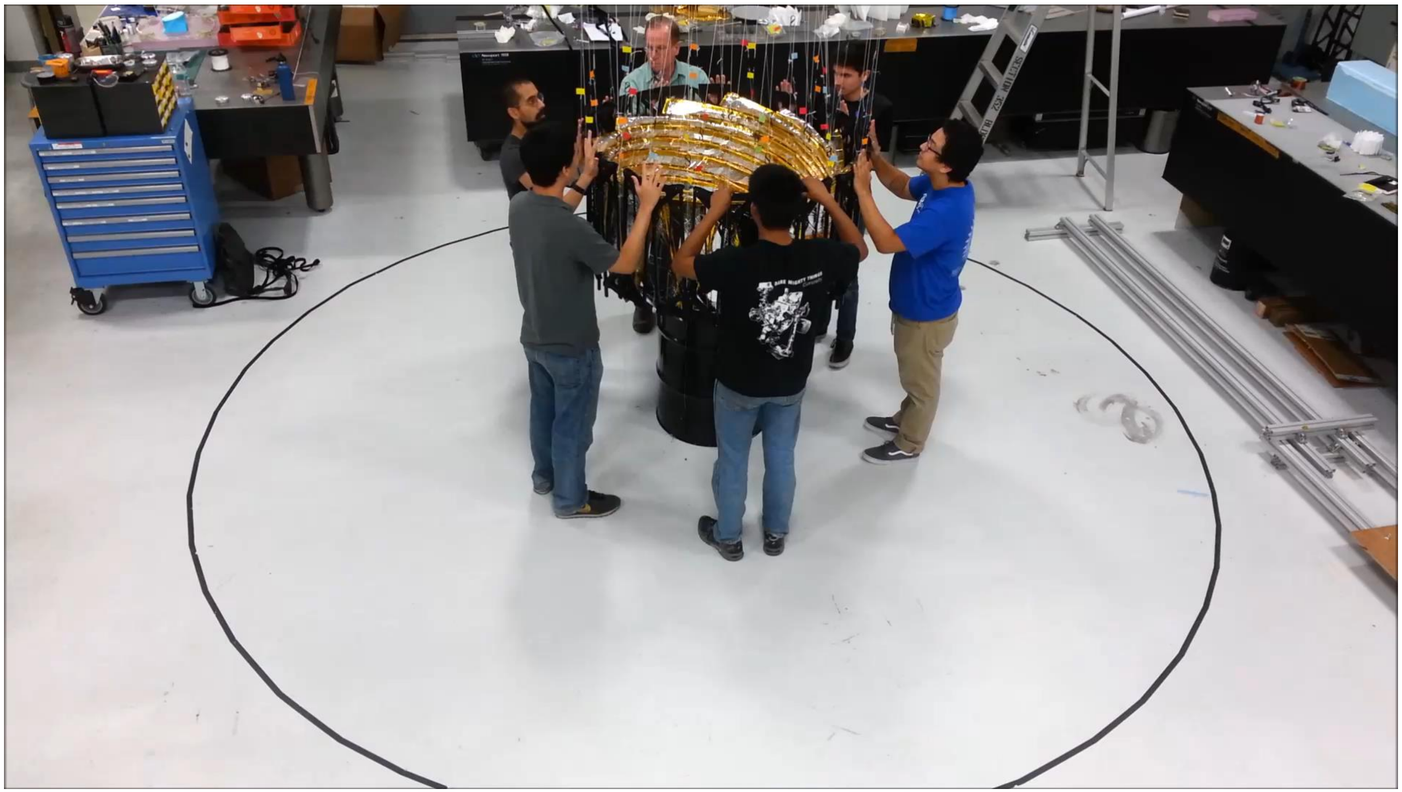






Inner Disk Structure (half Scale)

