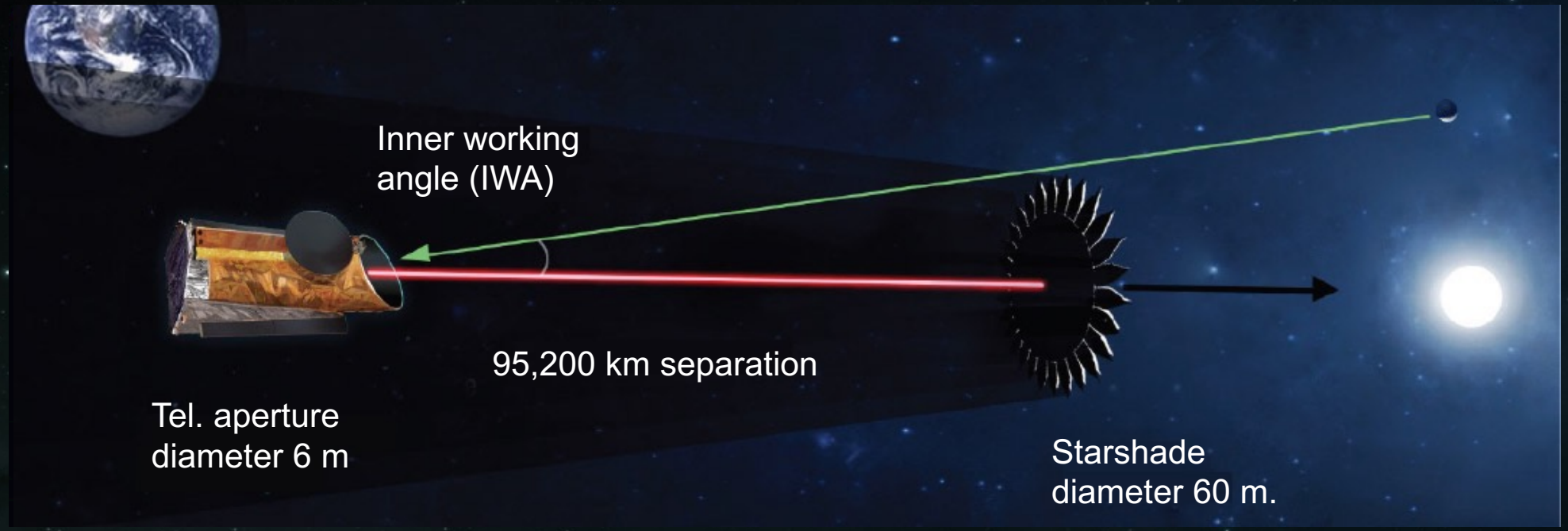
STARSHADE OVERVIEW

Sara Seager[a], Stuart Shaklan[b], Doug Lisman[b], Rhonda Morgan[b], Serena Ferraro[b], Manan Arya[c]

[a]Massachusetts Institute of Technology
[b]Jet Propulsion Laboratory, California Institute of Technology
[c]Stanford University

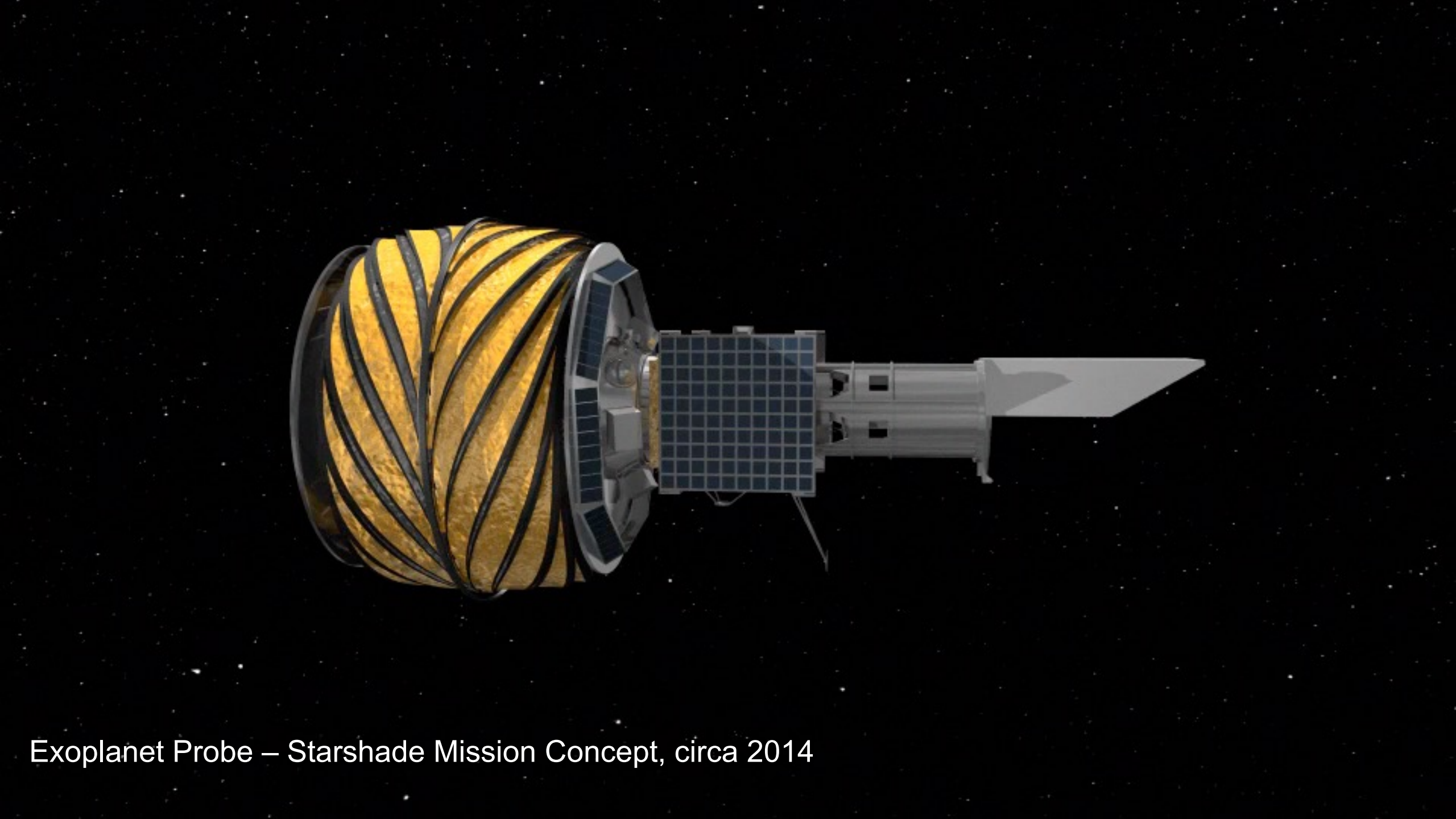
Towards Starlight Suppression for the Habitable Worlds Observatory Workshop
Caltech, August 9, 2023

What is a Starshade?



