Starlight Suppression Technologies for Exoplanet Imaging

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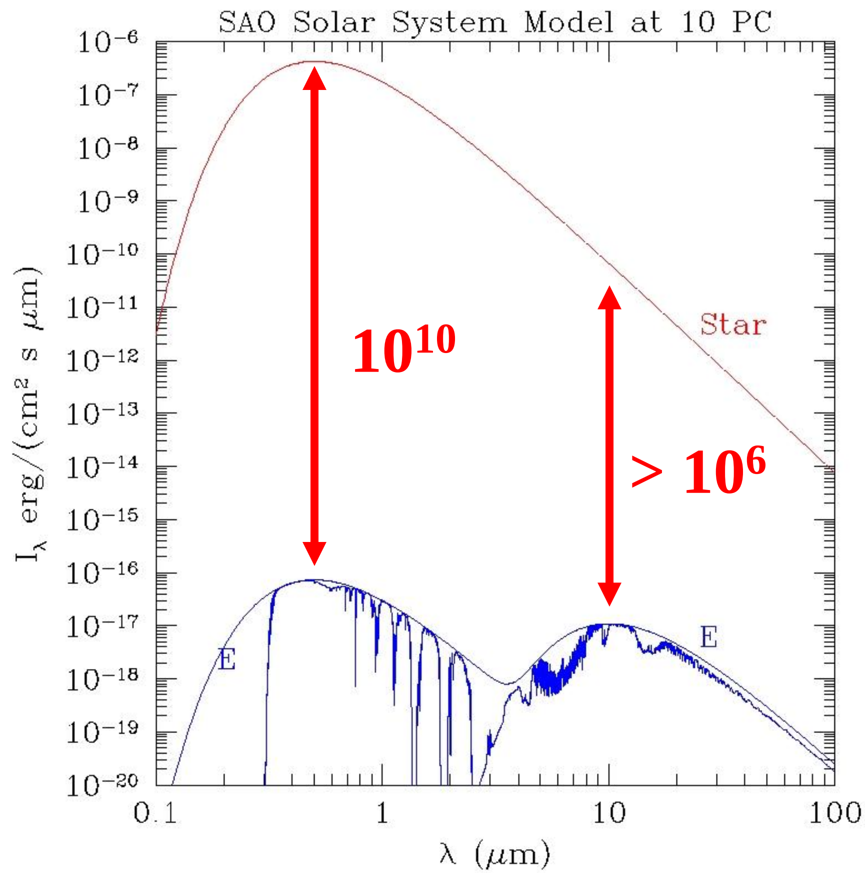
Why it's hard to see Exoplanets