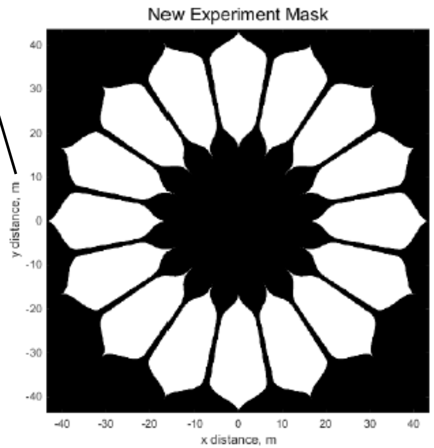
5m Optical Shield w/solar array deployment video

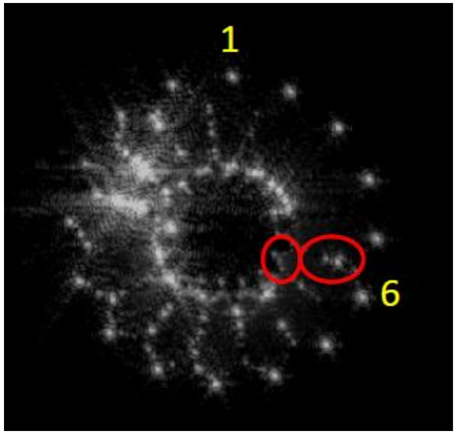


Princeton Starshade Tests

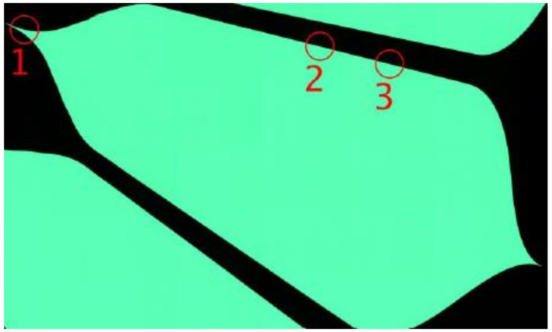
- Goal is to observe 1e-9 suppression – consistent with flight requirements and about 3 orders of magnitude deeper than previous tests.

77 m tube in basebment of Frick Chemistry Bldg.





Petal 6 known defects



S2.01 Proximity Glare Suppression

Lead Center: JPL, subtopics mgr Stuart Shaklan
Participating Center(s): ARC, GSFC

- This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources.

Starlight Suppression Technologies

- Image plane hybrid metal/dielectric, and polarization apodization masks in linear and circular patterns.
- Transmissive holographic masks for diffraction control and PSF apodization.
- Sharp-edged, low-scatter pupil plane masks.
- Low-scatter, low-reflectivity, sharp, flexible edges for control of scatter in starshades.
- Systems to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of high-dynamic range apodizing masks.
- Methods to distinguish coherent and incoherent scatter in broad band speckle field.
- Coherent fiber bundles consisting of up to 10,000 fibers with lenslets on both input and output side, such that both spatial and temporal coherence is maintained across the fiber bundle for possible wavefront/amplitude control through the fiber bundle.

S2.01 Cont'd

Wavefront Measurement and Control Technologies

- Small stroke, high precision, deformable mirrors and associated driving electronics scalable to 10,000 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices.
- Instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront.
- Integrated mirror/actuator programmable deformable mirror.
- Multiplexers with ultra-low power dissipation for electrical connection to deformable mirrors.
- Low-order wavefront sensors for measuring wavefront instabilities to enable real-time control and post-processing of aberrations.
- Thermally and mechanically insensitive optical benches and systems.

S2.01 Cont'd

Optical Coating and Measurement Technologies

- Instruments capable of measuring polarization cross-talk and birefringence to parts per million.
- Highly reflecting, uniform, broadband coatings for large (> 1 m diameter) optics.
- Polarization-insensitive coatings for large optics.
- Methods to measure the spectral reflectivity and polarization uniformity across large optics.
- Methods to apply carbon nanotube coatings on the surfaces of coronagraphs for broadband suppression of visible to NIR.

