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

Mirror Tech Days 2015
Annapolis, MD

Nov 10, 2015

Stuart Shaklan

Jet Propulsion Laboratory

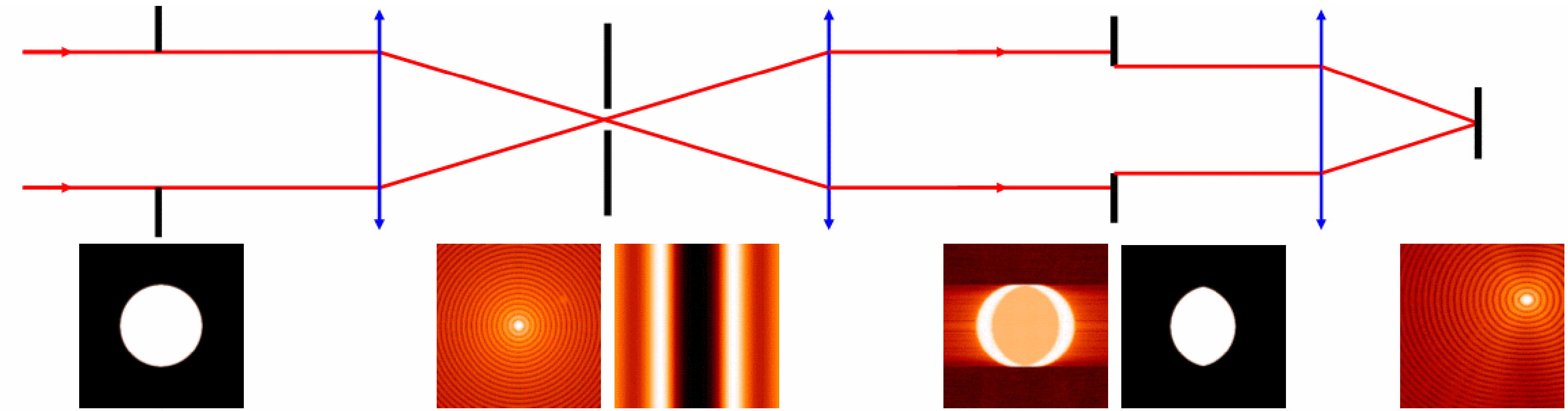
California Institute of Technology

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

What is a Stellar Coronagraph?

- A series of pupil-plane and image-plane masks and stops that block the on-axis starlight and allow off-axis planet light to reach the detector plane.



1st pupil

1st image with Airy rings

mask, centered on star image

2nd pupil

Lyot stop, blocks bright edges

2nd image, no star, bright planet

Hybrid Lyot Coronagraph Experimental Results
Unobscured Aperture, a.k.a. "The Good Ol' Days"

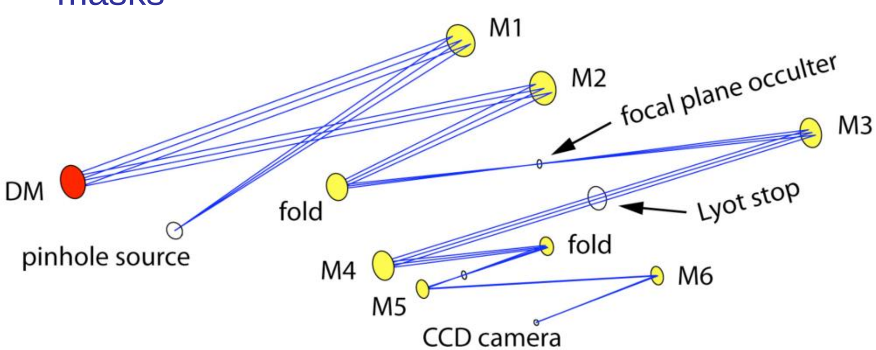
Coronagraph Technology Milestone:
Demonstration of ≤ 10^{-9} contrast w/ hybrid-Lyot Masks @ 3λ/D & 20% BW

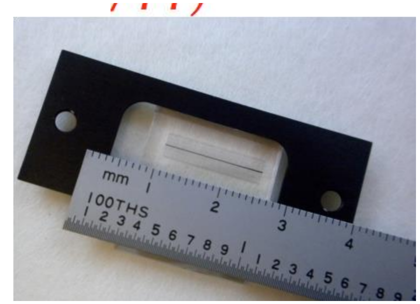
Facility: High Contrast Imaging Testbed 1, JPL

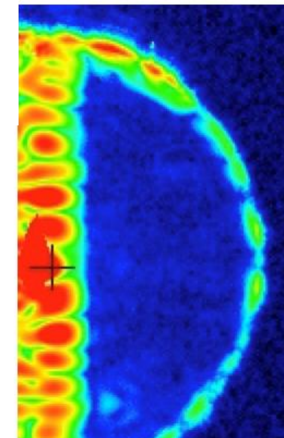
Current Status: 2×10^{-9} contrast @ 3-4 λ/D and 20%

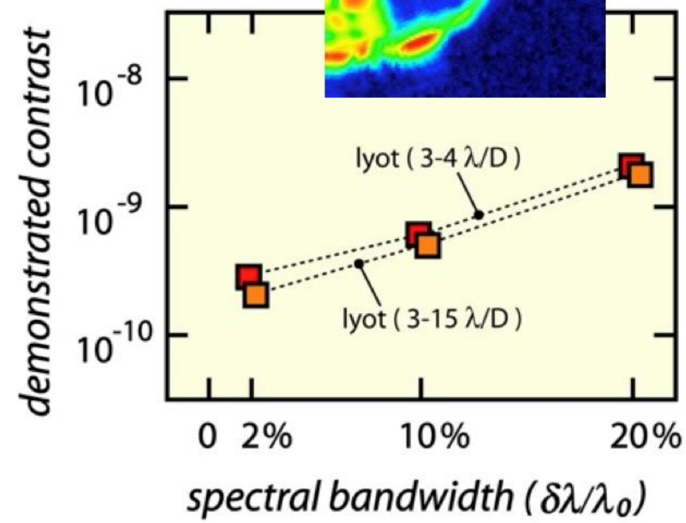
Challenges: Calibration of the dielectric layer during manufacturing.