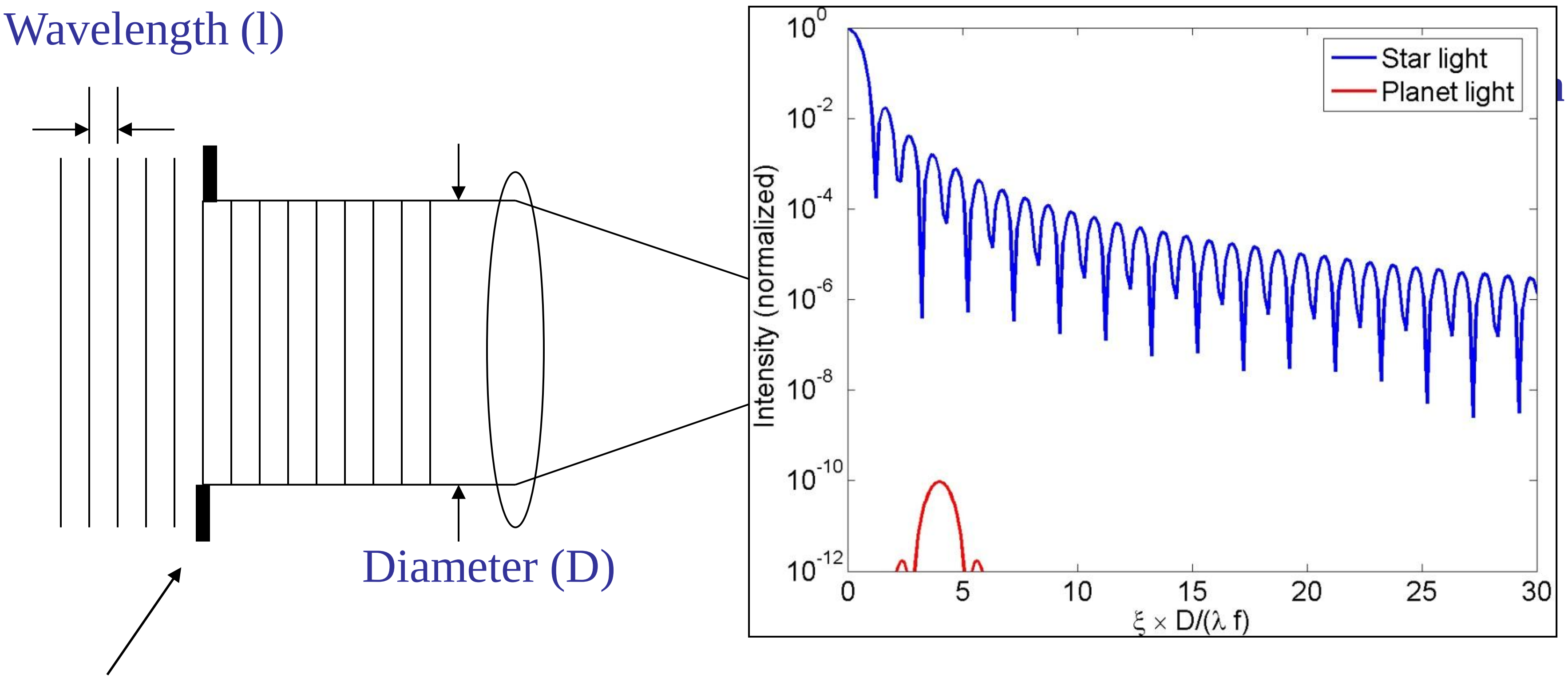
- The planet is 10^{-10} times dimmer than the star.
- A star 20 parsec (66 ly) away, with a planet 1 AU from the star: the angular separation is 0.05 arcsecond.
- Using a 10m telescope, operating at λ=600 nm, the star / planet angular separation would be 4 λ/D (4th Airy ring).