- Flower-shaped screen, 10's of meters in diameter.
- Flies in formation with a telescope, aligning with a target star.
- Controls diffraction, forms a deep shadow where the telescope is positioned.

- Inner working angle (IWA) is the starshade radius divided by its distance.
- For the HWO concept, r = 30 m, D = 95.2 Mm, IWA_{tips} = 65 mas.
- Repositioning requires ~ 7 – 15 days.
- Highly efficient planet characterizer.



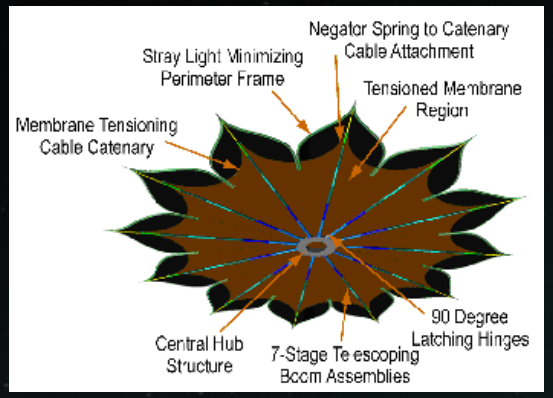
Exoplanet Probe – Starshade Mission Concept, circa 2014

Why Consider a Starshade?

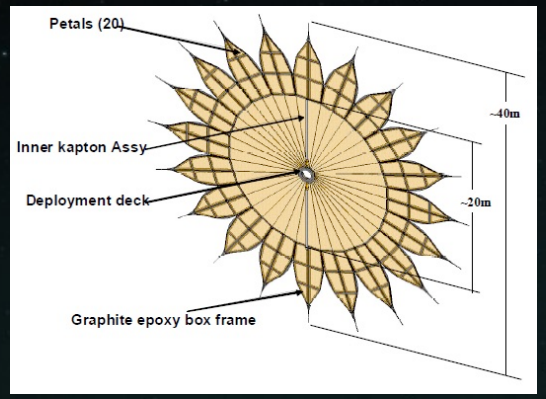
Starshades remove the starlight before it can scatter into the telescope. This allows the system to achieve the ultimate high-contrast sensitivity.

Parameter	HWO Starshade concept
Inner Working Angle	1.9 λ/D
Outer Working Angle	Unlimited
Bandwidth	One octave
Instrument Contrast	Better than 4e-11 at tips
Throughput	100% beyond the tips
Telescope stability, shape, segmentation	Works equally well with any aperture, segmented or monolithic, on- or off-axis. Does not drive stability.

‘Modern’ History of Starshade Studies

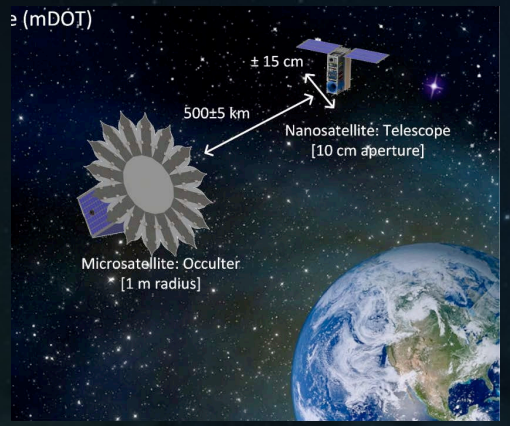


New Worlds Observatory, 50 m, Cash 2008

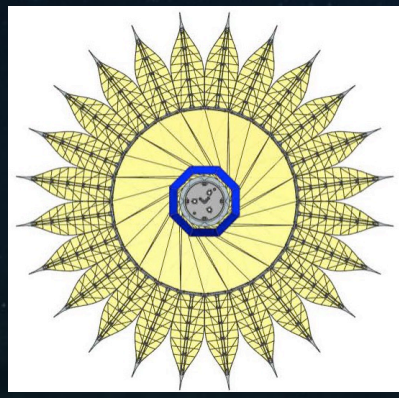


THEIA, 40 m, Kasdin 2009

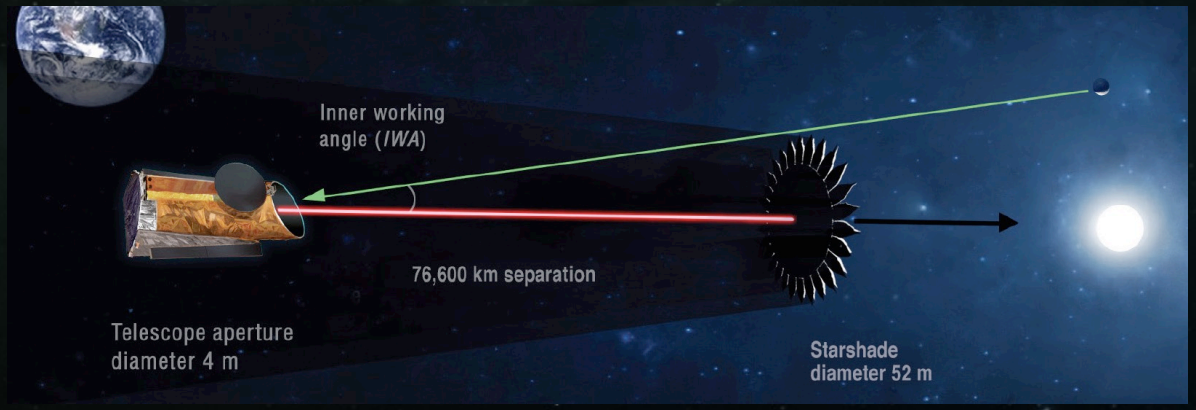
Exo-S Dedicated, 2014



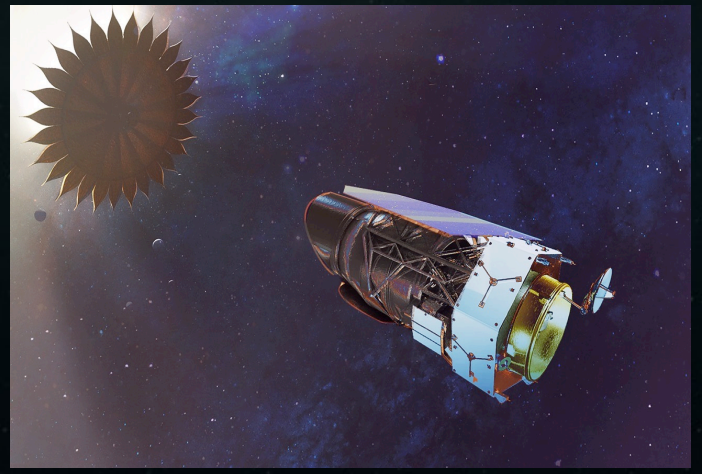
mDot, 3 m, Koenig 2015



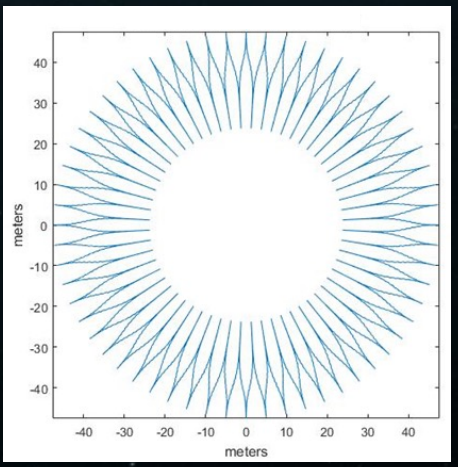
O3, 16 m, Lisman 2019



HabEx, 52 m, 2019



SRM, 26 m, Seager & Kasdin 2019



HOEE, 100 m
Mather 2020

Starshade Size

Here is an HWO concept. The starshade has a **60 m diameter** and is designed to achieve IWA_{tip} = 65 mas and $IWA_{0.5}$ = 51 mas, over the band 500-1000 nm.