Other

- Methods to fabricate diffractive patterns on large optics to generate astrometric reference frames.
- Artificial star and planet point sources, with 1e10 dynamic range and uniform illumination of an f/25 optical system, working in the visible and near infrared.
- Deformable, calibrated, collimating source to simulate the telescope front end of a coronagraphic system undergoing thermal deformations.
- Technologies for high contrast integral field spectroscopy, in particular for microlens arrays with or without accompanying mask arrays, working in the visible and NIR (0.4 - 1.8 microns), with lenslet separations in the 0.1 -0.4 mm range, in formats of ~140x140 lenslets.

Current S2.01Proposals

2016	Phase I	S2.01	1015 PTT Segment MEMS DM Development	Iris AO, Inc., Berkeley, CA
2016	Phase I	S2.01	Robust Optical Edge for a Starshade Petal	Tendeg, LLC, Louisville, CO
2015	Phase II	S2.01	Improved Yield, Perfomrance and Reliability of High-Acutator-Count Deformable Mirrors	Boston Micromachines Corp., Cambridge, MA
2015	Phase II	S2.01	Switching Electronics for Space-Based Telescope with Advanced AO Systems	Sunlite Science & Technology, Lawrence, KS
2012	Phase II	S2.01	Nanostructured Super-Black Optical Materials	Nanolab, Inc., Waltham, MA
2012	Phase II	S2.01	Fabrication Process and Electronics Development for Scaling Segmented MEMS DMs	Iris AO, Inc., Berkeley, CA
2012	Phase II	S2.01	Driver ASICs for Advanced Deformable Mirrors	Microscale, Inc., Woburn, MA

S2.02 Precision Deployable Optical Structures and Metrology

Lead Center: JPL, subtopic mgr Greg Agnes
Participating Center(s): GSFC, LaRC

- Planned future NASA Missions in astrophysics, such as the Wide-Field Infrared Survey Telescope (WFIRST), Large Ultraviolet Visible Infrared (LUVOIR) telescope, and Habitable Planet Explorer (HabEX), the Exo-C coronagraph, and Exo-S starshade will push the state of the art in current optomechanical technologies.
- “Everything but the shiny stuff”
- Precision deployable structures and metrology for optical telescopes (e.g. innovative active or passive deployable primary or secondary support structures).
- Architectures, packaging and deployment designs for large sunshields and external occulters.
- Innovative concepts for packaging fully integrated subsystems (e.g. power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally stable materials (CTE < 1ppm) for deployable structures.
- Innovative testing and verification methodologies.
- Innovative systems that minimize complexity, mass, power, and cost.
- Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop the relevant subsystem technologies and to transition into future NASA program(s).

Current S2.02 Proposals

2016	Phase I	S2.02	Optical Shield for a Starshade Petal	Tendeg, LLC, Louisville, CO
2015	Phase II	S2.02	Macro-Fiber Composite-Based Acutators for Space	Extreme Diagnostics, Inc., Boulder, CO
2015	Phase II	S2.02	Dimensionally Stable Structrural Space Cable	Roccor, LLC, Louisville, CO
2014	Phase II	S2.02	Optical Precision Deployment Latch	Physical Sciences, Inc, Andover, MD
2012	Phase IIx	S2.02	An Outrigger Component for a Deployable Occulter System	Roccor, LLC, Louisville, Co

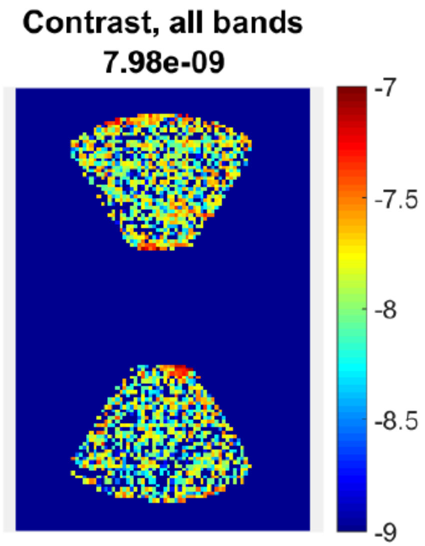
- BACKUP MATERIAL

WFIRST Coronagraph Success in the Laboratory

Milestone 5 Wording

Occulting Mask Coronagraph (HLC or SPC) in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with broadband light (10%) at 550 nm in a static environment