Future Work: New masks, better contrast at 20% bandwidth. Fabrication and testing of circular masks







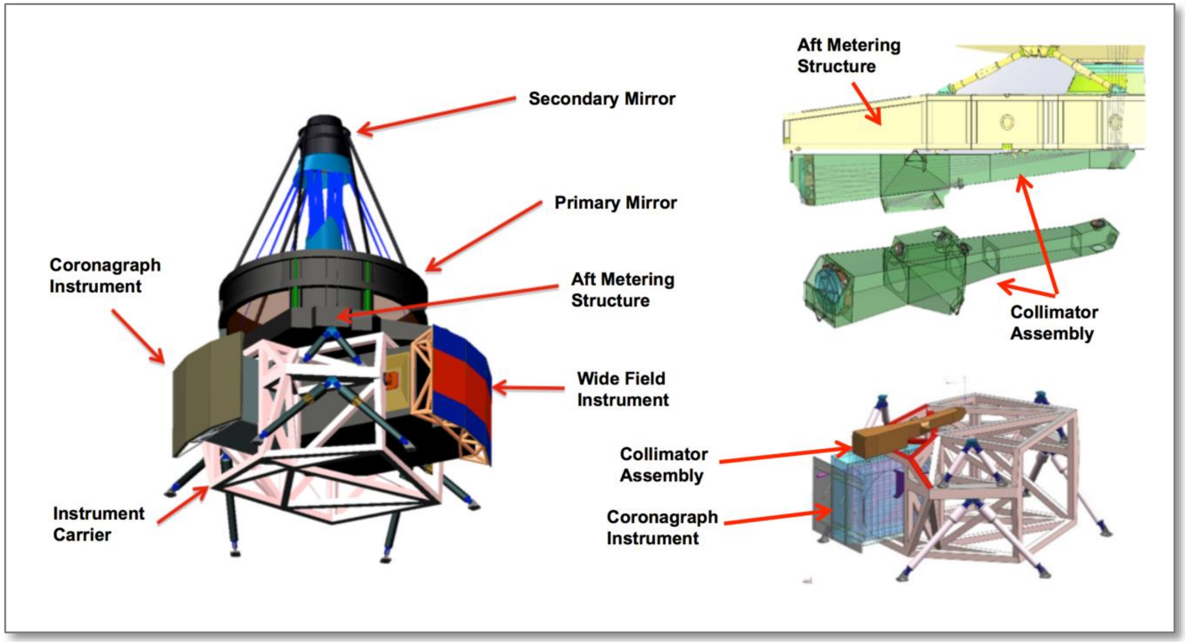


Hybrid Lyot Contrast Achieved to Date (Trauger TDEM)			
Inner Working Angle	Bandwidth		
	2%	10%	20%
3-4 λ/D	3.2 10^{-10}	6.0 10^{-10}	1.9 10^{-9}
3-15 λ/D	2.0 10^{-10}	5.2 10^{-10}	1.9 10^{-9}

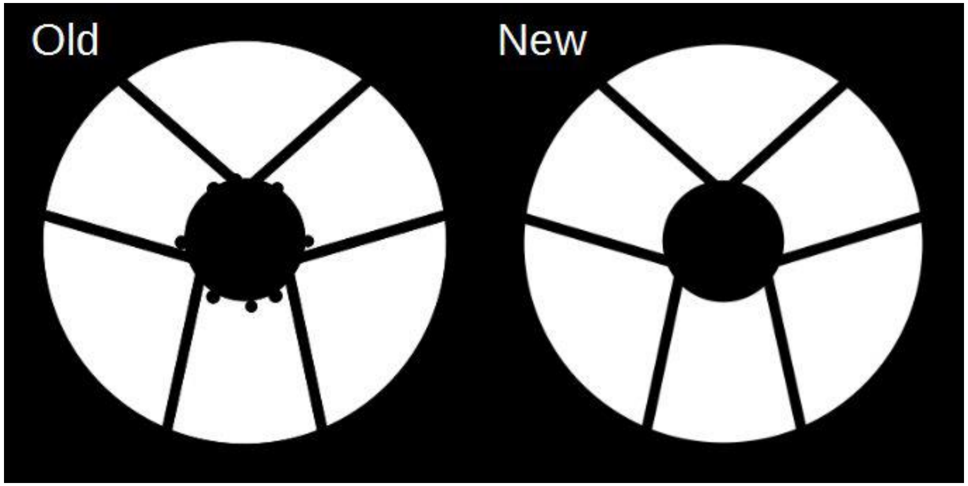
Trauger et al, 2012

WFIRST/AFTA Coronagraph

Demers et al, 2015



Krist et al, 2015



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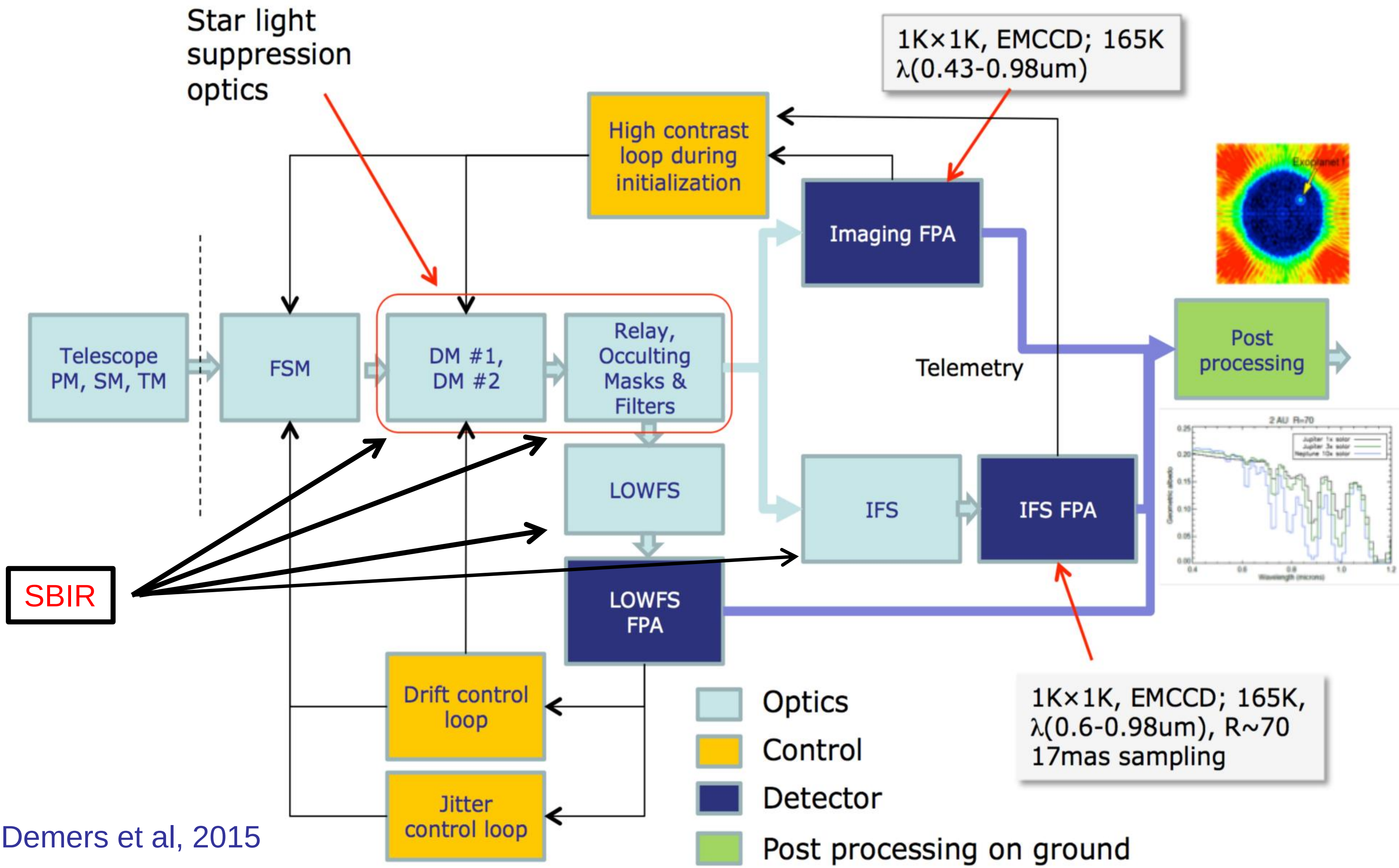
WFIRST/AFTA Coronagraph Schematic