Model spectrum of the Sun and Earth as seen from a distant star

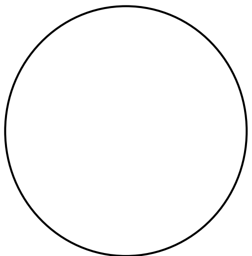


The Diffraction Problem

Unfortunately, the planet would be



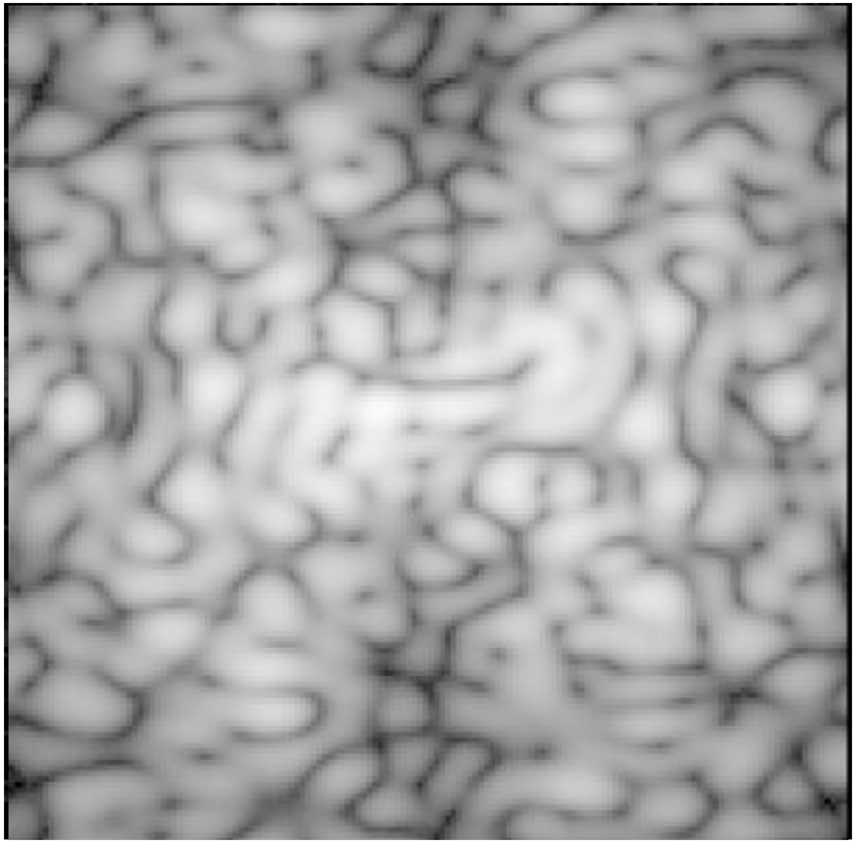
Entrance Pupil



Slide courtesy of A. Give'on

The Scatter Problem

What's left over
After removing diffraction



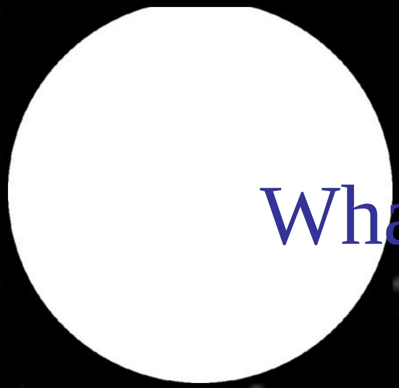
Stellar Coronagraph: Remove Diffraction

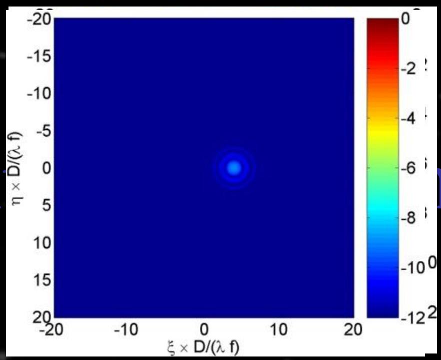
Entrance pupil

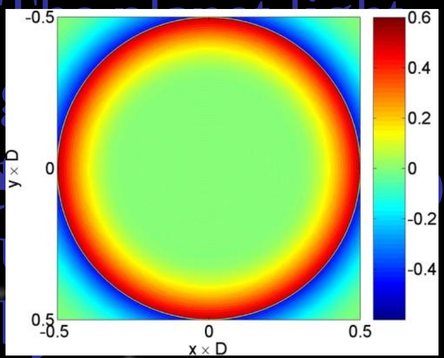
Occulter

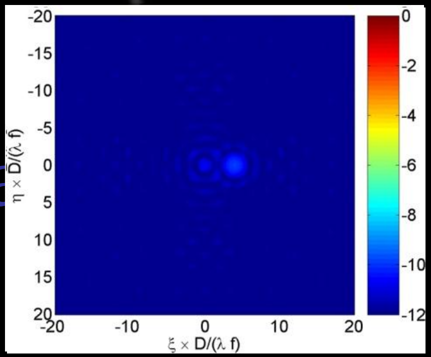
Lyot stop

Image plane