The starshade bandpass is inversely proportional to its distance from the telescope.

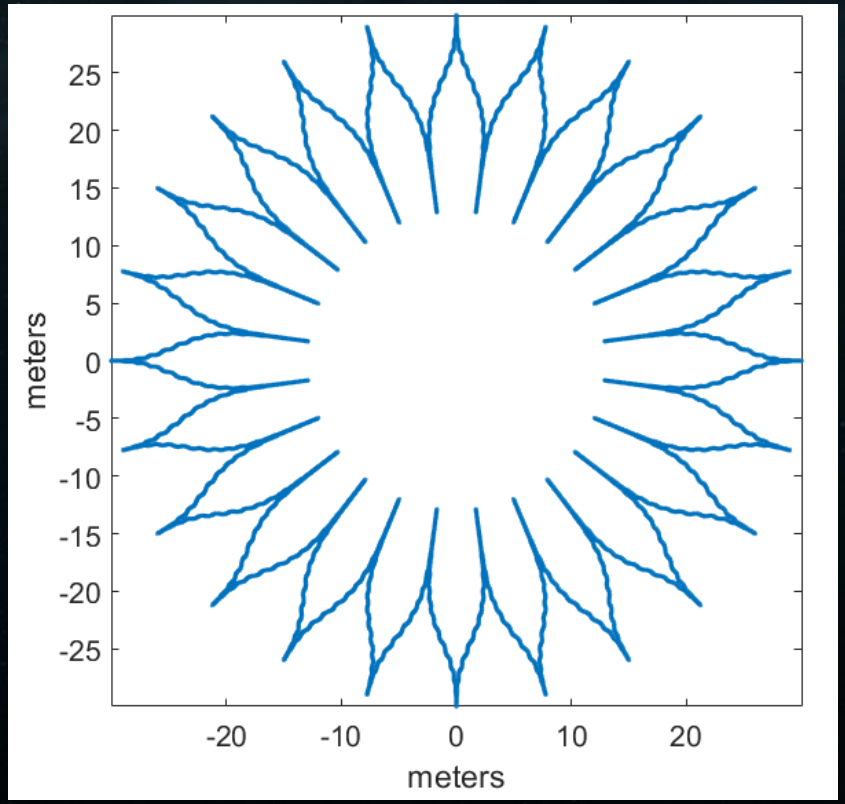
For example, it can be moved 1.8x closer to work in the band 900-1800 nm, with and has $IWA_{0.5}$ = 92 mas.

HWO concept parameters:

- Tip width: 16 mm
- Gap width: 2.1 mm
- Petals: 16 m long, 24 petals
- Disk Diameter: 28 m

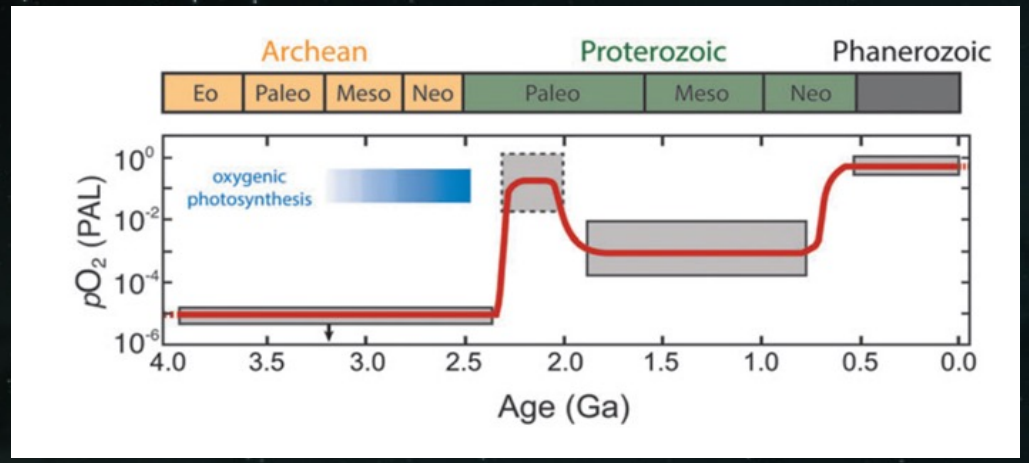
HWO concept 60 m starshade

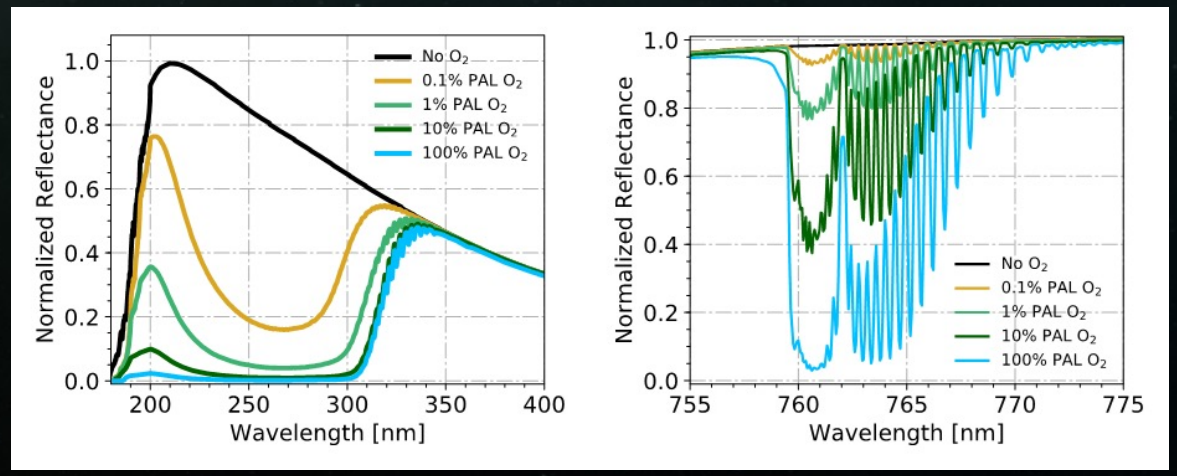
Bandpass (nm)	IWA (mas) Tip / 50%	Distance (Mm)
250-500	32.5 / 43	190.4
500-1000	65 / 51	95.2
900-1800	117 / 92	47.6