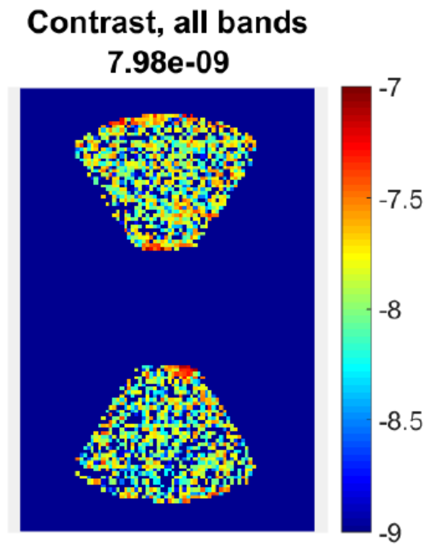
Demers et al, 2015

WFIRST Coronagraph Success in the Laboratory

Milestone 5 Wording

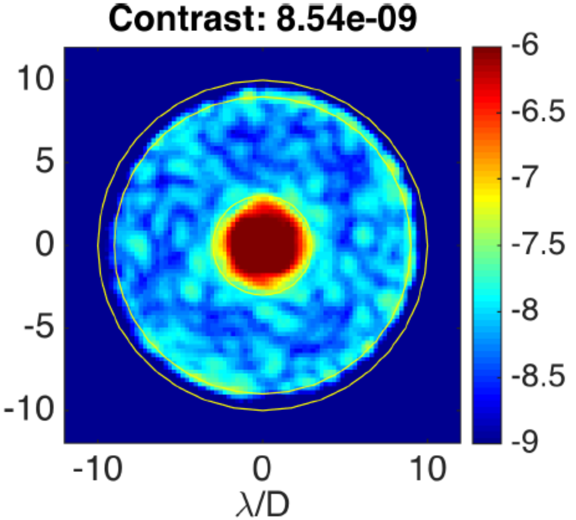
Occulting Mask Coronagraph (HLC or SPC) in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with broadband light (10%) at 550 nm in a static environment

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

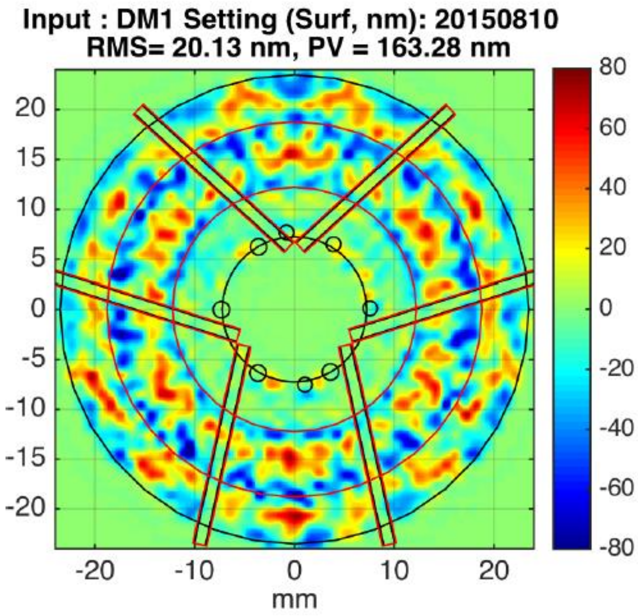


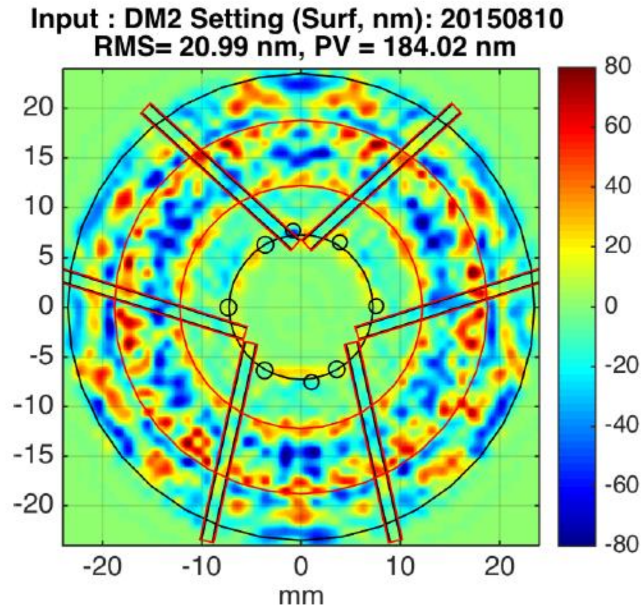
Cady et al, JPL internal document 2015

Large Static Wavefronts Required

HLC version of “ACAD” diffraction control

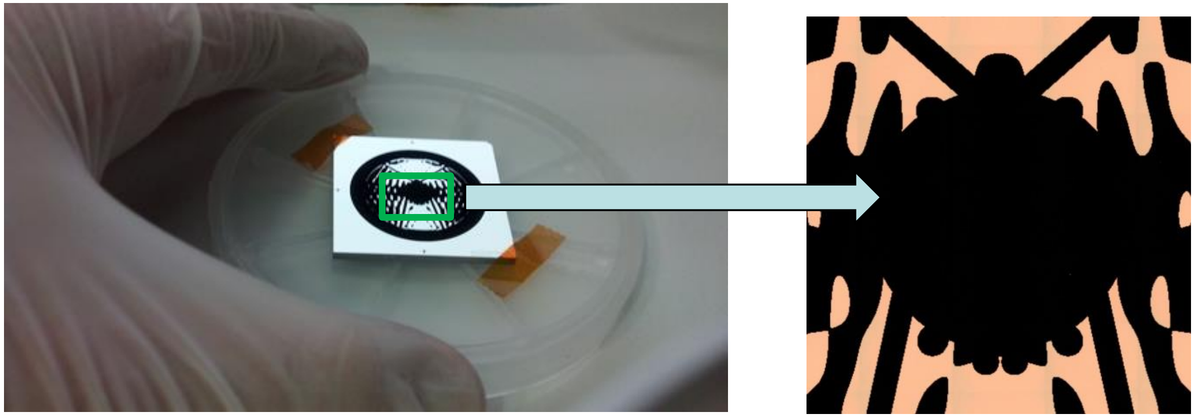
- For Milestone #5, it was critical to apply model-generated ‘broadband jitter-insensitive DM solution’ to testbed prior to EFC
  - ‘Broadband jitter-insensitive DM solution’ for the testbed is shown below
  - Required DM stroke reduced by ~40% p-v vs. Milestone 4 design
  - Demonstrated jitter sensitivity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