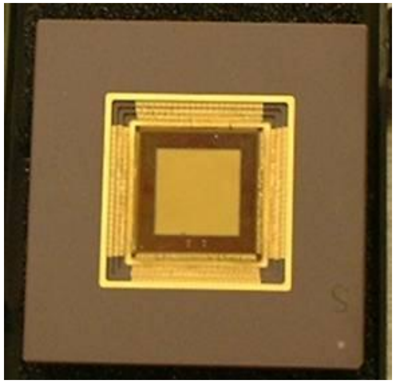




Slide courtesy of A. Give'on

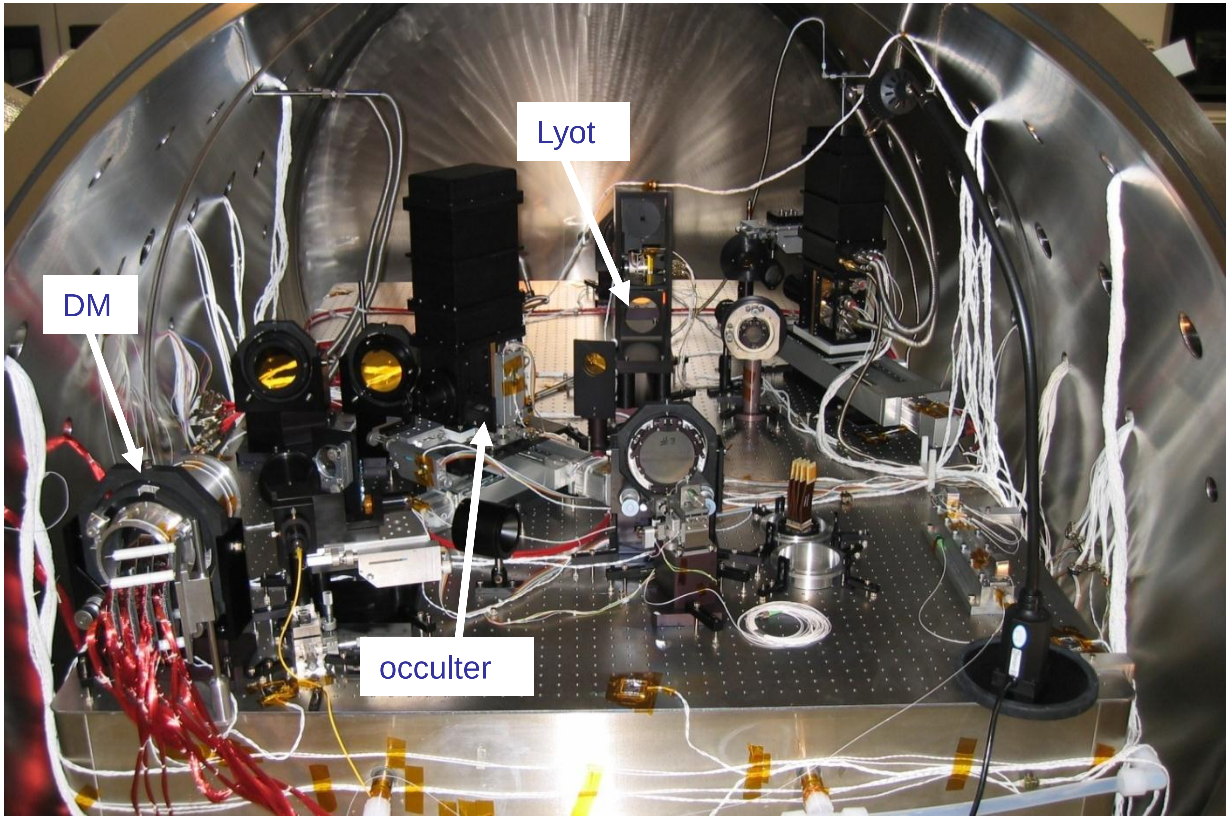
Wavefront Control for Scatter

Xinetics, 64x64 DM



Boston Micromachine
32 x32 MEMS

High Contrast Imaging Testbed (HCIT) provides experimental validation and guidance to models



Hybrid Lyot Coronagraph Experimental Results

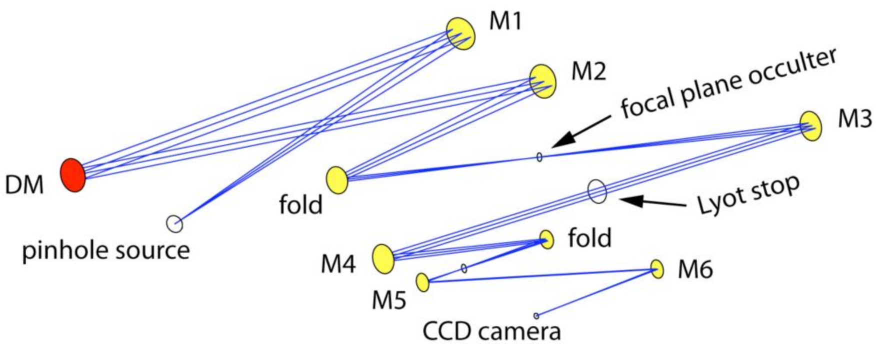
Coronagraph Technology Milestone:
Demonstration of ≤ 10^{-9} contrast w/ hybrid-Lyot Masks @ 3λ/D & 20% BW

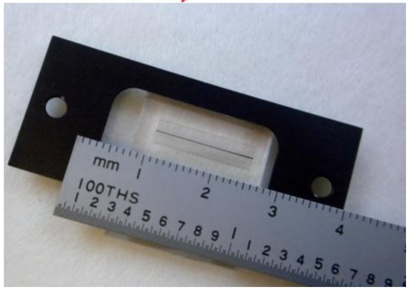
Facility: High Contrast Imaging Testbed 1, JPL

