

STARSHADE: A BROAD-BAND, HIGH-THROUGHPUT ARCHITECTURE FOR EXO-EARTH DISCOVERY AND CHARACTERIZATION

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EXOPLANETS ARE COMPLEX

Characterizing exoplanets demands broad-band, high-throughput, deep contrast, small working angle.



NOAA/NASA EPIC Team

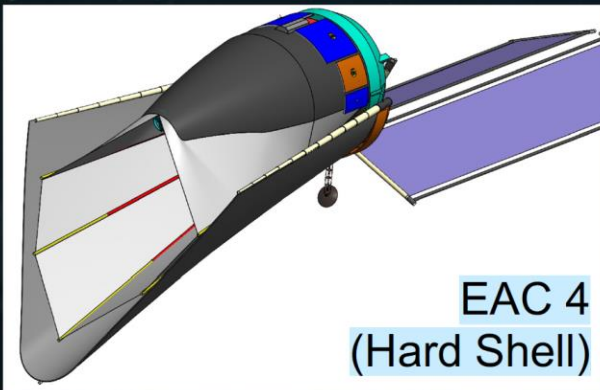


Voyager 1's Pale Blue Dot

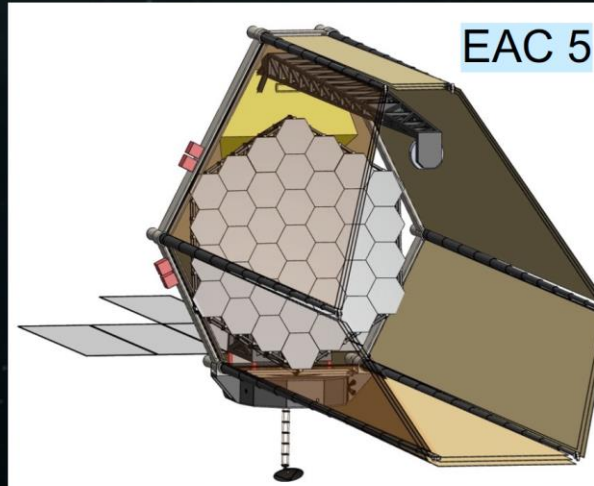
NASA's PLAN

- HWO is being designed to characterize ~ 25 Exo-Earths
 - Coronagraphs require weeks for a partial spectrum in 20% bandwidth snippets within 400-1000 nm band. Can possibly expand to 250-1800 nm for a few planets assuming the addition of UV and NIR coronagraphs, in first or second generation instruments.
- Gap: how to fully characterize planets without investing in a 2nd HWO?