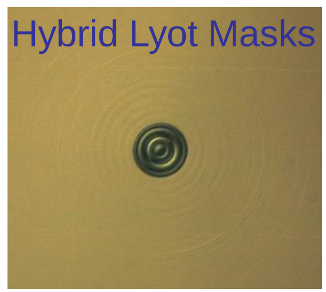


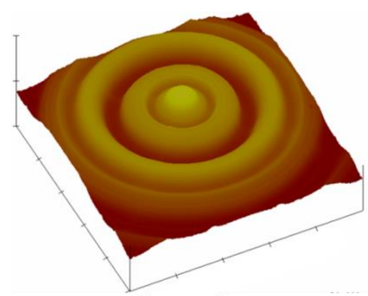
WFIRST/AFTA Coronagraph Technologies

Reflective Shaped Pupil Masks with Black Silicon AR surface

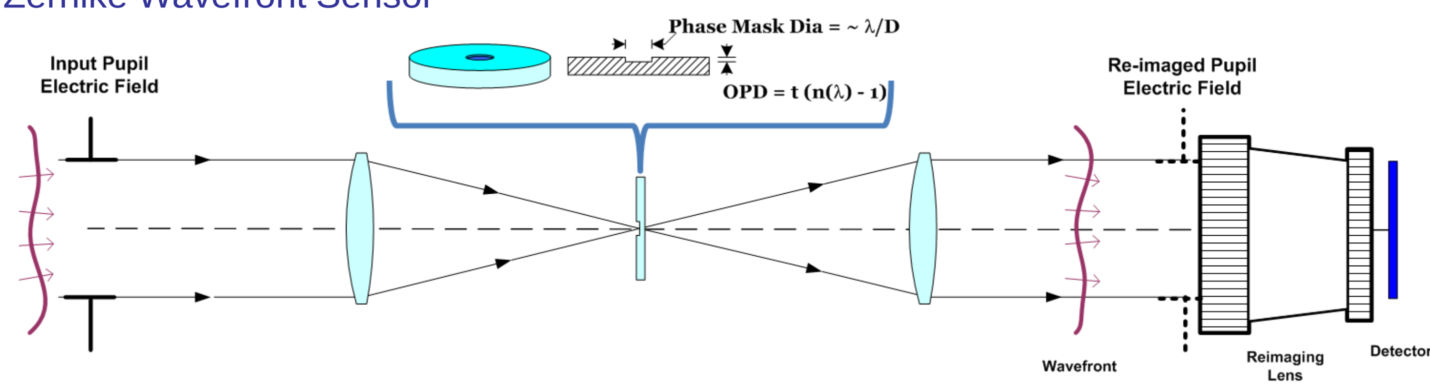


Hybrid Lyot Masks

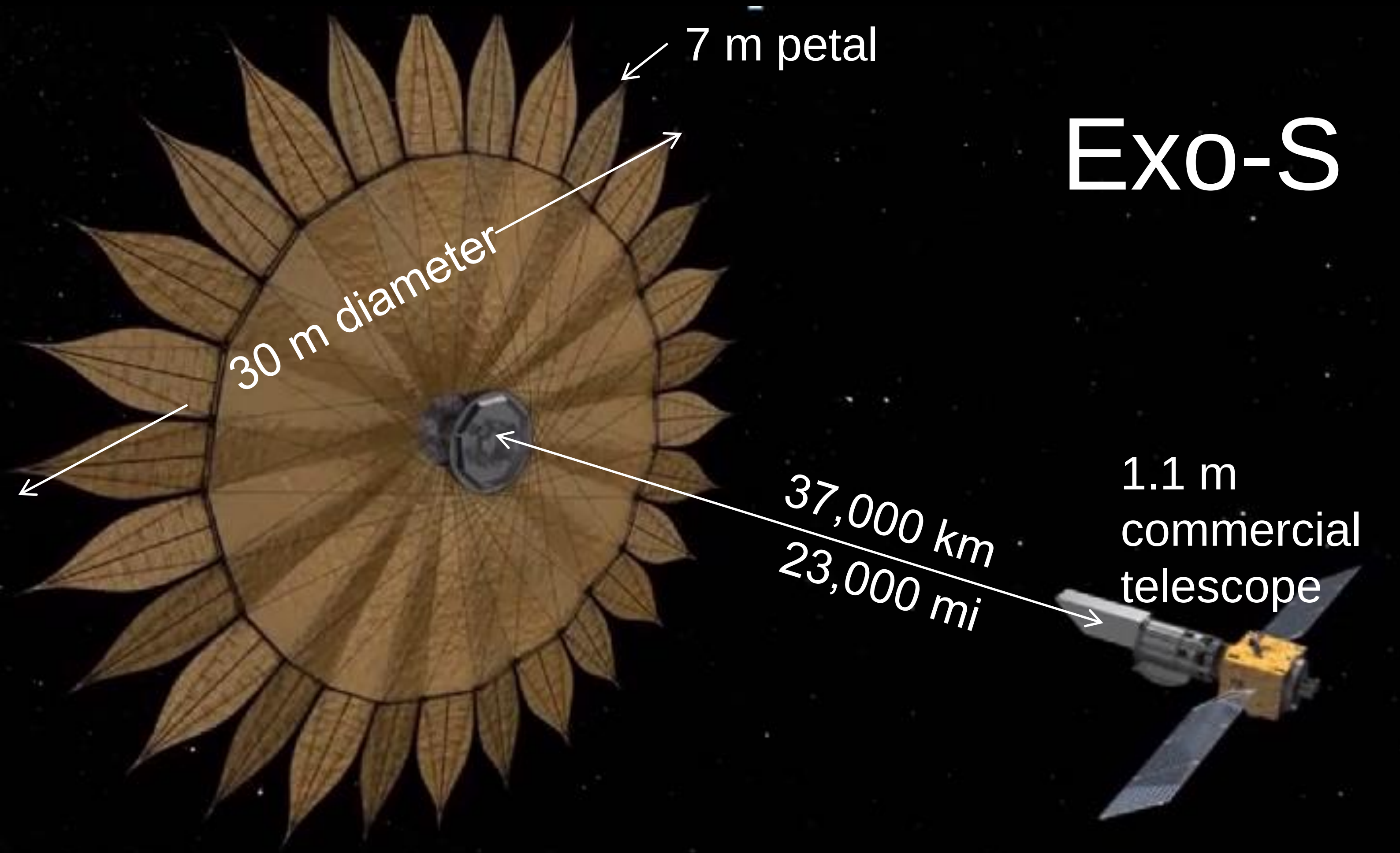




Zernike Wavefront Sensor



Exo-S


7 m petal
30 m diameter
37,000 km
23,000 mi
1.1 m
commercial
telescope

WFIRST Telescope Joined by a Starshade

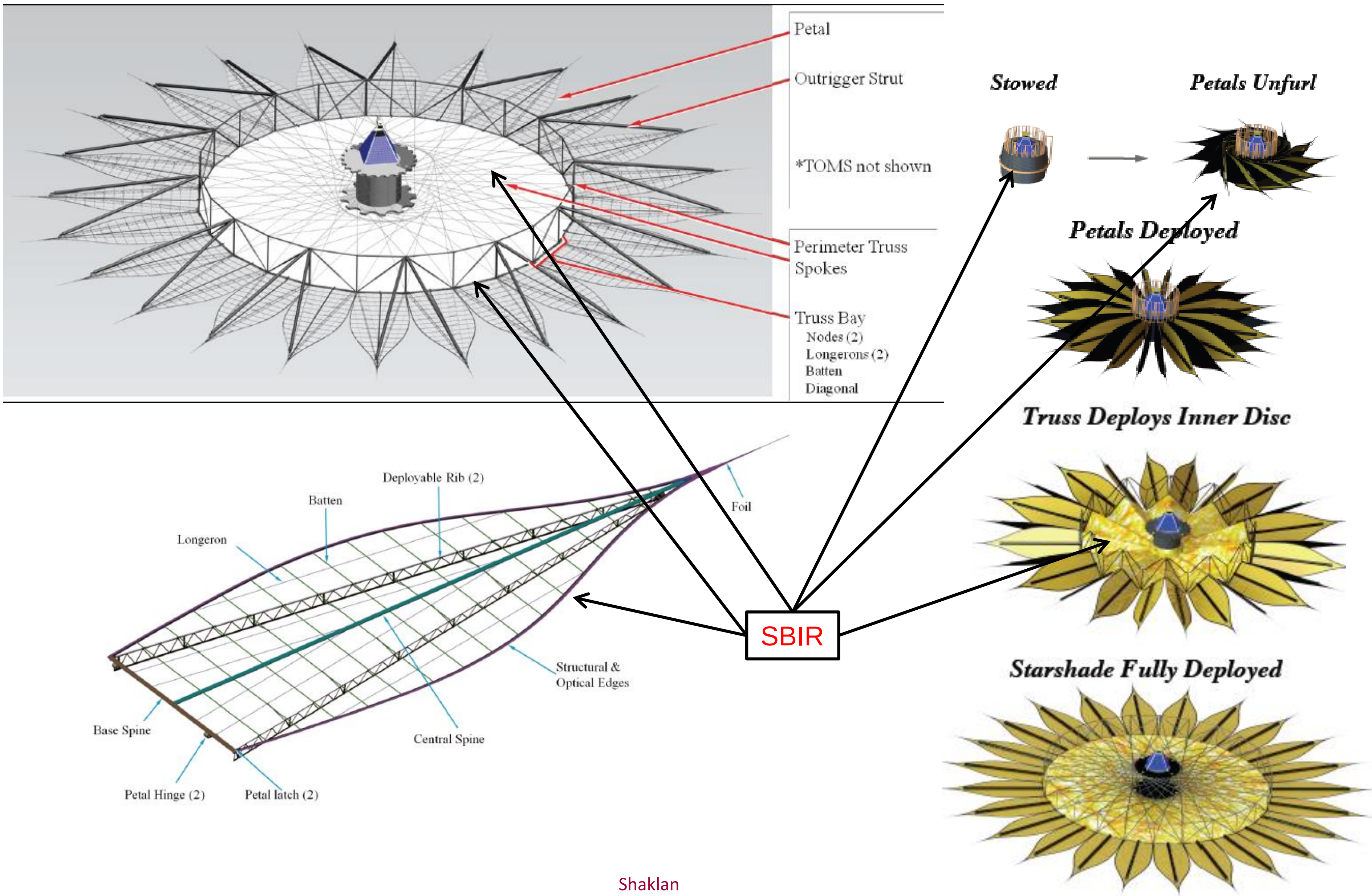