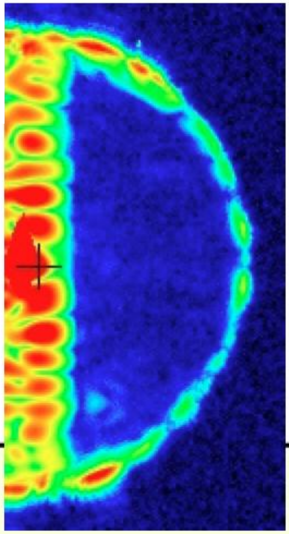
Current Status: 2×10^{-9} contrast @ 3-4 λ/D and 20%

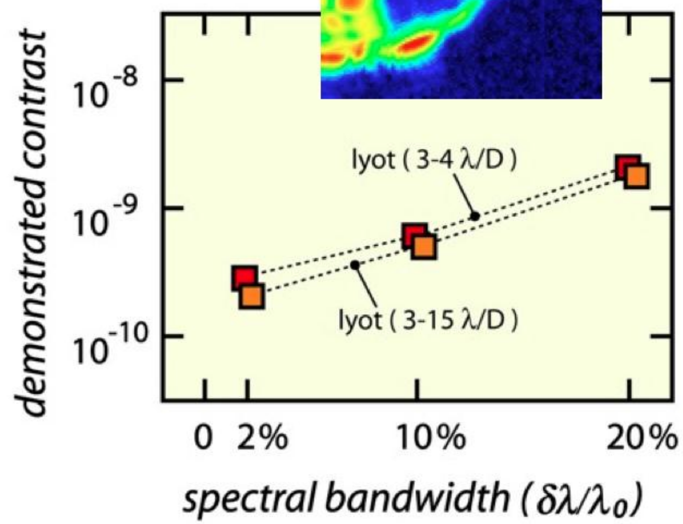
Challenges: Calibration of the dielectric layer during manufacturing.

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







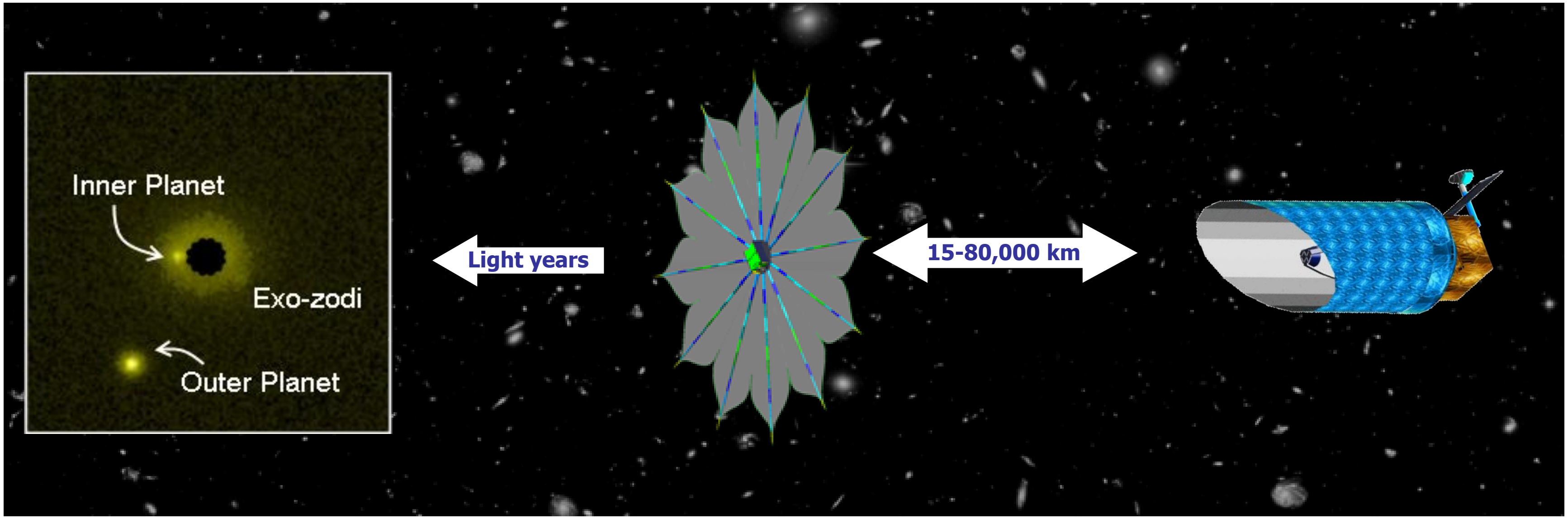


Hybrid Lyot Contrast Achieved to Date (Trauger TDEM)			
Inner Working Angle	Bandwidth		
	2%	10%	20%
3-4 λ/D	$3.2\ 10^{-10}$	$6.0\ 10^{-10}$	$1.9\ 10^{-9}$
3-15 λ/D	$2.0\ 10^{-10}$	$5.2\ 10^{-10}$	$1.9\ 10^{-9}$