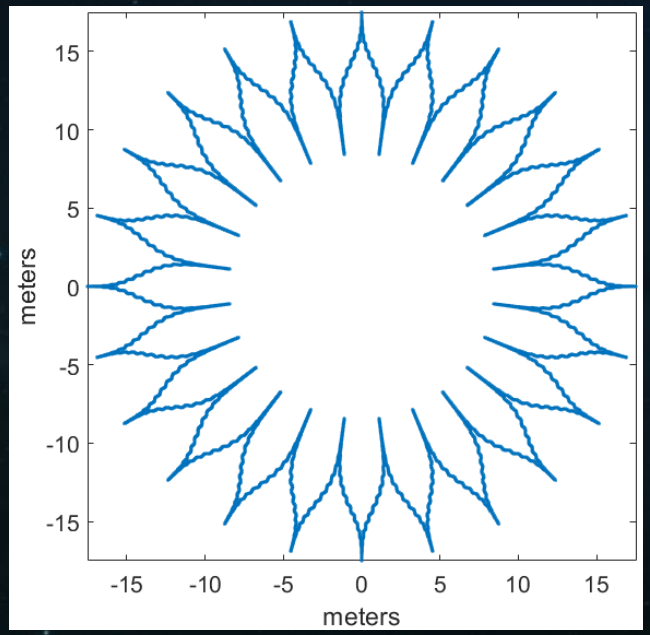
UV Observations

The Decadal survey emphasized the importance of UV exoplanet spectroscopic capabilities. Starshades work exceptionally well in the UV.





HWO UV concept 35 m starshade

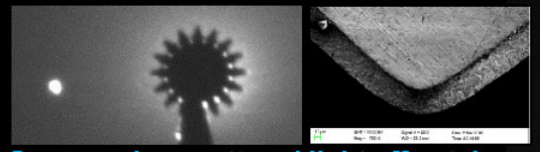


HWO UV concept parameters:

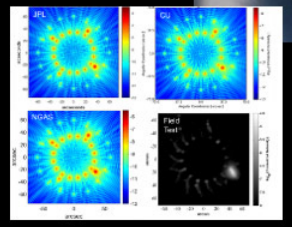
- Tip width: 3 mm
- Gap width: 2 mm
- Petals: 9 m long, 24 petals
- Disk Diameter: 17 m

STARSHADE TECHNOLOGY GAPS

(1) Starlight Suppression

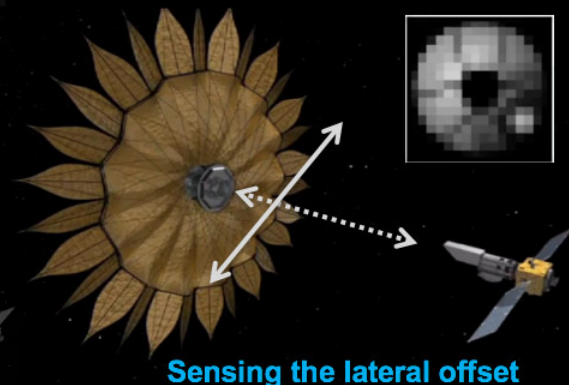


Suppressing scattered light off petal edges from off-axis Sunlight (S-1)



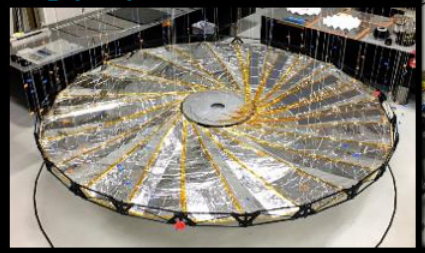
Suppressing diffracted light from on-axis starlight and optical modeling (S-2)

(2) Formation Flying



Sensing the lateral offset between the spacecraft (S-3)

(3) Deployment Accuracy and Shape Stability



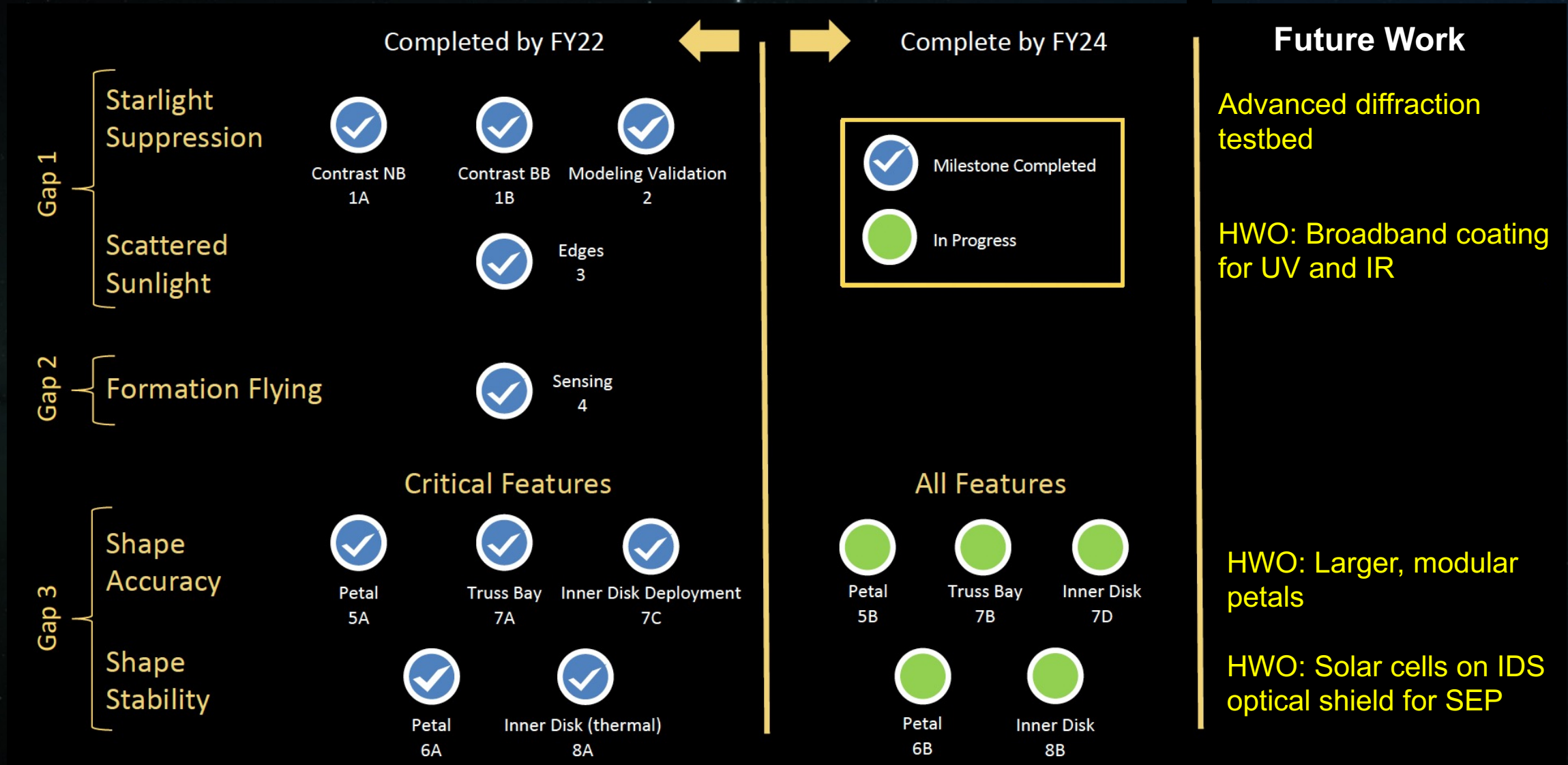
Positioning the petals to high accuracy, blocking on-axis starlight, maintaining overall shape on a highly stable structure (S-5)