“WFIRST Rendezvous Mission” Complements Coronagraph, with sensitivity to discover Exo-Earths in the Habitable Zone

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

2.4 m telescope

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Starshade Construction and Deployment



Inner Disk Structure Precision Deployment

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

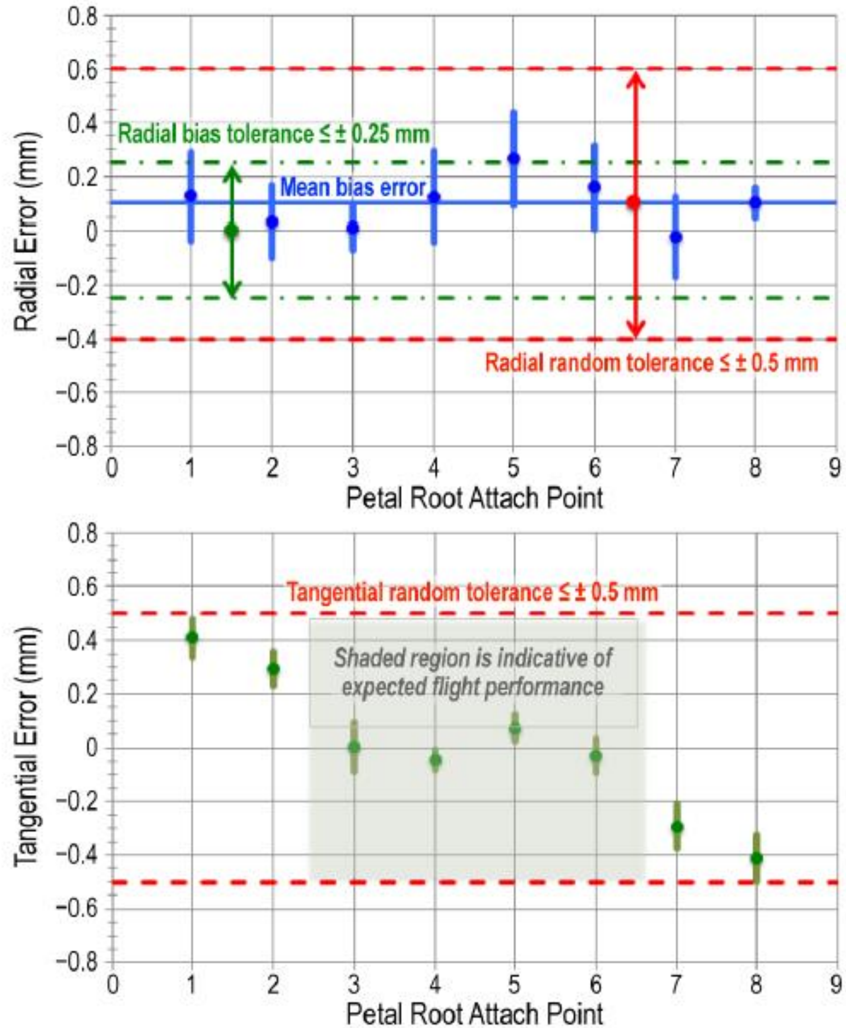


Figure 9.5-2. Measured deployment errors (3 σ with 90% confidence) are all within tolerance allocations.