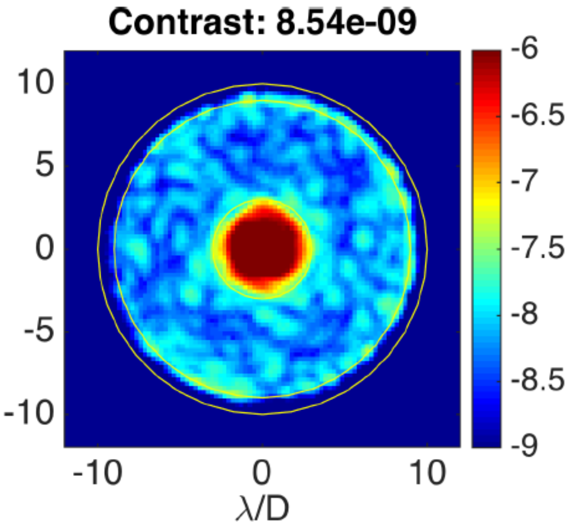
DUE: 9/15/15



Results

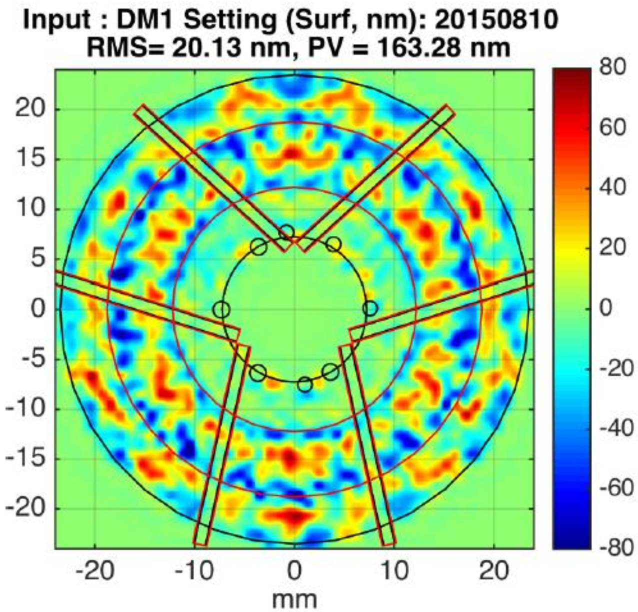
Both shaped pupil and hybrid Lyot coronagraphs have demonstrated repeatable convergence to $<9\times10^{-9}$ mean contrast across a 3-9 λ/D dark hole in broadband light (10%) centered at 550 nm

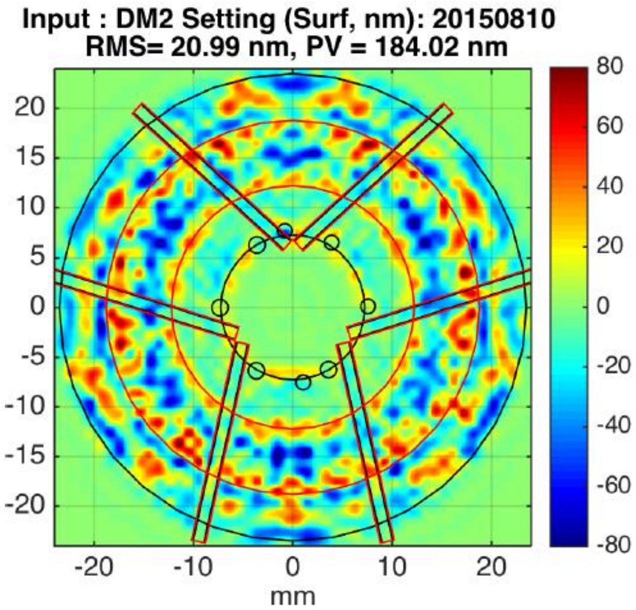
Cady et al, JPL internal document 2015



Large Static Wavefronts Required

- For Milestone #5, it was critical to apply model-generated ‘broadband jitter-insensitive DM solution’ to testbed prior to EFC
  - ‘Broadband jitter-insensitive DM solution’ for the testbed is shown below
  - Required DM stroke reduced by ~40% p-v vs. Milestone 4 design
  - Demonstrated jitter sensitivity reduced by ~10x vs. Milestone 4 narrowband DM solution





Inner Disk Structure Precision Deployment

Figure 9.5-1. Deployed position tolerance demonstration. Petal root positions are measured after each of 20 deployments.