CML 4 Starting Point



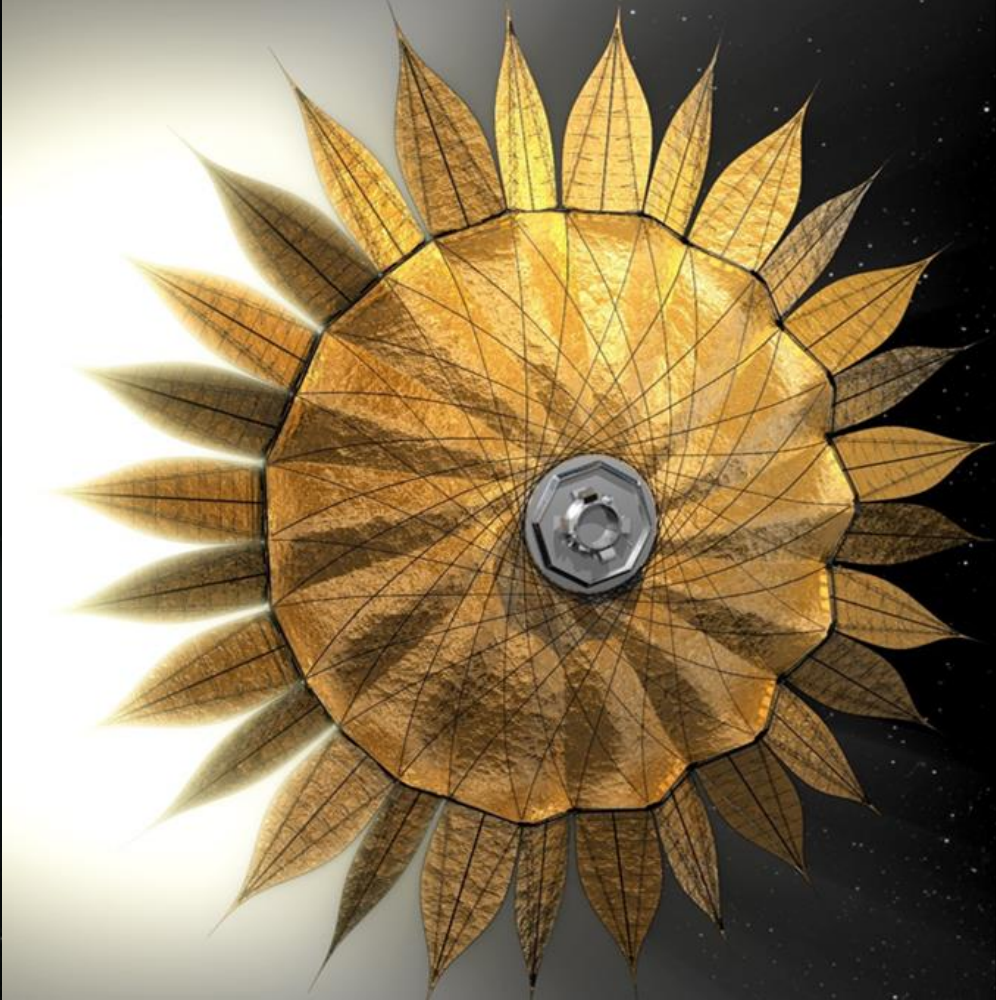
Off axis, >6m
Volume dual rocket
compatible
5 instruments w/UV IFU
2 channel Vis+NIR
Coronagraph



Off axis, >8m
Volume dual rocket
compatible
5 instruments w/UV IFU
3 channel Vis / Vis + NIR
Coronagraph

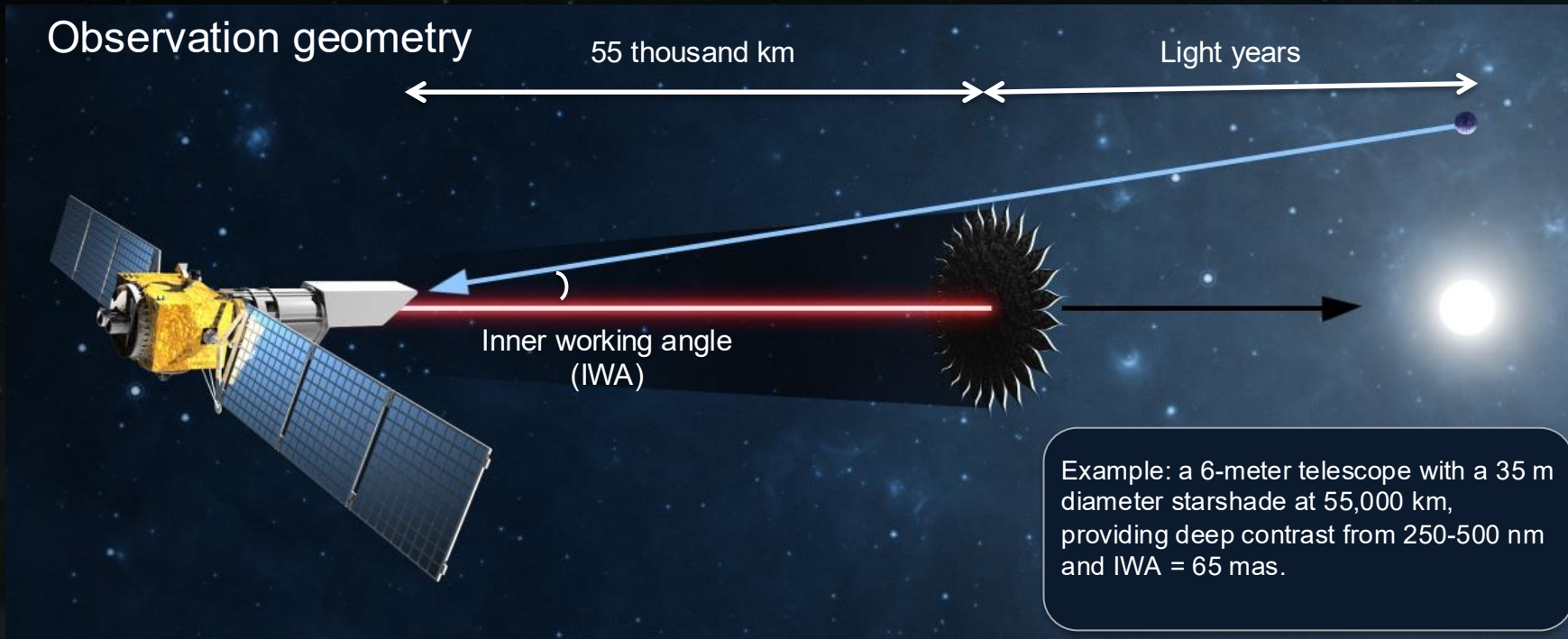
Images from J. Ziemer. HWO ICS Workshop, May 2026