Precision Full Scale Petals

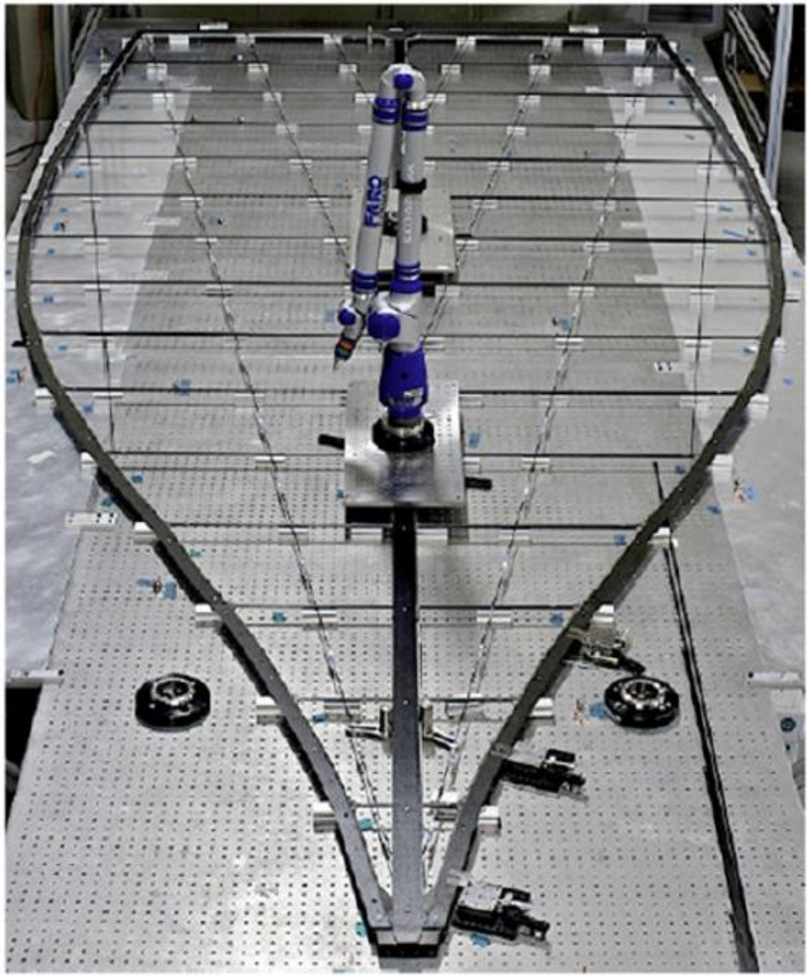


Figure 9.4-1. TDEM-09 petal prototype used to demonstrate manufacturing tolerance on petal width profile. Micrometer stages for positioning edge segments shown at bottom right.

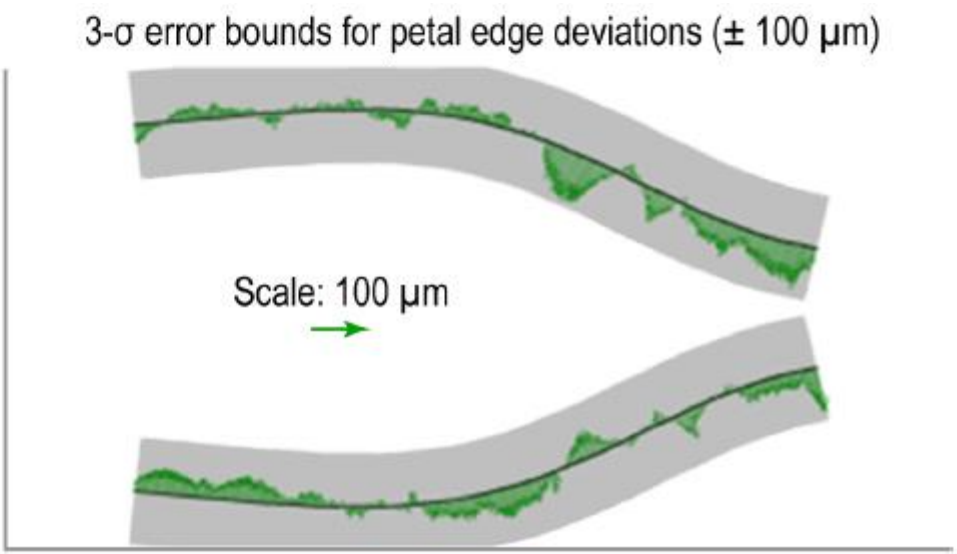
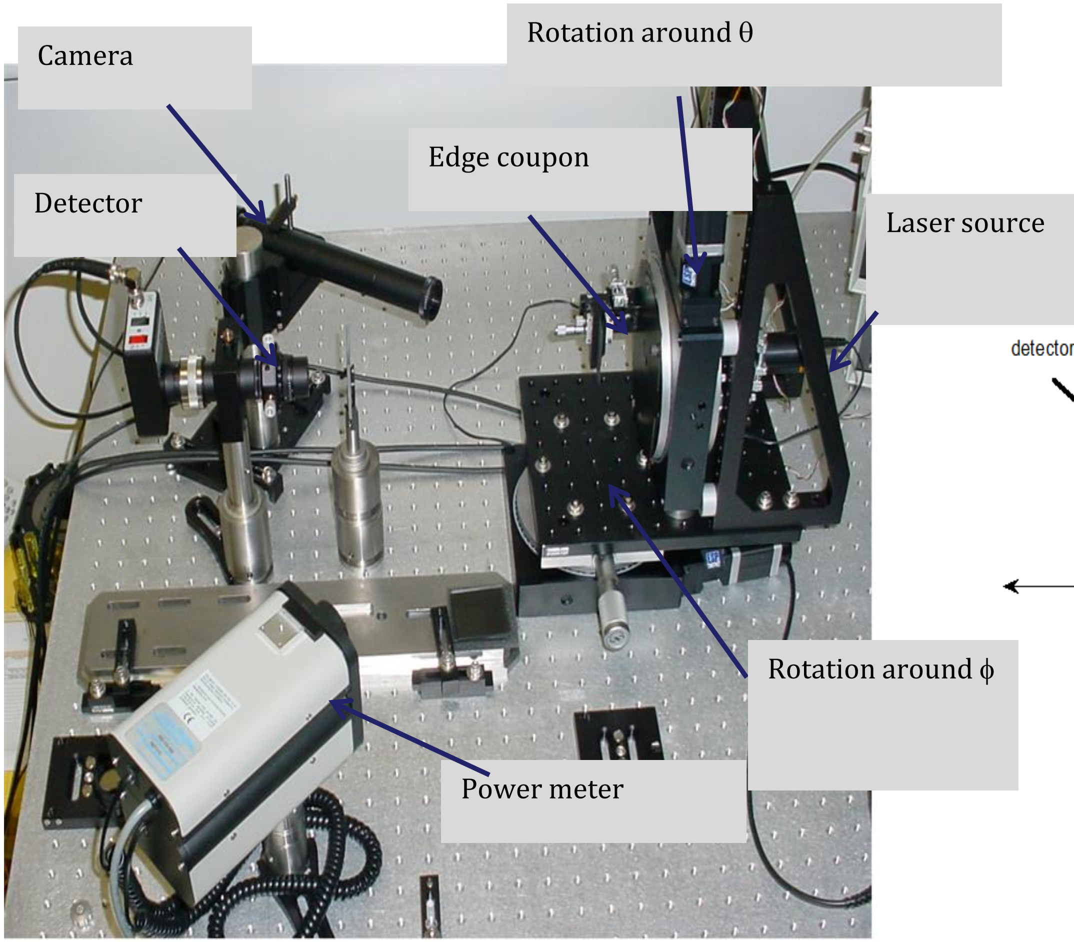
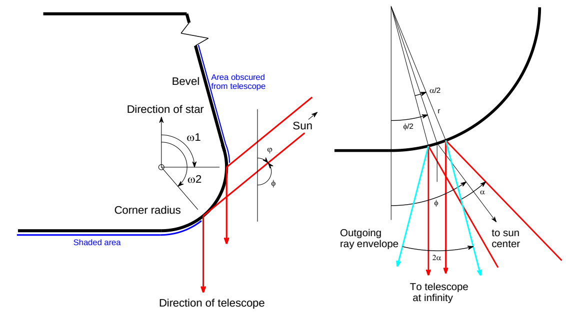
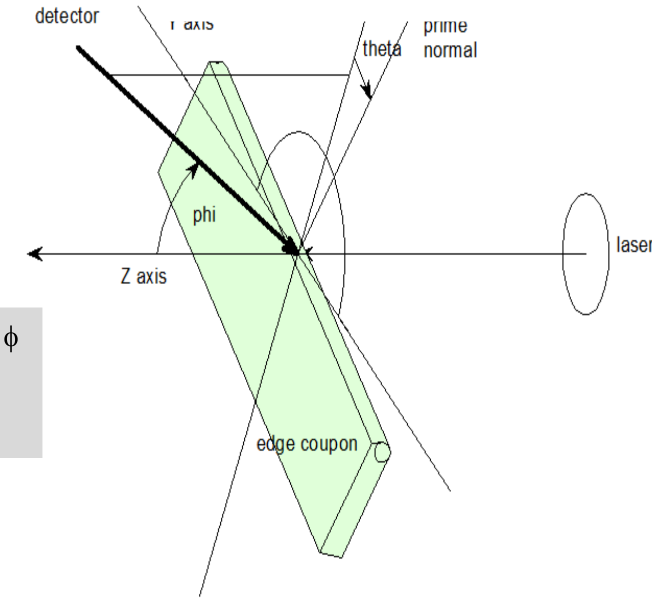


