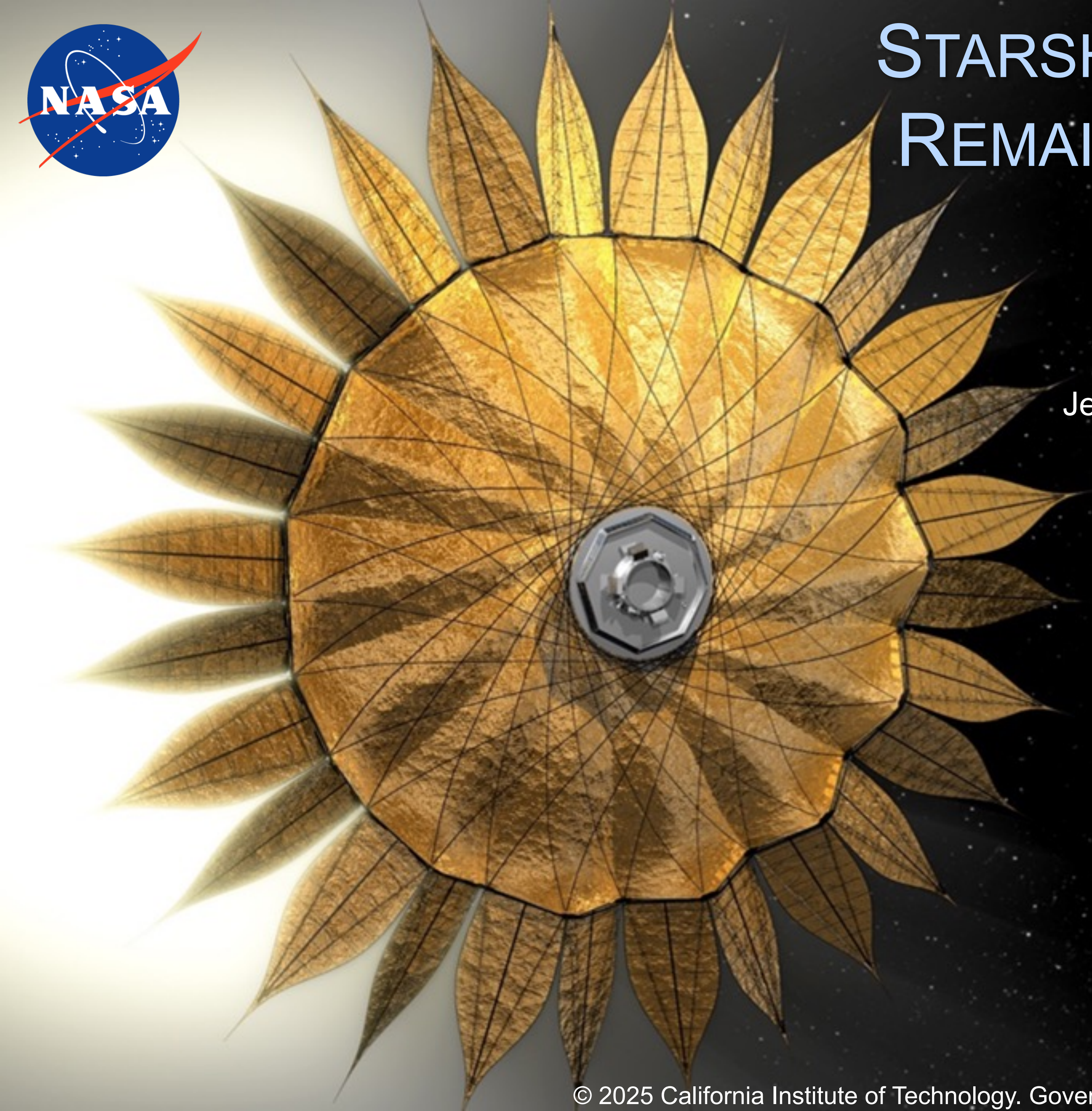

STARSHADE TECHNOLOGY STATUS: REMAINING DEVELOPMENT WORK TOWARDS HWO

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Starshade S5 Closeout Briefing
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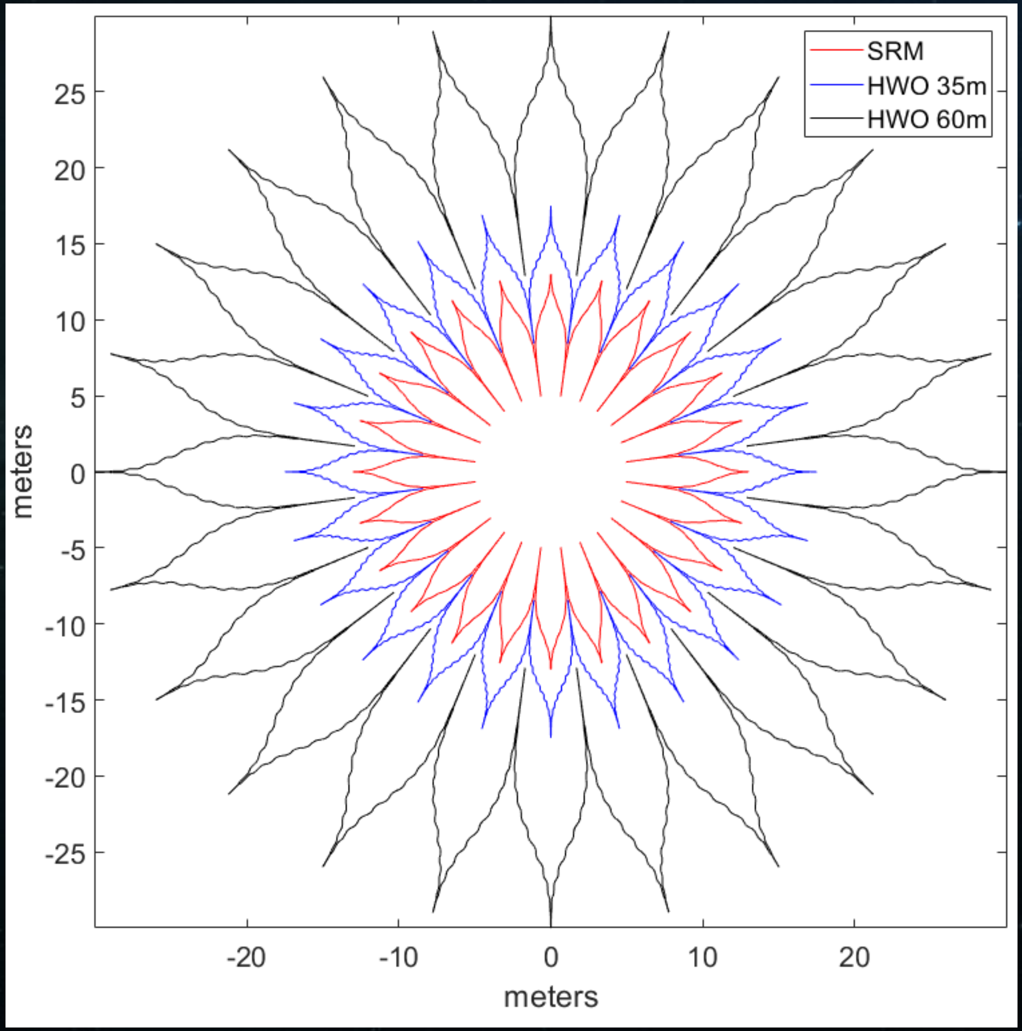
S5 BASELINE (SRM) VS. HWO STARSHADES

	S5 Baseline	HWO (UV-VIS)	HWO (VIS-NIR)
Starshade Diameter	**26 m**	**35 m**	**60 m**
Disk/Petals	**10 m, 8 m**	**17 m, 9 m**	**28 m, 16 m**
Telescope	**2.4 m**	**6 m**	**6 m**
Wavelength	**616-800 nm**	**250-500 nm**	**500-1000 nm**
IWA_{tip} (λ_{max}/D), mas	1.5 λ/D, 103 mas	3.8 λ/D, 65 mas	1.9 λ/D, 65 mas
Fresnel Number	8.1-10.5	11.0 – 22.1	9.5-19.9
Separation	26.0 Mm	55.5 Mm	95.2 Mm
Diam/Sep^2 (m/Mm^2)	0.039	0.011	0.007