Fabricating the petals to high accuracy (S-4)

S-# corresponds to ExEP Starshade Technology ID# (http://exoplanets.nasa.gov/exep/technology/gap-lists)

September 27, 2018

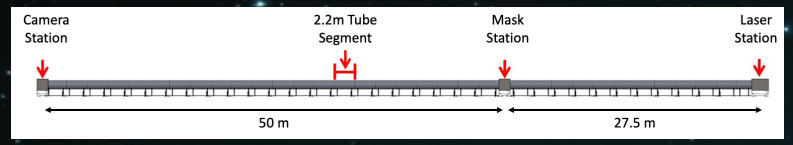
Path to TRL5: Closing Technology Gaps

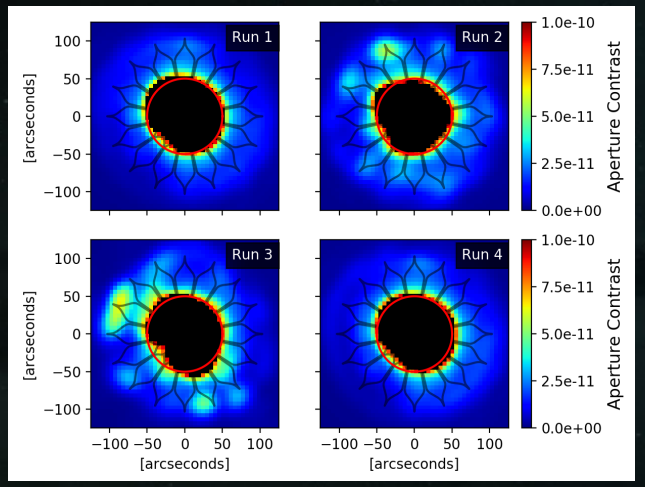


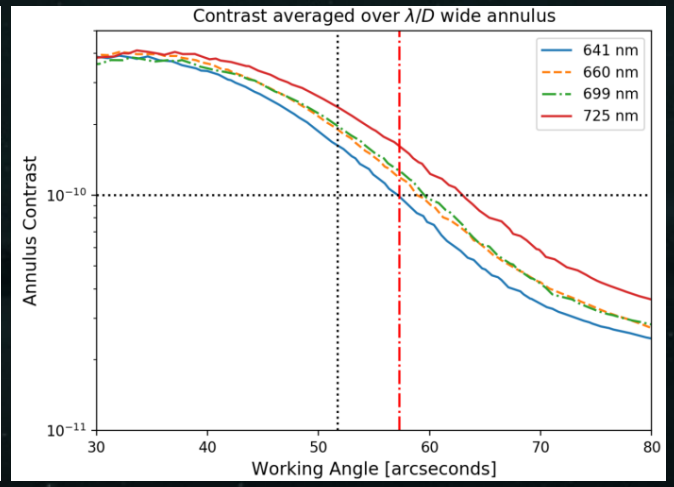
Overall "Starshade to TRL5" (S5) plan for closing technology gaps and S5 Milestone reports accessible at https://exoplanets.nasa.gov/exep/technology/starshade/

Optical Technology

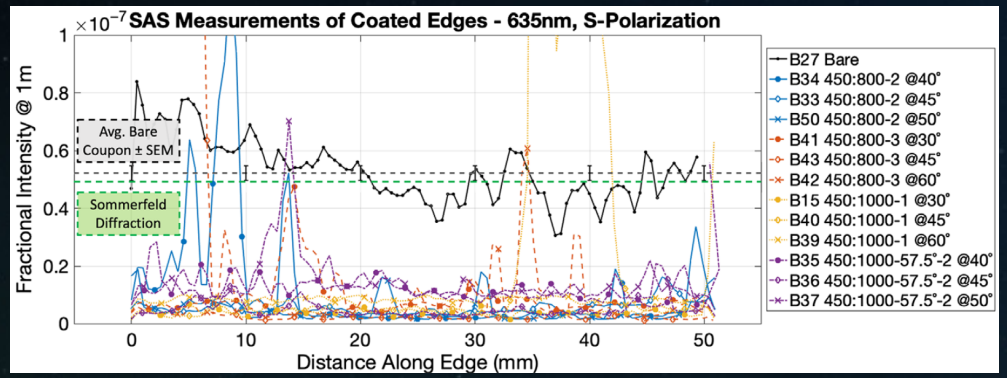
Starlight suppression: Demonstrated < 1e-10 contrast over 75% of search space.