FILLING THE GAP: STARSHADE-READY TELESCOPE



- ANY NUV/Vis/NIR telescope in deep space or multi-day Earth orbit can be transformed into a powerful exoplanet observatory by pairing it with a starshade.
 - Minor investment in “starshade ready” including a camera, spectrometer, and communication with the starshade.
- Because the starshade blocks the starlight before it can enter the telescope:
 - There are NO DRIVING REQUIREMENTS ON THE TELESCOPE.
 - 100% planet throughput, 60-100% bandwidth, better than 10^{-10} contrast, small working angle (e.g. 60 mas).
- Augments HWO exoplanet characterization including UV, Vis, and NIR.

STARSHADE 101

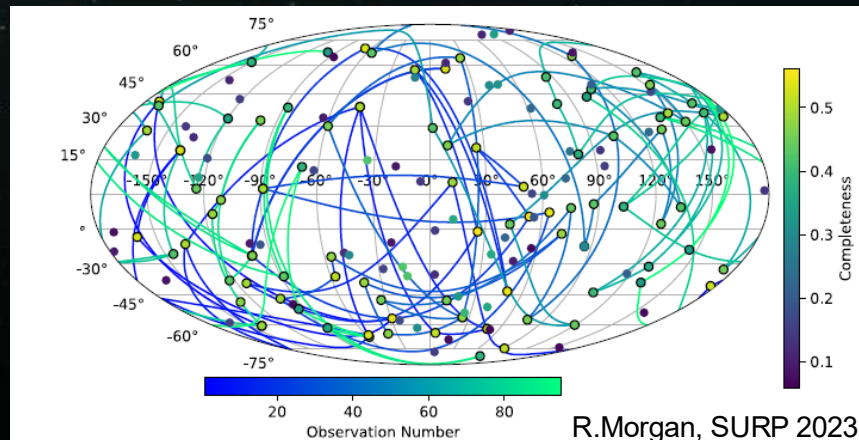


The starshade blocks starlight in space where the signal from the planet and the signal from the star do not overlap.

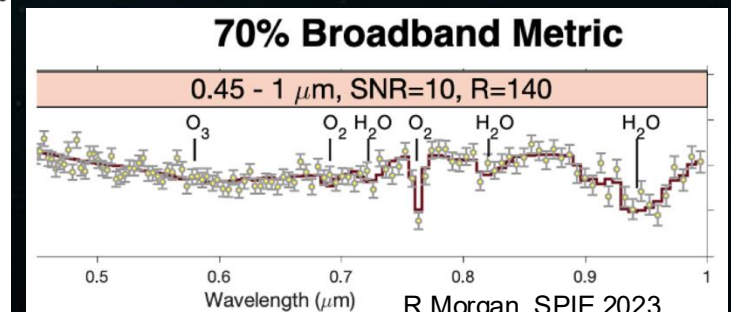
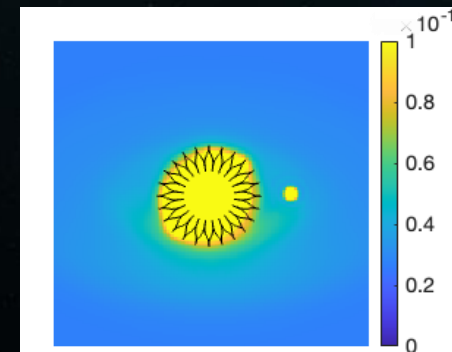
Starshades attributes:

- 100% throughput
- Wide bandwidth
- Excellent in the UV
- Small Inner Working Angle
- Standard Machine Tolerances, no picometers
- Works with any telescope, e.g. on- or off-axis, segmented or monolithic

Slew from target to target, 1-2 weeks/slew



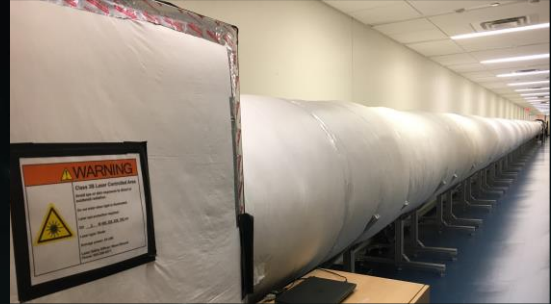
Science products are direct images and spectra



STARSHADE TECHNOLOGY: TRL-5 FOR OPTICAL PERFORMANCE, FORMATION

FLYING, AND MECHANICAL SUBSYSTEMS (PETALS, TRUSS)

Princeton optical testbed



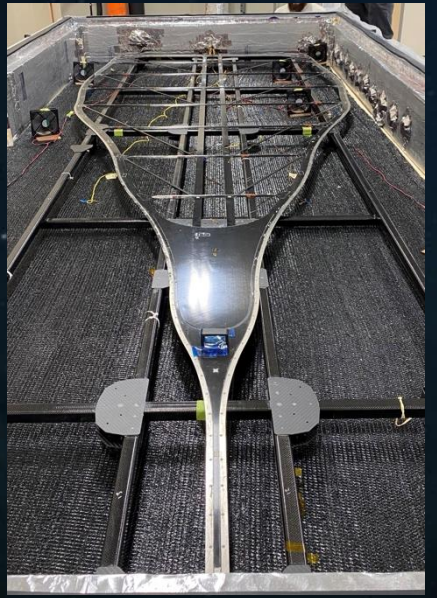
Precision mask



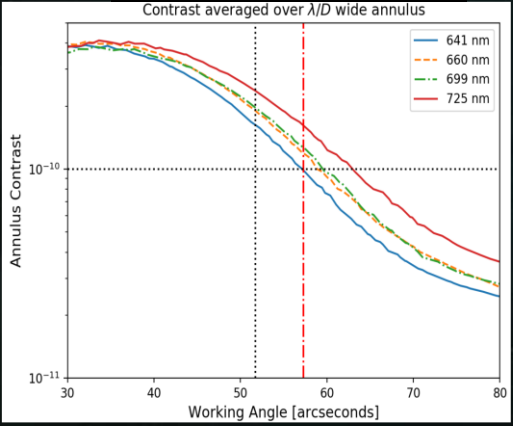
10 m disk with petals



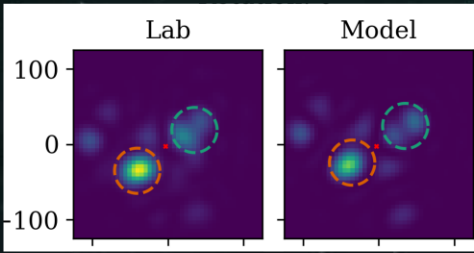
Half-scale precision petal



10^{-10} contrast



Model Validation



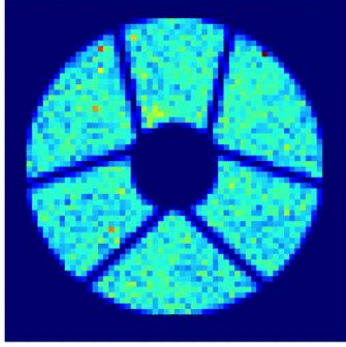
Demonstrated deep contrast, formation sensing and control, stowage, deployment, accurate petals, thermal stability