S5 Baseline vs. HWO Starshades

	S5 Baseline	HWO (UV-VIS)	HWO (VIS-NIR)	
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Disk/Petals	10 m, 8 m	17 m, 9 m	28 m, 16 m	
Telescope	2.4 m	6 m	6 m	
Wavelength	616-800 nm	250-500 nm	500-1000 nm	
IWA_{tip} (λ_{max}/D), mas	**1.5 λ/D =103 mas**	***3.8 λ/D* = 65 mas**	***1.9 λ/D* = 65 mas**	Resolving power
Fresnel Number	**8.1-10.5**	***11.0 – 22.1***	***9.5-19.9***	Large F = easier
Separation	**26.0 Mm**	**55.5 Mm**	**95.2 Mm**	
Diam/Sep^2 (m/Mm^2)	**0.039**	***0.011***	***0.007***	Scatter factor

Well-resolved IWA, **3.8 λ/D**: telescope resolves perturbations away from the planet.
Large Fresnel Number, **11-22**: easier to form a shadow, reduced sensitivity to perturbations.
D/Separation^2, **0.011**: Solar glint scales as edge length / distance^2. Smaller means fainter glint.

HWO UV-VIS and VIS-NIR have reduced sensitivities to perturbations and 3.5 – 5 times less solar glint compared to the S5 baseline.

Remaining Development Work Towards HWO

Overview

26 m Baseline (TRL 5)	35 m UV/V (TRL 5)	60 m V/NIR (TRL 5)
Achieved:	Needed/Desirable:	Needed/Desirable:
• Optical tests 640-725 nm with deep contrast < 10^{-10}, limited by polarization.	• UV tests at 250 nm with deep contrast, true broadband vis with reduced polarization.	• True broadband NIR demo
• Optical Model Validation		
• Formation flying demo < 1 m		
• Scatter testing in the visible	• Scatter testing in the UV, quality control for AM etching vendor	• Quality control for AM etching vendor
• 4 m petal accuracy, thermal, deploy, stability.	• Already TRL 5 for a 35 m (9 m petals)	• Build half scale petal (8 m) with all defining features, demonstrate manufacturing, deployment cycles, thermal cycles, storage
• 10 m inner disk thermal, deploy, stability	• Already TRL 5 for a 35 m (17 m disk)	• Build a half-scale inner disk (14 m) with all defining features, including 4 representative petals, demonstrate manufacturing, deployment cycles, thermal cycles, storage, and solar arrays.

Starlight Suppression Towards HWO

26 m Baseline (TRL 5)

Achieved:

- Better than 1e-10 contrast in air at flight Fresnel number.
- 4 wavelengths 640, 660,700 725 nm (12.5% bandpass)
- Perturbation sensitivity study at 1e-9 – 1e-8 contrast.
- Models validated to factor of 1.25 (petal shape) and 2 (petal position)
- Limited by polarization due to small mask size

35 m UV/V (TRL 5)

Needed/Desirable:

- Optical/NUV Testbed demo (at XRCF for example) over 260 m of beam line (inner mask diam 36 mm)
- Goals: 1e-10 contrast at 250 nm, < 3e-10 peak polarization effect in the visible, and true broadband 500-740 nm (inner mask diam 47 mm).
- Secondary goals: add 1e-10 exoplanet, spin starshade, in-the-loop out of band formation flying.
- *Risk: L*
- *Effort: M ($2M, 2 yrs)*

- *Comment: the risk is in the execution, e.g. fabricating the mask, setting up at XRCF. The physics is very low risk.*

60 m V/NIR (TRL 5)

Needed/Desirable:

- No new tests if NUV tests are carried out.
- Performance risk for NIR considered very low.

- *Comment: The combination of UV tests and already-completed visible tests span a factor of 3 in wavelength. Not expected to learn anything new in the NIR.*

Risk / Level of effort are specified as Low, Medium, High (LMH).

Petal Edge Scatter Towards HWO

26 m Baseline (TRL 5)

Achieved:

- Measured scatter of coated edges to be equivalent to mag 30 integrated over starshade
- Measured in 4 bands
- In good agreement with FDTD models.
- Tested 80 cm long thermally and environmentally distorted segments.