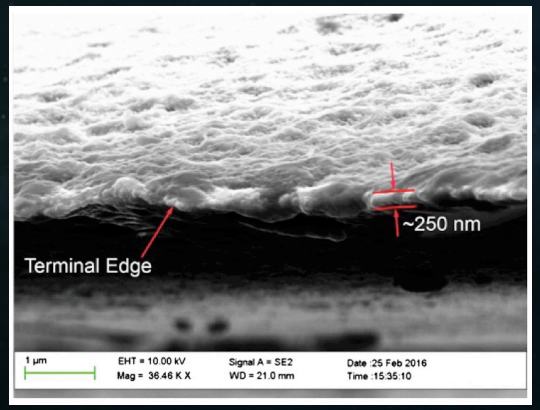


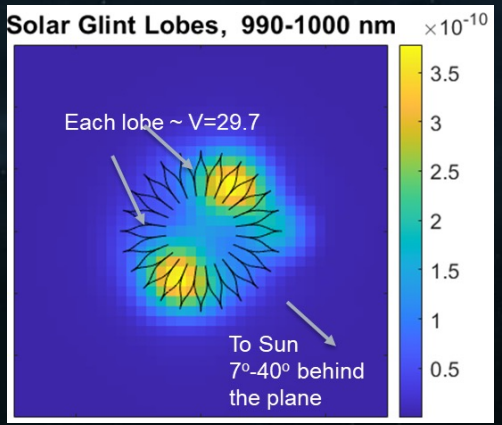




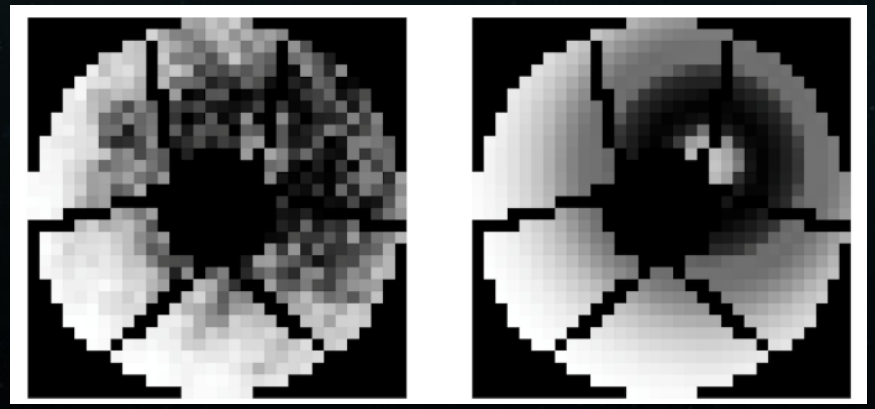
Solar Glint

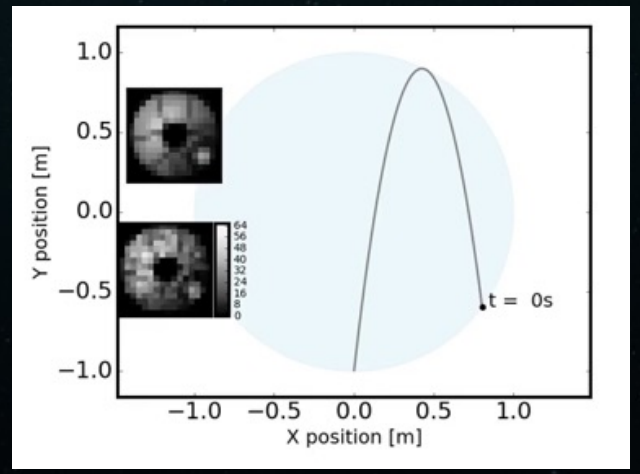






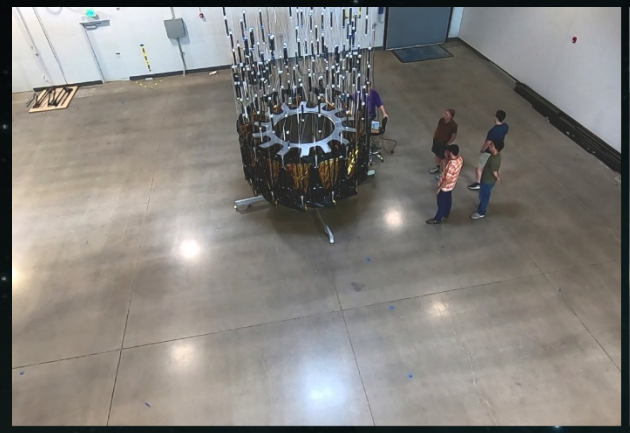
Formation flying sensing



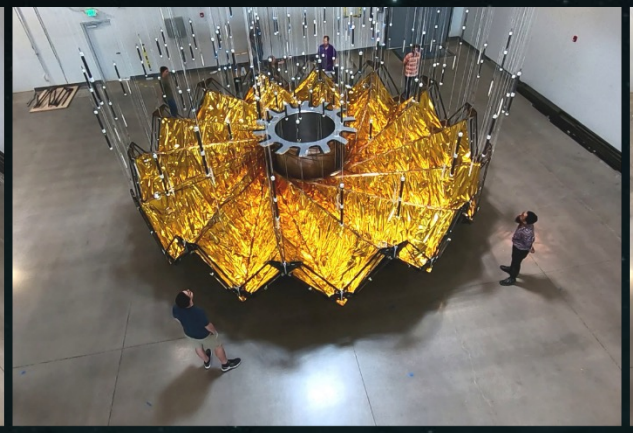


MECHANICAL TECHNOLOGY

Inner Disk: 10 m diameter with shield deploys to well within requirements.