Stowed and partially deployed 10 m disk with optical shield

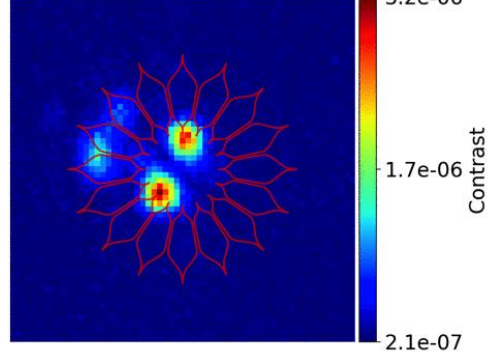


Hardware in the loop formation sensing and control

Pupil Plane



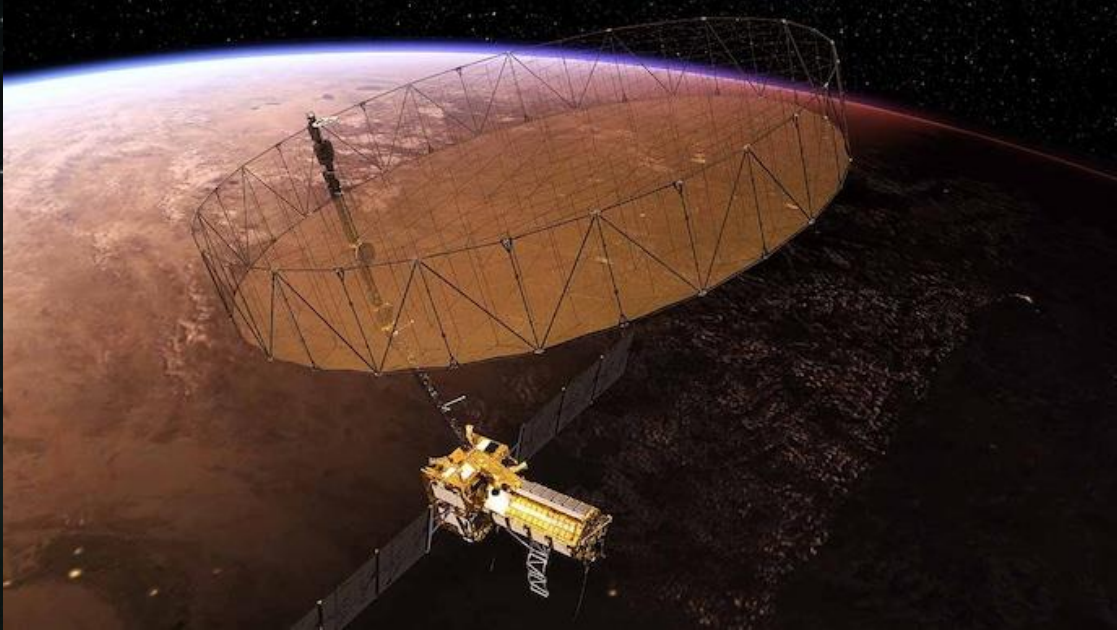
Focal Plane



Petal position and shape
Tolerancing is 0.1 – 1 mm.

FLIGHT HERITAGE

NISAR: 12 m diameter perimeter truss (NASA/ISRO)

