National Aeronautics and Space Administration

FY24 Strategic University Research Partnership (SURP)

Starshade Scenario Options Analysis for Large IR /O/UV Observatory

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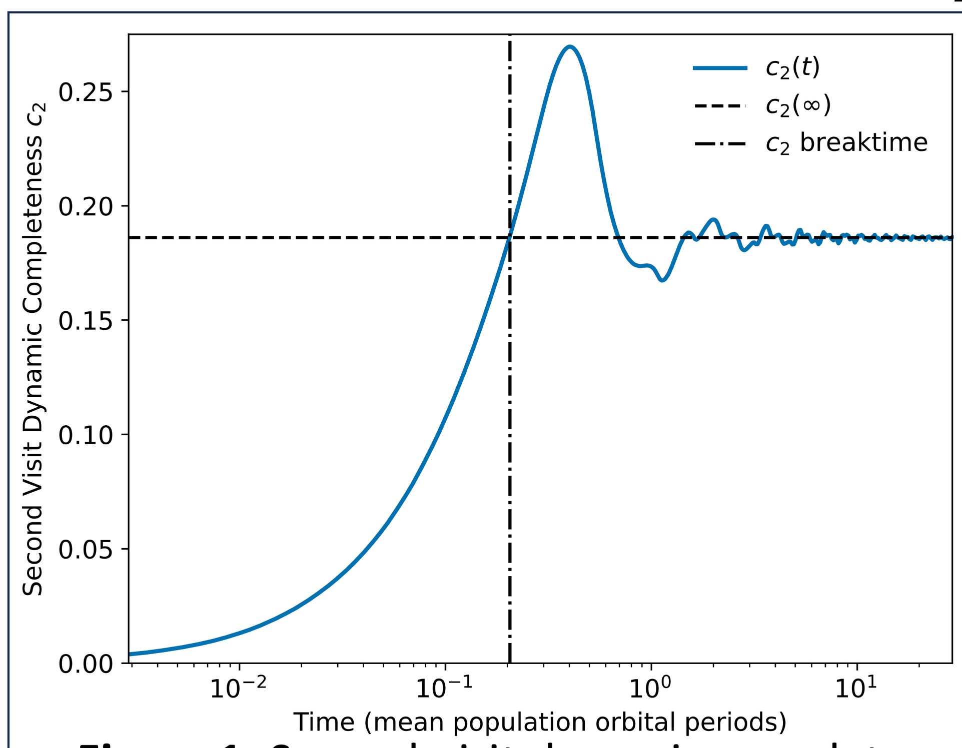
Objectives: Create new capabilities in the simulation of starshade-based exoplanet imaging missions by expanding the starshade-specific modeling capabilities of EXOSIMS, an open-source codebase for exoplanet mission simulation.

- model starshade refueling
- model multiple starshades operating with one telescope
- model starshades that change separation distance (and thereby change their wavelength range)
- simulate starshades optimized for UV (because UV coronagraphs have not been proven to be feasible)
- explore new observation scheduling algorithms capable of taking advantage of these starshade operations concepts

Background: The Astro 2020 decadal survey recommended as a top priority the maturation of a "large (~6 m aperture) infrared/optical/ultraviolet space telescope … to search for biosignatures from a robust number of about ~25 habitable zone [exo]planets." While the recommendation was agnostic as to the nature of the starlight suppression system to be utilized, the survey mentioned only coronagraphs, putting starshades at a perceived disadvantage. As JPL has made significant effort in starshade maturation via the S5 program and strategic RTDs, it is highly desirable to demonstrate the competitiveness of starshades for Habitable Worlds Observatory, which requires updated simulation tools, operations concepts, and challenging assumptions made in previous work that predicted a degradation of starshade science yield beyond the 4-5 m telescope scale. This can be accomplished with targeted enhancements and extensions to the EXOSIMS software framework—a modular, open-source codebase for exoplanet imaging space mission simulation.

Significance/Benefits to JPL and NASA: . The extent of JPL's participation in HWO will be seeded in the architecture trades likely to occur in FY25-26. The current suite of EXOSIMS updates are geared for starshades to remain viable and exciting in the architecture trade space in FY25. These tool updates and analyses are a critical path to ensuring that JPL's interest in starshades and the JPL-developed segmented primary mirrors enabled by starshades are assessed fairly and accurately when technology roadmaps are developed and technology development investments are made through SATs and directed funds. Additionally, these updates also help position EXOSIMS as a mission development tool through Phase A, and the JPL-Cornell collaboration as a leader of mission science performance modeling for the next astrophysics flagship. The collaboration led to a successful ADSPS ROSES proposal which will further support these efforts over the next two years.

Approach and Results:



Dynamic completeness[1] is the probability of detecting an exoplanet on the *j*th observation of a particular target star.

- A new, faster method to calculate dynamic completeness was created by treating the mean anomaly distribution as a damped oscillator
- Monte Carlo evaluations are accelerated by propagating only eccentric anomalies (no direct computation of true anomaly)

Figure 1: Second-visit dynamic completeness measures the benefit of re-observing a target star as a function of time between observations. As demonstrated in Savransky (2024), the maximum benefit occurs when re-observing 0.4 times the mean orbital period of the planet population.