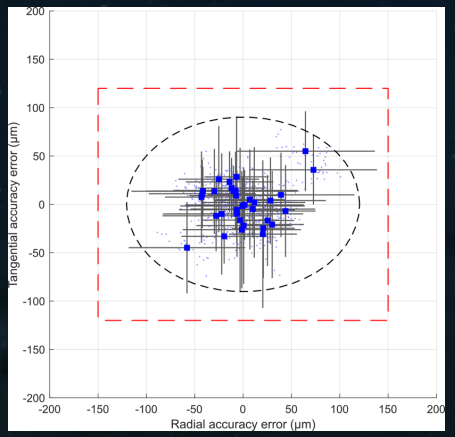


Stowed

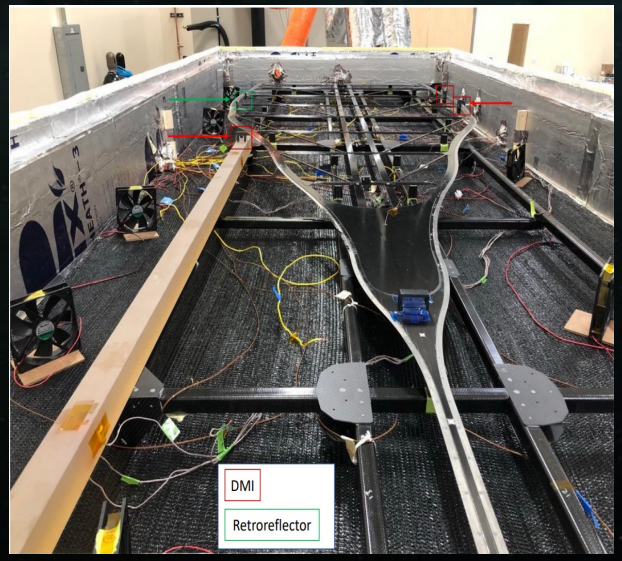


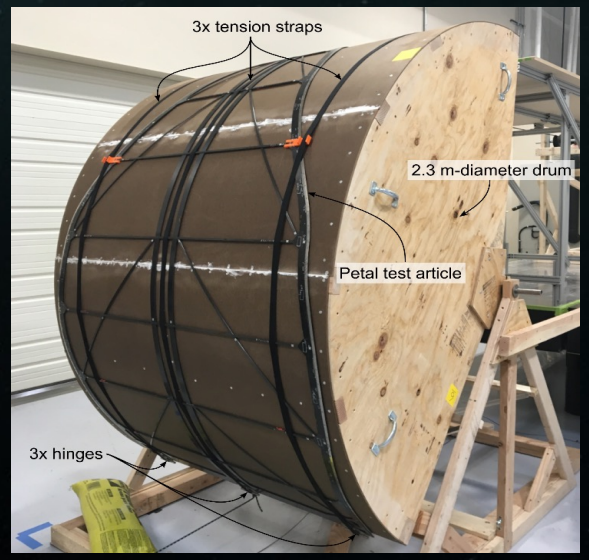
Partly deployed

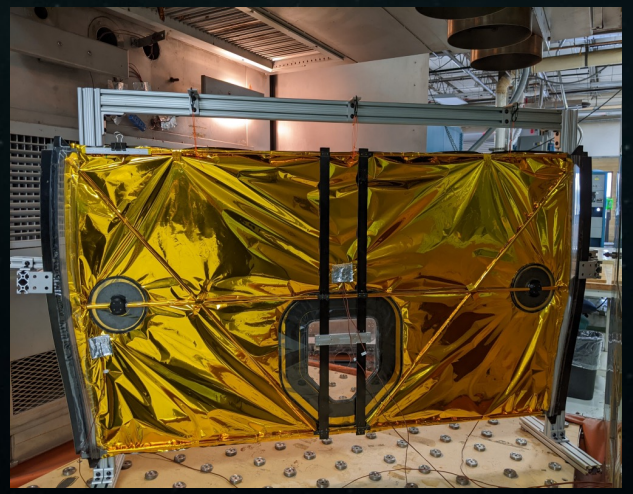
Fully deployed

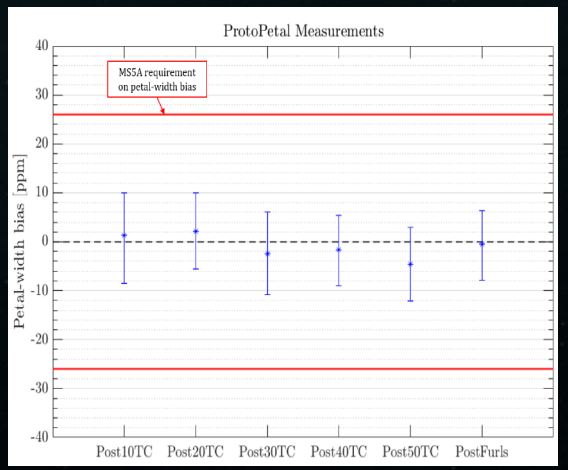


Petals: 4 m petal furled, thermally tested, meets accuracy and stability requirements.