Trauger et al, 2012

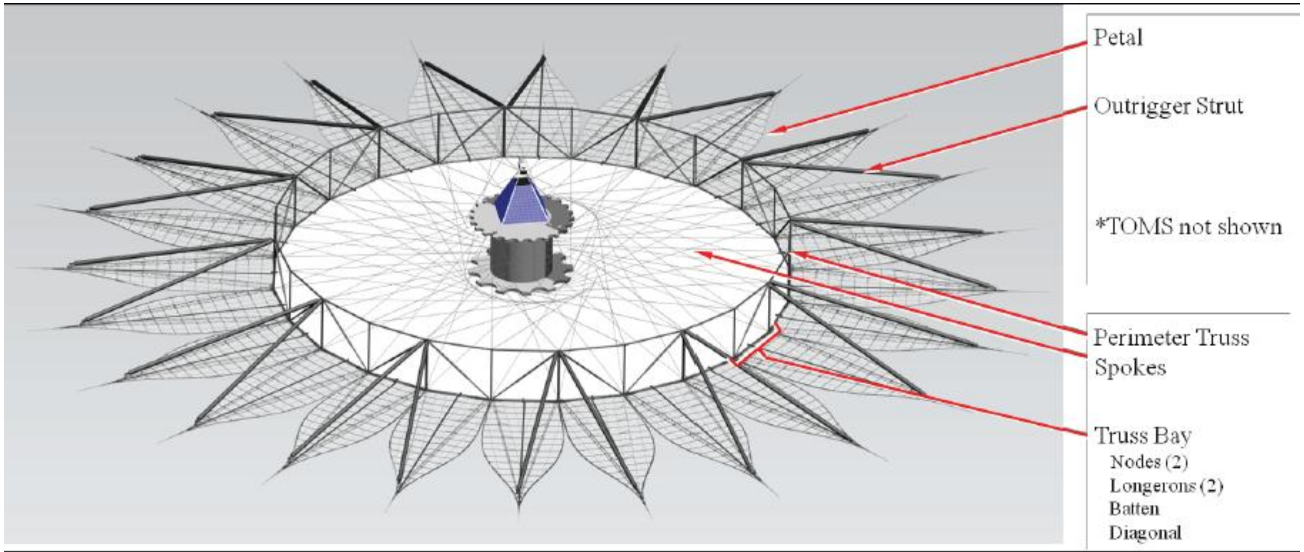
External Occulter

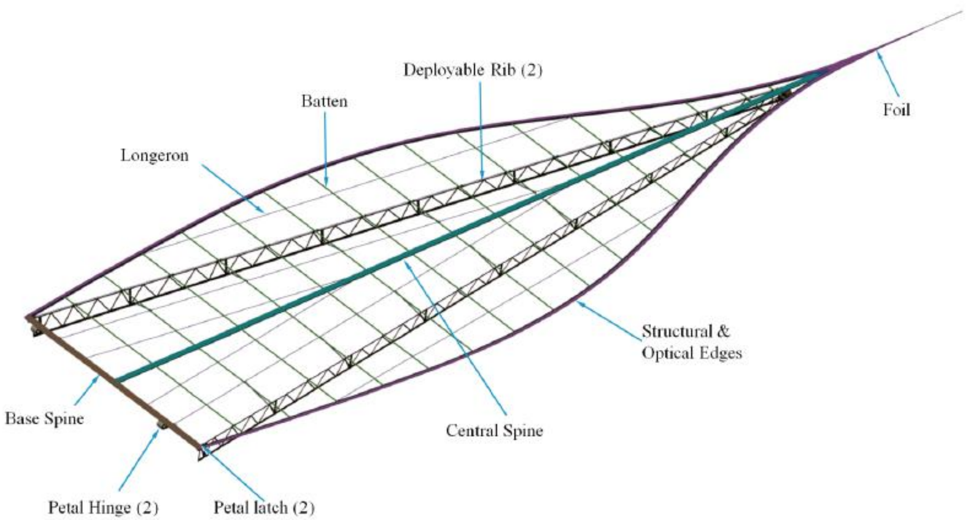
slide courtesy of Chuck Lilly et al., 2007