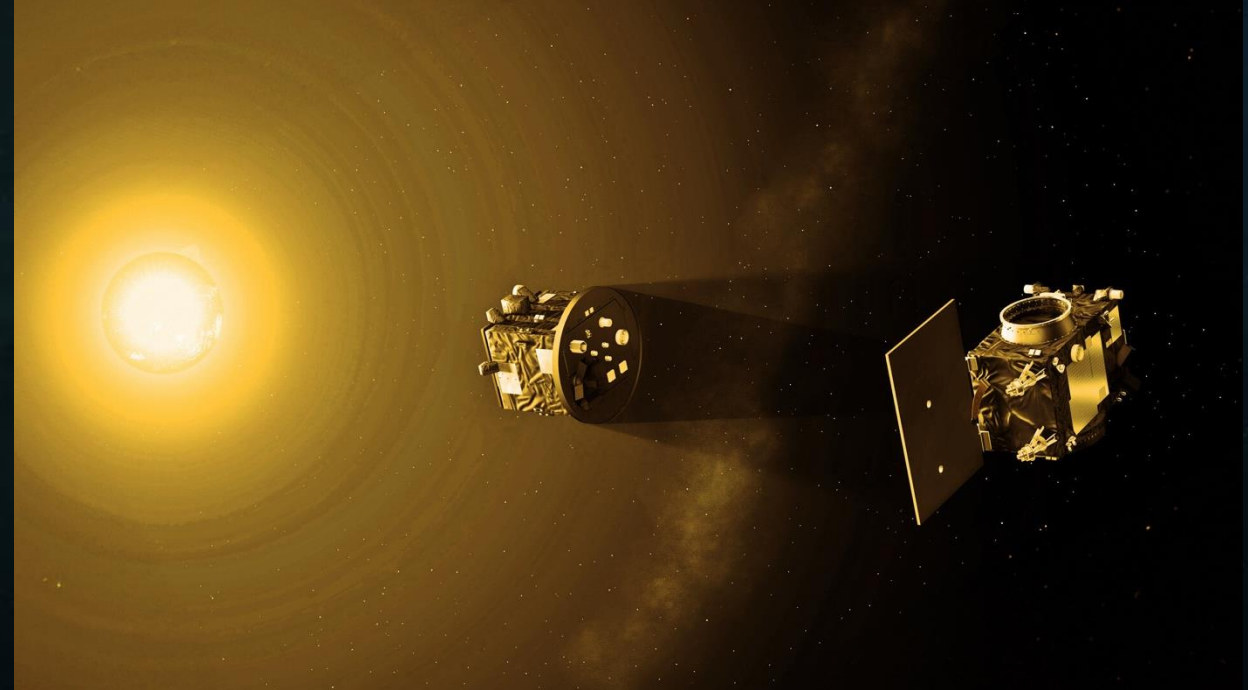


Launched June 30, 2025

Truss built by Astro Aerospace (NG)



Proba-3: Formation flying external coronagraph (ESA/ISRO)



Launched Dec 5, 2024

Millimeter lateral control in a 20 hour orbit. Alignment for 6 hours each orbit.



MISSION CONCEPTS



Concept	Starshade(s) + Telescope(s)	Targets	Science
Occulting Ozone Observatory	16 m + 1 m	Dozens of nearby solar type stars.	Detects O3 on Earth-like planets in days.
Starshade Rendezvous Mission	24 m + 2.4 m Roman	~ 100 nearby solar type stars	V/NIR spectroscopy at R=70 Note: Roman not starshade compatible.
HWO UV+blue Starshade	35 m + 6 m HWO	> 100 nearby solar type stars	Robustly detects O3 at 10 pc in 1-3 days, and Rayleigh even in 50 zodi
HWO + Starshades	(35 m * 2 + 60 m) + 6 m HWO	> 100 nearby solar type stars, binary stars	Efficient for exoplanet discovery, NUV/V/NIR characterization at R=140
HOEE	99 m + 39 m ELT	> 100 nearby solar type stars	Extremely efficient V/NIR characterization at high SR
Nautilus + Starshade	35-60 m with 4-8 m Nautilus Array	> 100 nearby solar type stars	Efficient for exoplanet discovery, NUV/V/NIR characterization
Lazuli	35 m	Dozens of nearby solar type stars.	NUV/V characterization, need telescope to be starshade ready.