35 m UV/V (TRL 5)

Needed/Desirable:

- Repeat scatter measurements for UV on UV-optimized coatings.
- Quality control process for etched edges.
- Goals: scatter equiv to mag 31.
- Segment length remains ~ 1 m.
- *Risk: L*
- *Effort: L*

- *Comment: Effort involves coating design and fab, procurement and fab of edges, modification and calibration of scatterometer.*

60 m V/NIR (TRL 5)

Needed/Desirable:

- No new tests if NUV tests are carried out.
- Quality control process for etched edges
- Performance risk for NIR considered very low. Segment length remains ~ 1 m.
- *Risk: L*
- *Effort: L*

- *Comment: 60 m has a lower scatter factor than the 35 m, and coatings are generally considered to be easier.*

Formation Sensing Towards HWO

26 m Baseline (TRL 5)

Achieved:

- Through a small-scale laboratory demonstration, measured ability to determine lateral alignment to 30 cm using an out-of-band pupil plane sensing approach.
- Separate from S5 tests, the Princeton testbed demonstrated hardware-in-the-loop formation control with 10^{-10} in-band contrast. (Palacios et al 2020).

35 m UV/V (TRL 5)

Needed/Desirable:

- Design and requirements are the same. Different band is used but no performance degradation expected.
- No new tests.

60 m V/NIR (TRL 5)

Needed/Desirable:

- Design and requirements are the same. Different band is used but no performance degradation expected.
- No new tests.

Petal Shape Accuracy and Stability Towards HWO

26 m Baseline (TRL 5)

Achieved:
- Petal pre-launch shape accuracy and stability
- Petal thermal stability on-orbit
- This was with a 4 m petal, and section of a 6 m petal

- We do not have model validation of Optical Shield influence on petal shape.

35 m UV/V (TRL 5)

Needed/Desirable:
- At TRL-5 for a 9 m petal.
- No additional tests for TRL-5.

60 m V/NIR (TRL 5)

Needed/Desirable:
- Design, build, and test an 8 m petal.
- Demonstrate manufacture accuracy and thermal and shape stability, test hinge interfaces
- Medium fidelity, all defining features
- Validate models of optical shield influence on shape.
- *Risk: L*
- *Effort: H*
- *This is a repeat of all the S5 petal milestones with a larger petal.*

Inner Disk Accuracy and Stability Towards HWO

26 m Baseline (TRL 5)

Achieved:
- Pre-launch inner disk accuracy and on-orbit stability
- Inner disk thermal stability on orbit.
- This was with a 10 m disk including a multi-layer optical shield but no closeout shield.

- We do not have model validation of Optical Shield influence on disk shape.

35 UV/V (TRL 5)

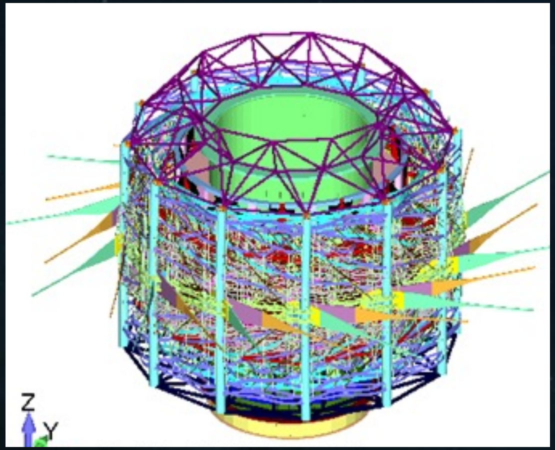
Needed/Desirable:
- At TRL 5 for a 17 m disk.

60 m V/NIR (TRL 5)

Needed/Desirable:
- Test a medium fidelity14-m truss with four 8-m petals.
- Medium fidelity truss bay pair (for 14 m truss) with all defining features.
- Demonstrate manufacture accuracy and thermal and shape stability.
- Validate models of optical shield influence on shape.
- Demonstrate solar panel integration including cabling.
- *Risk: L*
- *Effort: H*
- *This is a repeat of all the S5 petal milestones with a larger petal.*

System-Level Activities Towards TRL5 for HWO

- **Launch loads analysis**
  - S5 Starshade was analyzed for launch loads in stowed configuration with petal launch and unfurling system (PLUS)
  - Repeat analyses for larger starshades



- **Solar array integration**
  - Larger starshades retargeting will be propelled by solar-electric propulsion
  - Put PV cells on disk optical shield
  - Preliminary studies have already demonstrated that the current disk optical shield design can host PV cells (stow-deploy testing showed no degradation)
  - Further design and testing is needed, especially with regards to power harnessing for DC power delivery from optical shield to hub