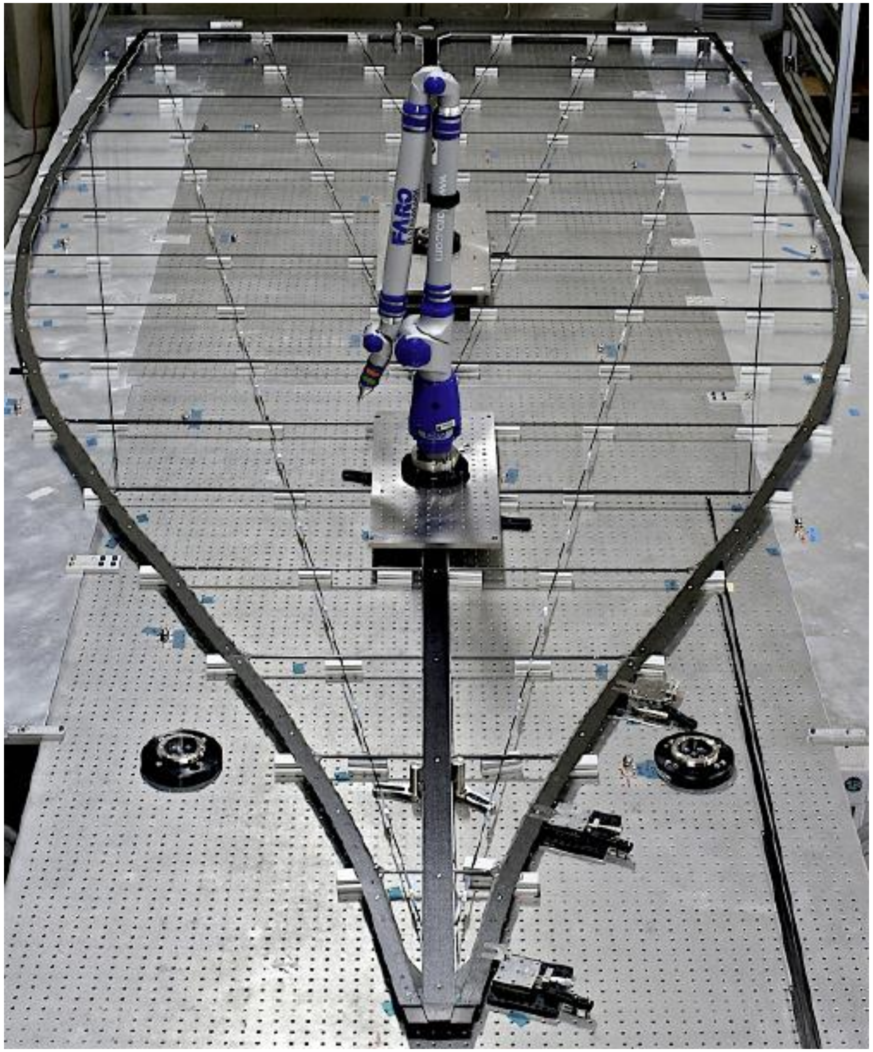
- Diffraction of a star's light by an "apodized" occulter yields a very dark shadow
- A telescope located in the shadow can "peek" around the occulter and directly detect the planet's light