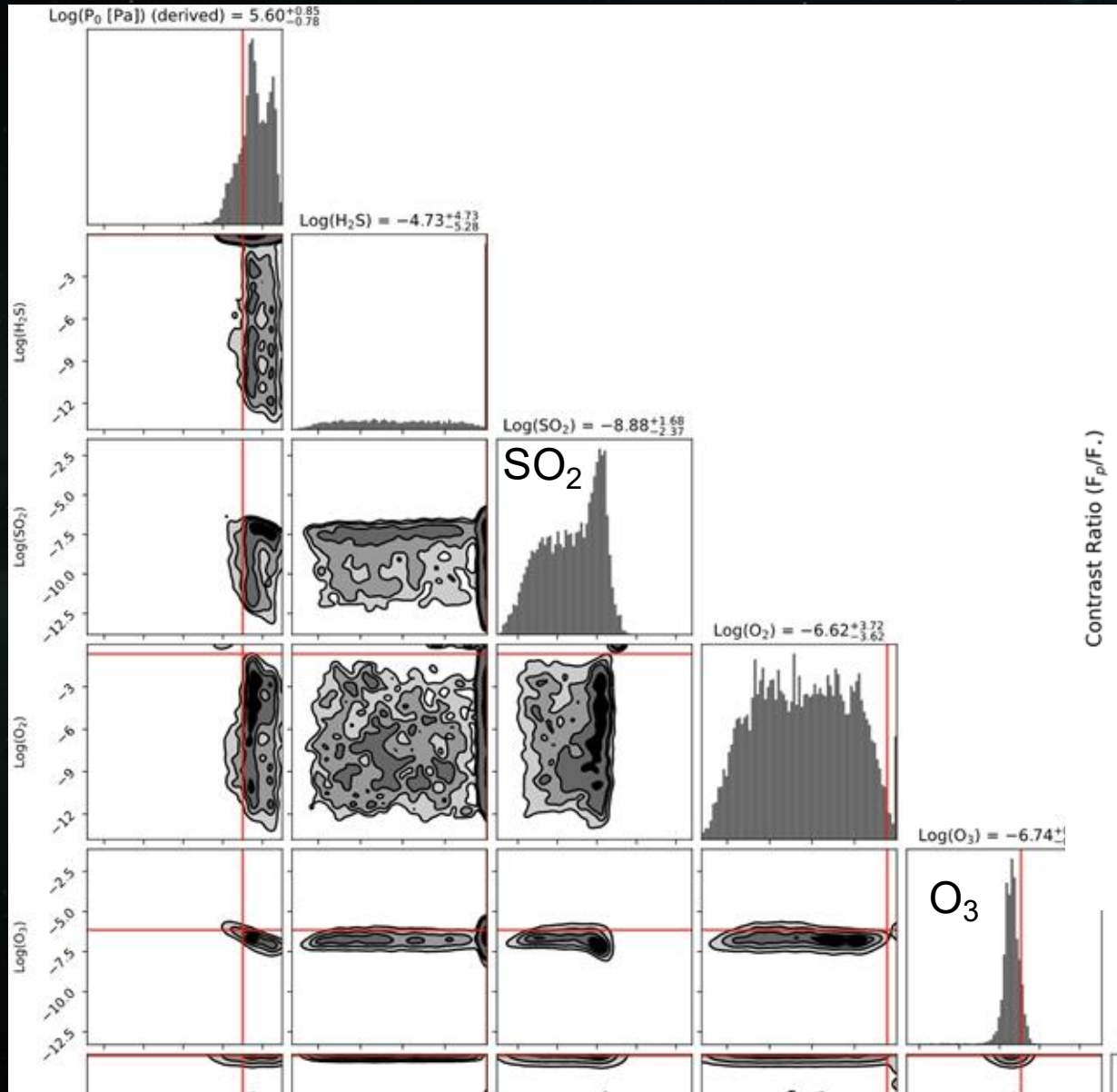
CONCLUSION

- Multi-mission: for a modest investment, turn your NUV/Vis/NIR telescope into a powerful exoplanet imager and characterizer.
 - Does not impose any strenuous design requirements on the telescope.
 - Starshade does all the work of blocking the starlight. The telescope does standard imaging.
 - For deep-space missions and long-period (multi-day) Earth-orbits.
- Technology is TRL-5 for petals, disk, optical performance (Vis).
- Ideal for international collaboration.
 - Starshade and telescope are developed independently.
- Include starshade compatibility in your mission profile to ensure the capability to detect and characterize exoplanets.

BACKUP

UV SPECTRAL RETRIEVAL EXAMPLE

(Z. AHMED ET AL, STANFORD U., TO BE PUBLISHED)



Three day observation with HWO, 250-500 nm.
Solar-type star at 10 pc, planet at quadrature,
10 zodis, face on.