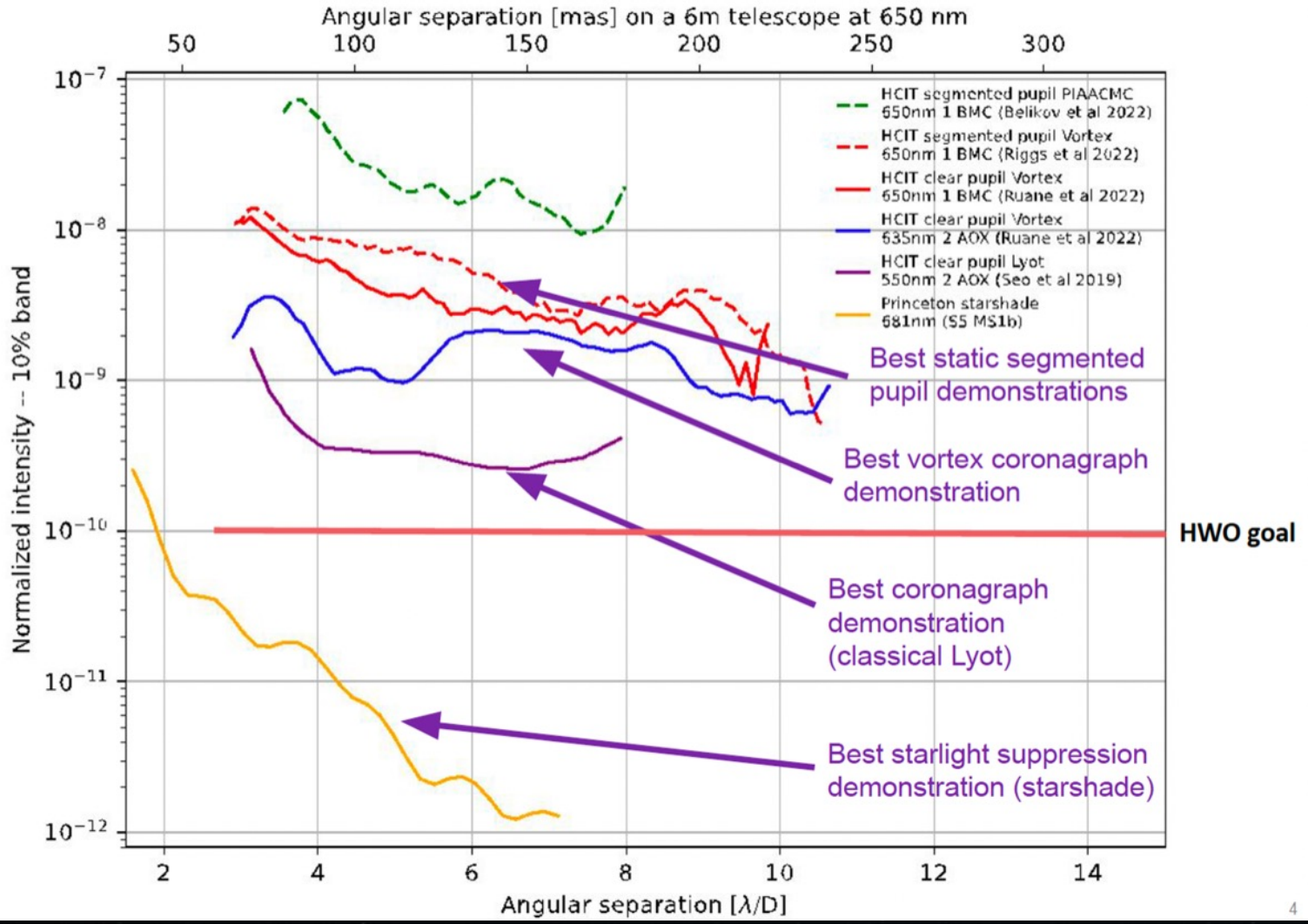






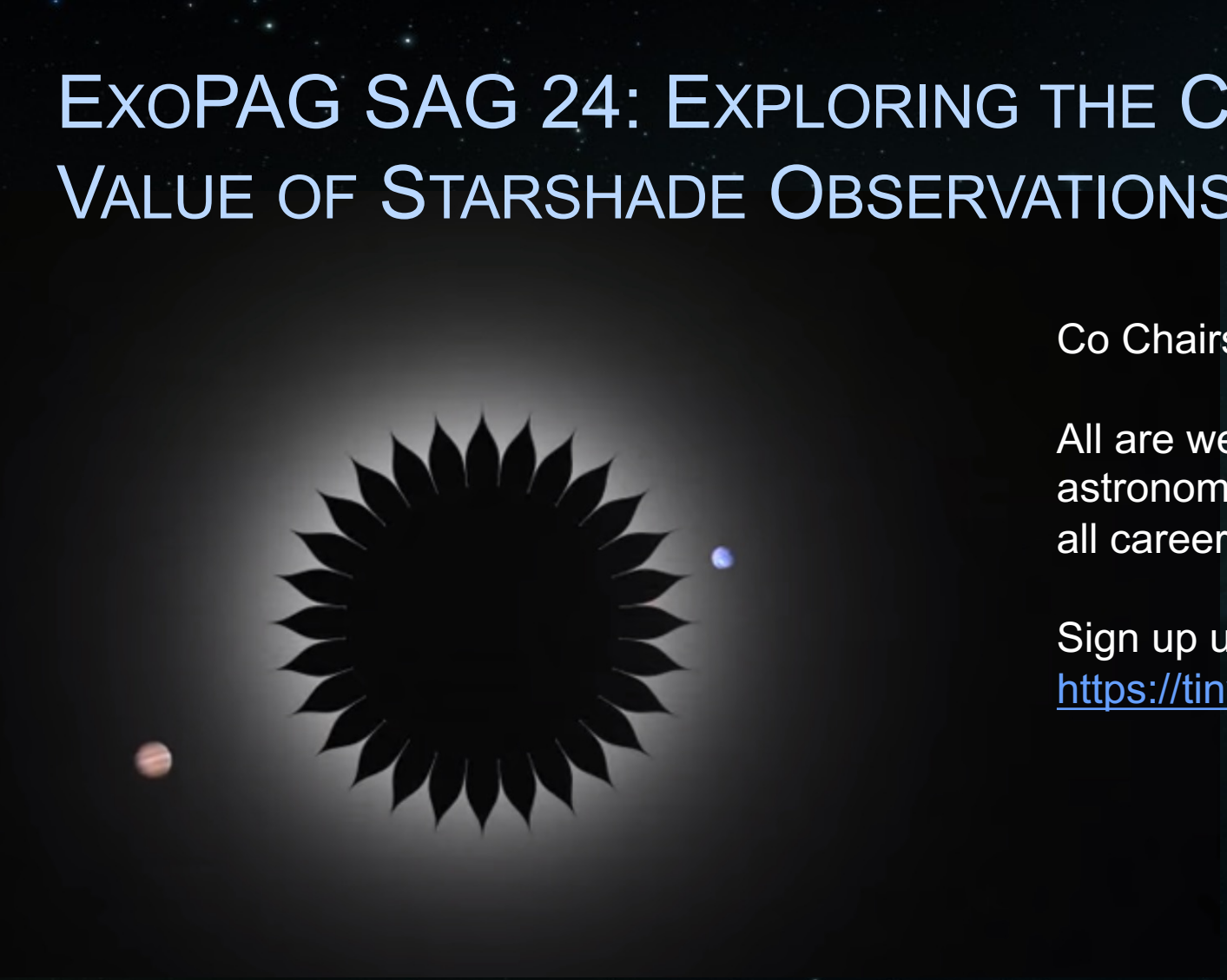


Best Broadband Demonstrations to Date



https://exoplanets.nasa.gov/internal_resources/2664/

ExoPAG SAG 24: Exploring the Complementary Science Value of Starshade Observations



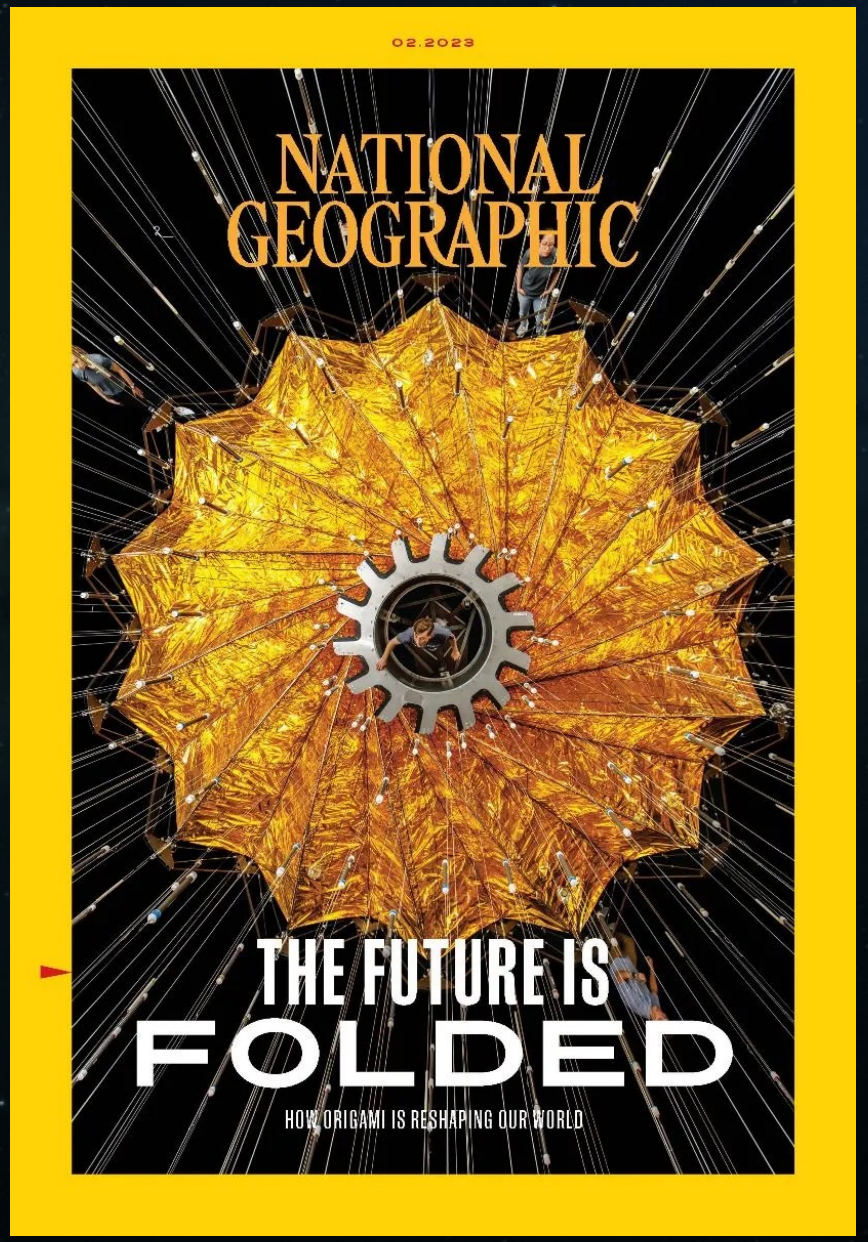
Co Chairs: Sara Seager, Stuart Shaklan

All are welcome as SAG members from the broad astronomy and aerospace engineering communities and all career stages are encouraged.

Sign up url:
https://tinyurl.com/StarshadeSAG

SUMMARY

- Starshades perform compelling science, particularly for UV/O/IR characterization of exoearths and planetary systems.
- HWO concepts, both with IWA_{tip} = 65 mas:
  - 60 m starshade, bandpass 500-1000 nm
  - 35 m starshade, bandpass 225-500 nm
- NASA directed/competed funding has led to tremendous strides in technology:
  - Proven optical performance
  - Proven ability to sense position
  - Proven mechanical feasibility
- Starshades capture the imagination of the public, as shown here!



National Geographic Cover, February 2023