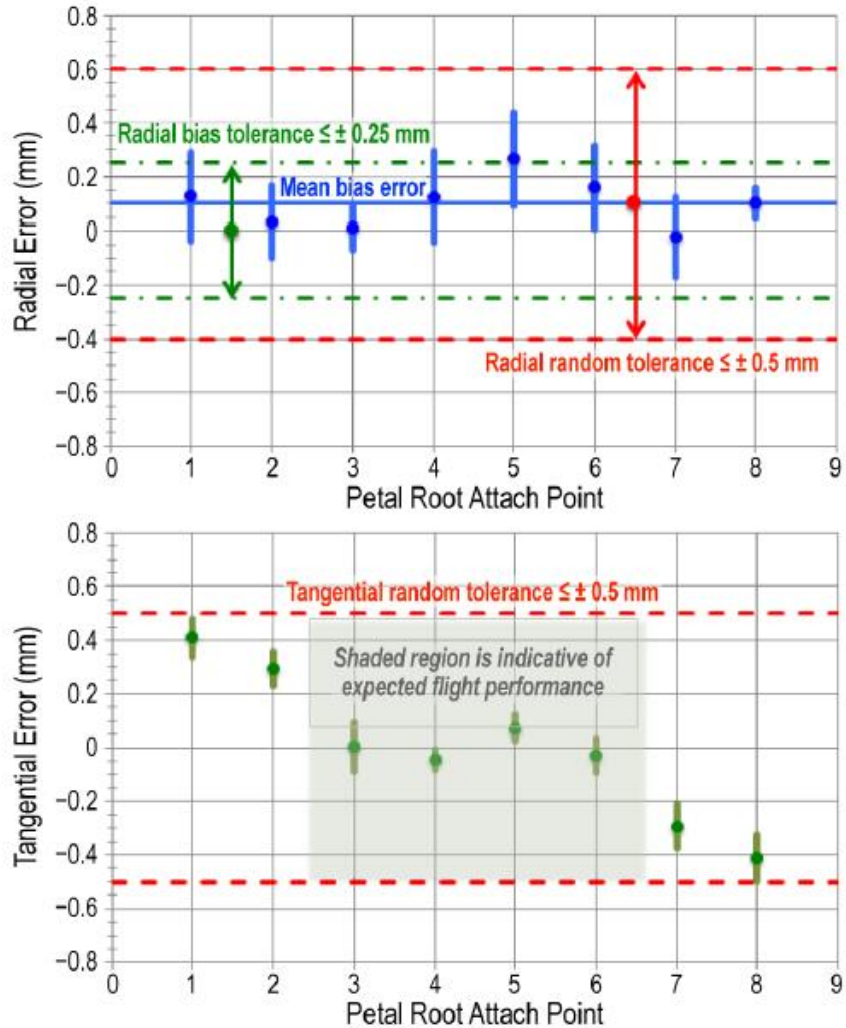


Figure 9.5-2. Measured deployment errors (3 σ with 90% confidence) are all within tolerance allocations.