Figure 9.4-2. Measured petal shape error (green arrows) vs. 100 μm tolerance for 1×10^{-10} imaging (gray band) shows full compliance with the allocated tolerance.

Scatterometer for Characterizing Starshade Edges







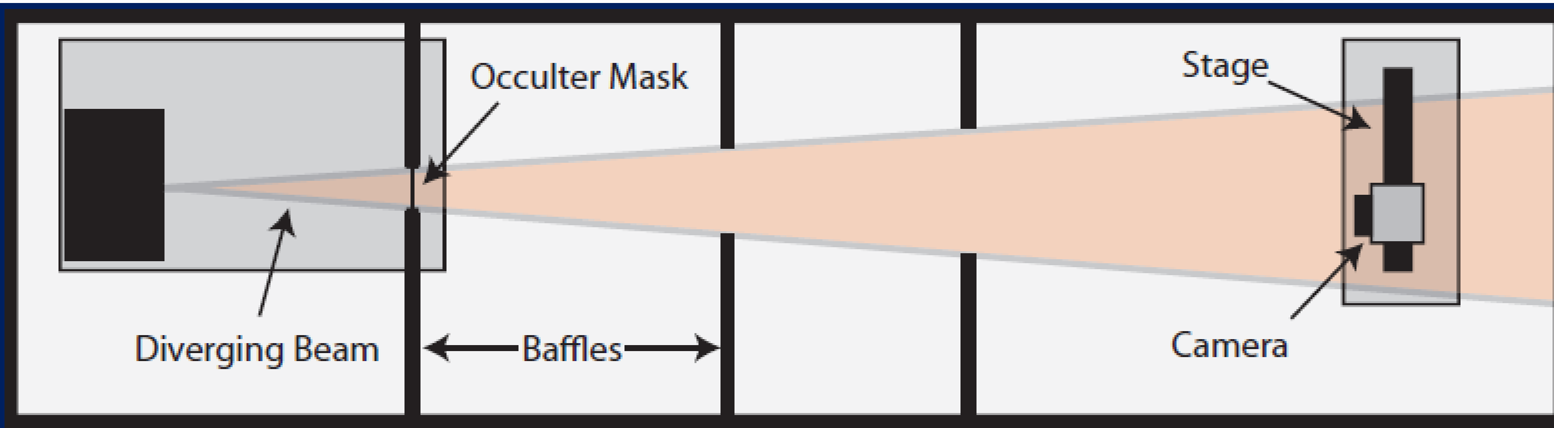
Scatterometer testbed showing the two axis stage used to rotate the edge coupon. A ccd camera was used to assist in setup and alignment and the laser source was attached to the rotation stages. The detector is in the effective optical position of the sun, while the laser is in the position of the telescope.

Martin et al 2013

Inner Disk Structure (half Scale)

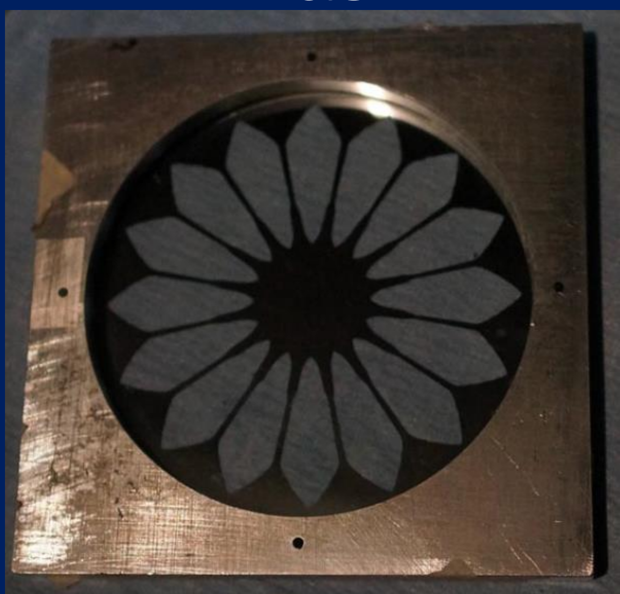
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Princeton Starshade Testbed