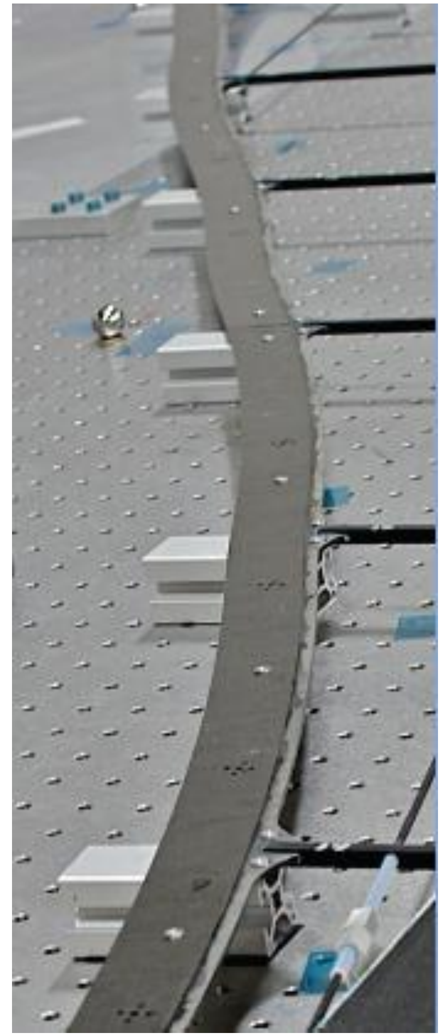
Starshade Construction and Deployment





Precision Starshade





SMD SBIR Technology Areas – S2.01, JPL

Subtopic:	Proximity Glare Suppression for Astronomical Coronagraphy
Manager:	Subtopic Mgr: Stuart Shaklan, JPL
Center(s):	Lead Center: JPL; Participating Centers: ARC, GSFC

Starlight suppression technologies: hybrid metal/dielectric masks; pupil apodization technologies; systems to measure optical density and phase uniformity in apodizing masks	**Science Traceability**	AFTA Coronagraph (M. Levine) Exoplanet Exploration Program (G. Blackwood)
	Need Horizon	2-3 yrs, for mid-decade technology downselect
	State of Art	Hybrid masks have been used to achieve better than 1e9 contrast in 20% bandpass. Performance is limited by mask uniformity. Characterization is difficult due to high-resolution needs on sub-mm mask scale.
	Importance	AFTA needs complex circular masks. These have never been used for high contrast imaging. Equally important is the ability to characterize the masks.
Artificial star and planet sources, with programmable aberrated wavefront	**Science Traceability**	AFTA Coronagraph (M. Levine) Exoplanet Exploration Program (G. Blackwood)
	Need Horizon	2-3 yrs, for mid-decade technology downselect and
	State of Art	Simultaneous observations of an artificial planet and star at high contrast ratio have not been tried yet. A front-end telescope based on low-order DM has not been used with a coronagraph.
	Importance	An artificial planet is needed to prove efficacy of planet extraction algorithms. The deformable front-end telescope is needed to prove ability to measure and control time-variable wavefront.
Wavefront Measurement and Control Technologies: scale, low-order aberration sensing; process improvements for yield, precision, and repeatability	**Science Traceability**	AFTA Coronagraph (M. Levine) Exoplanet Exploration Program (G. Blackwood)
	Need Horizon	2-3 yrs, for mid-decade technology downselect
	State of Art	64 x 64 DM used for 1e-9 broadband contrast. <5 dead or poor actuators. 4K wires to mirror. Low-order wavefront sensor shown to work on paper but not for multiple aberrations in the laboratory.
	Importance	Only one vendor's mirrors have so far achieved < 1e-9 contrast. Competing. approaches including ongoing SBIR are improving reliability and scale of MEMs DMs. LOWFS is critical to success of AFTA.

S2.01 Proximity Glare Suppression
(was S2.02 prior to 2012)

- **Lead Center: JPL**
  Participating Center(s): ARC, GSFC

  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.
- Pupil remapping technologies to achieve beam apodization.
- Techniques to characterize highly aspheric optics.
- Methods to distinguish the coherent and incoherent scatter in a 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 Continued

- ***Wavefront Control Technologie***s
- 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.

S2.01 cont'd

- ***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 TDEMS

2012 PHASE I

- *Fabrication Process and Electronics Development for Scaling Segmented MEMS DMs IRIS AO Inc.*
- *Driver ASICs for Advanced Deformable Mirrors Microscale, Inc.*
- *An Outrigger Component for a Deployable Occulter System Roccor LLC. (S2.02)*

2011 PHASE II

- *Nanostructured Super-Black Optical Materials Nanolab, Inc.*
- *Topography Improvements in MEMS DMs for High-contrast, High-resolution Imaging, Boston Micromachine Corp.*

2010 PHASE II

- *Achromatic Vector Vortex Waveplates for Coronagraphy Beam Engineering for Advanced Measurements*
- *Enhanced Reliability MEMS Deformable Mirrors for Space Imaging Applications Boston Micromachines Corp.*
- *Picometer-Resolution MEMS Segmented DM Iris AO Inc.*