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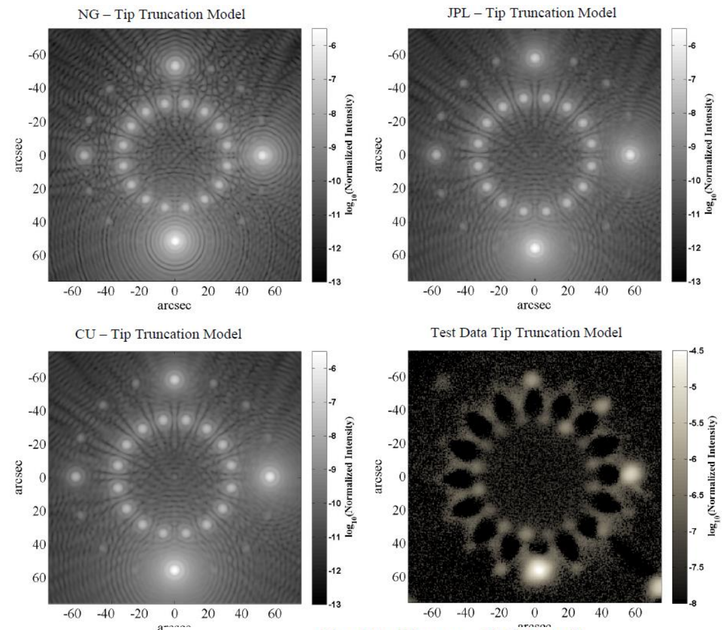
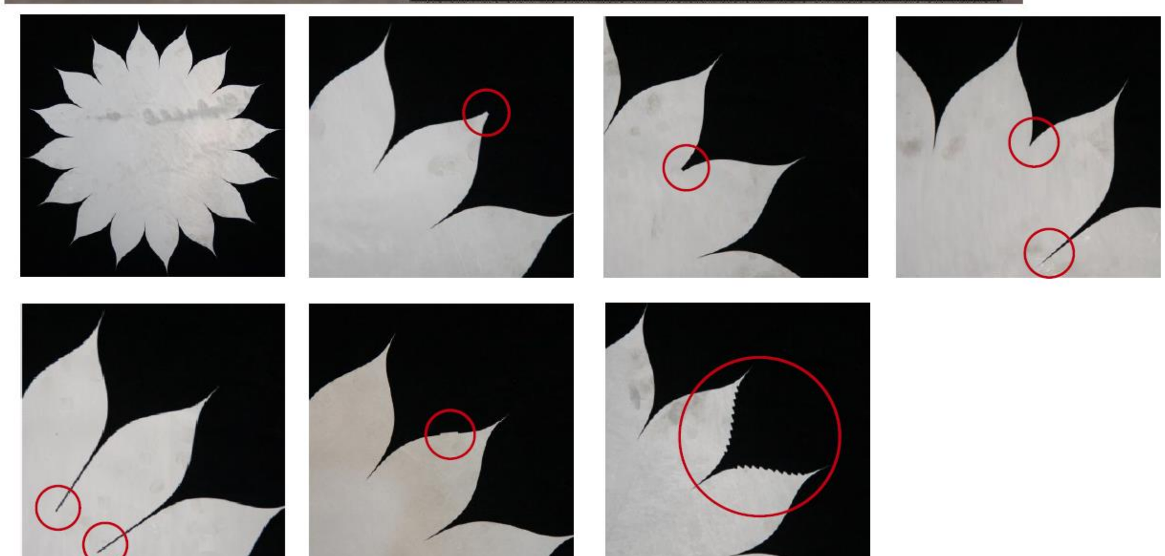
Starshade Testing over 2 km Path

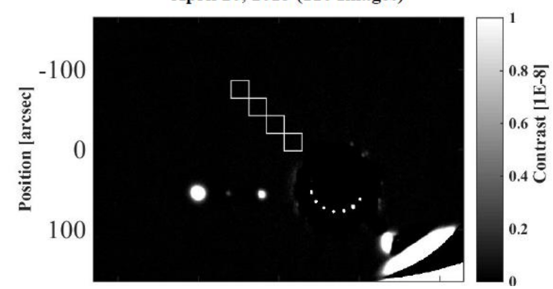
Smith et al, SPIE 2016





Combined Image – HG Etched

April 20, 2015 (116 Images)



Box	3σ Level
1	9.6E-10 ± 2.12E-10
2	8.47E-10 ± 1.87E-10
3	7.88E-10 ± 1.74E-10
4	7.42E-10 ± 1.64E-10
Center	9.95E-09 ± 2.20E-09
Far Away	6.12E-10 ± 1.35E-10

Starshade Testing at McMath Telescope

A. Harness et al, 2016