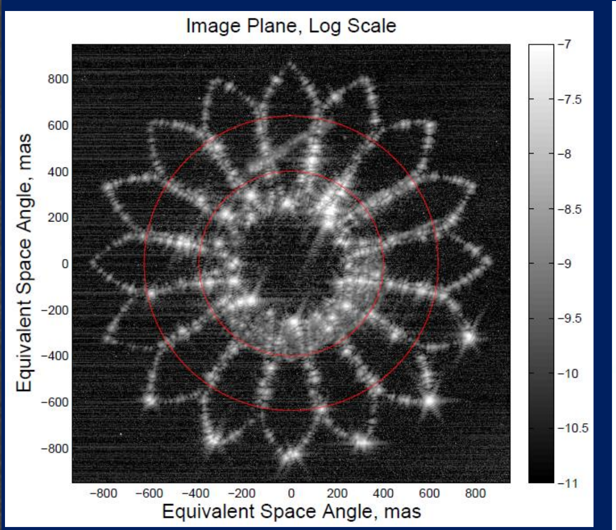


11 m

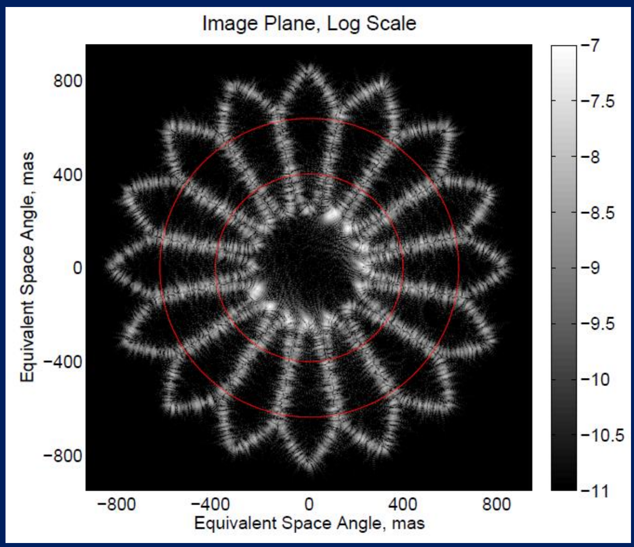
Mask



Measurement



Model

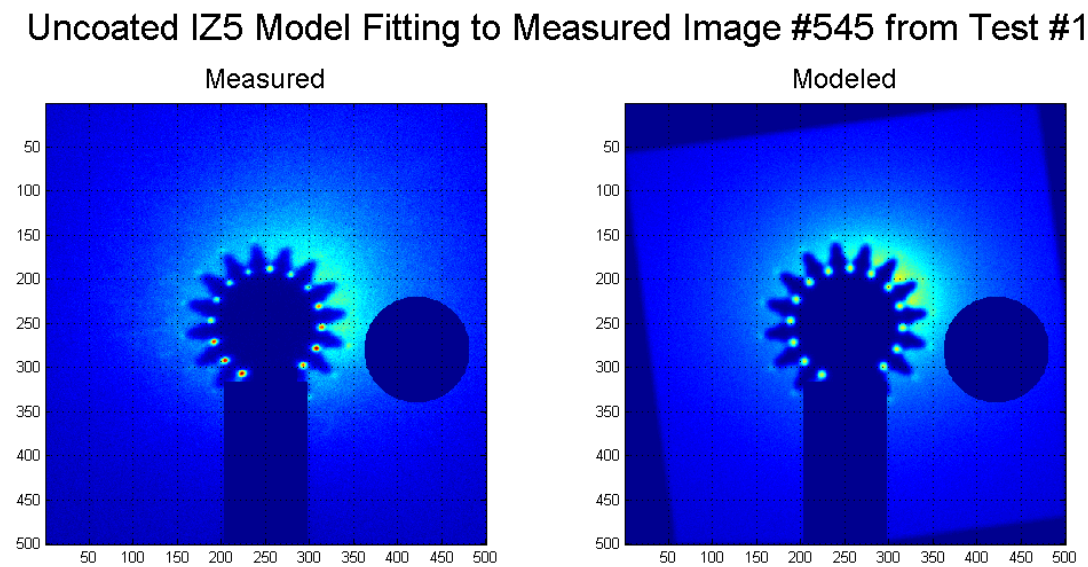


At Princeton: Jeremy Kasdin, Dan Sirbu, Robert Vanderbei

Shaklan

Starshade Testing over 2 km Path

Credit: Northrop Grumman



Dust constant: 5.6e-6
Dust center: (14.1, -14.2) pxls
Dust skewness: 0.9, 1.2
Dust seeing blurr: 3.0
Valley amplification: 3.0
Tip amplification: 0.8
SS seeing blurr: 2.8

Fitting residual: 8.1e-6

Relative image shift: (1.9, 1.3) pxls
Relative image rotation: 7.6 deg
Relative image scale: 0.90x

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 S2.01 Phase I Proposals

S2.01-8685	SBIR 2015-I	JPL	Single Crystal Piezoelectric Stack Actuator DM with Integrated Low-Power HVA-Based Driver ASIC	Microscale, Inc.	06/17/2015	12/17/2015	Jean Chr Shelton
S2.01-9488	SBIR 2015-I	JPL	Improved Yield, Performance and Reliability of High-Actuator-Count Deformable Mirrors	Boston Micromachines Corporation	06/17/2015	12/17/2015	Stuart B Shaklan
S2.01-9534	SBIR 2015-I	JPL	Switching Electronics for Space-based Telescopes with Advanced AO Systems	Sunlite Science & Technology, Inc.	06/17/2015	12/17/2015	Lewis C Roberts

Current S2.01 Phase II Proposals

S2.01-9417	SBIR 2012-II	GSFC	Fabrication Process and Electronics Development for Scaling Segmented MEMS DMs	Iris AO, Inc.	04/24/2014	04/23/2016	
S2.01-9884	SBIR 2012-II	JPL	Driver ASICs for Advanced Deformable Mirrors	Microscale, Inc.	04/23/2014	04/22/2016	Jean Chr Shelton
S2.02-9446	SBIR 2010-II	GSFC	Picometer-Resolution MEMS Segmented DM	Iris AO, Inc.	04/30/2012	09/30/2016	
S2.02-8177	SBIR 2011-II	JPL	Nanostructured Super-Black Optical Materials	NANOLAB, INC	07/22/2013	07/21/2015	Kunjithapatham Balasubramanian

(Note: S2.01 was called S2.02 until 2013)

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) and the Exoplanet Exploration Program (Exo-C coronagraph, Exo-S starshade) will push the state of the art in current optomechanical technologies.
- “Everything but the shiny stuff”
- Components and subsystem technology, for large apertures and small satellites
- Precision deployable structures and metrology for optical telescopes
- Architectures, packaging and deployment designs for large sunshields and external occulters.
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE < 1ppm) for deployable structures.
- Innovative testing and verification methodologies.
- 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 Phase I Proposals

S2.02-9221	SBIR 2015-I	JPL	Dimensionally Stable Structural Space Cable	ROCCOR, LLC	06/17/2015	12/17/2015	David Webb
S2.02-9994	SBIR 2015-I	LaRC	Macro-Fiber Composite-based actuators for space	Extreme Diagnostics, Inc.	06/17/2015	12/17/2015	

Current S2.02 Phase II Proposals

S2.02-8990	SBIR 2012-II	JPL	An Outrigger Component for a Deployable Occulter System	ROCCOR, LLC	04/24/2014	04/23/2016	Mark Thomson
S2.02-9261	SBIR 2014-II	JPL	Optical Precision Deployment Latch	Physical Sciences, Inc.	05/28/2015	05/27/2017	Greg S Agnes