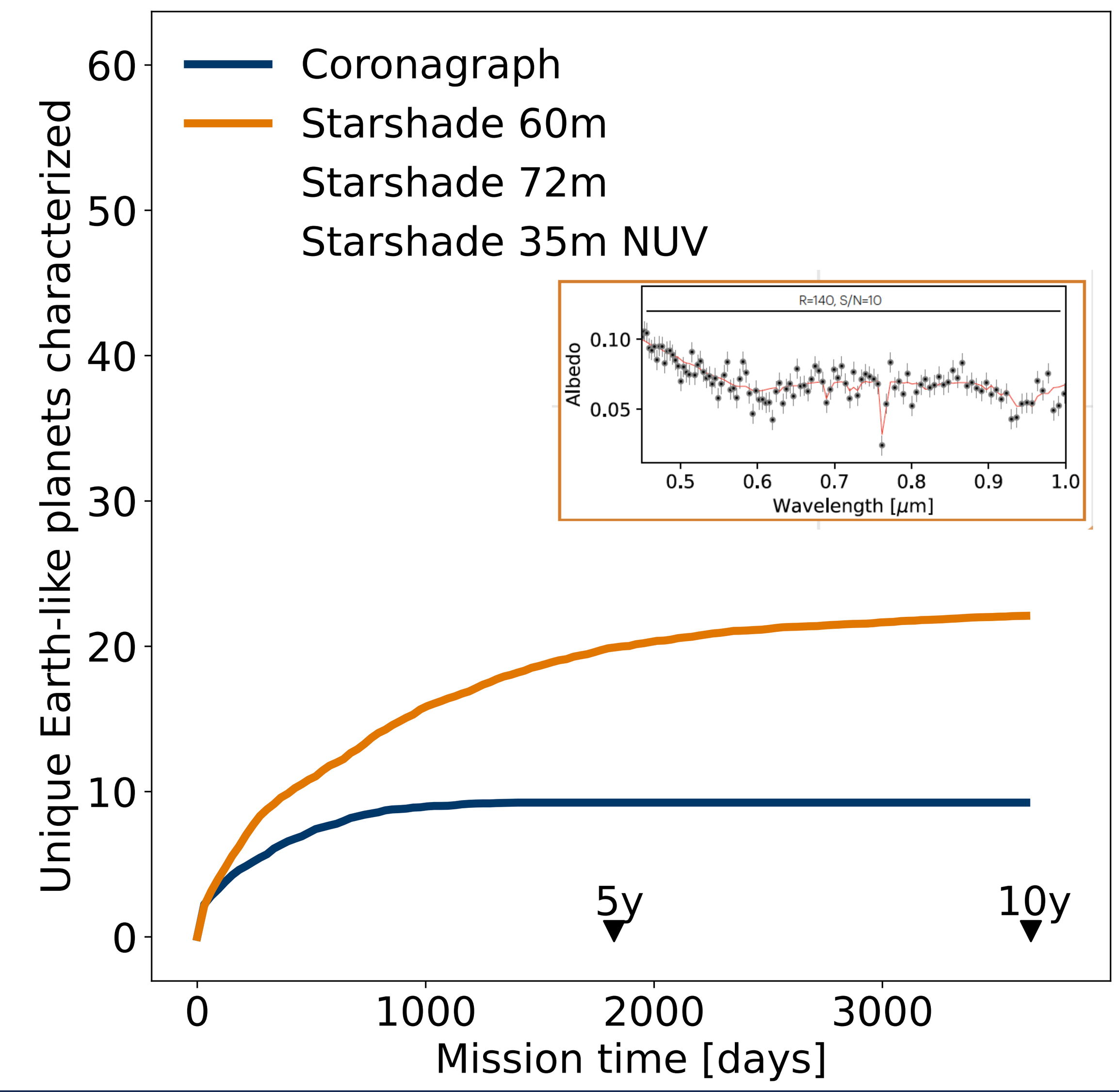


Figure 2. Exo-Earth **yields for starshade** (NUV) and starshade and coronagraph for broadband visible spectra. This observing scenario showcases the spectral characterization capability of each instrument by skipping the blind-search survey and only spectrally characterizing exo-Earths under realistic mission constraints and mission scheduling.

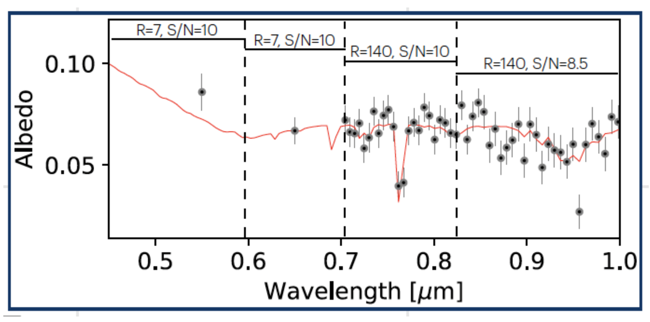


Figure 3 & 4. The starshade provides instantaneous observation across a 100% passband at R=140 (inset). The coronagraph uses 4 x 20% bandwidth sub-bands.

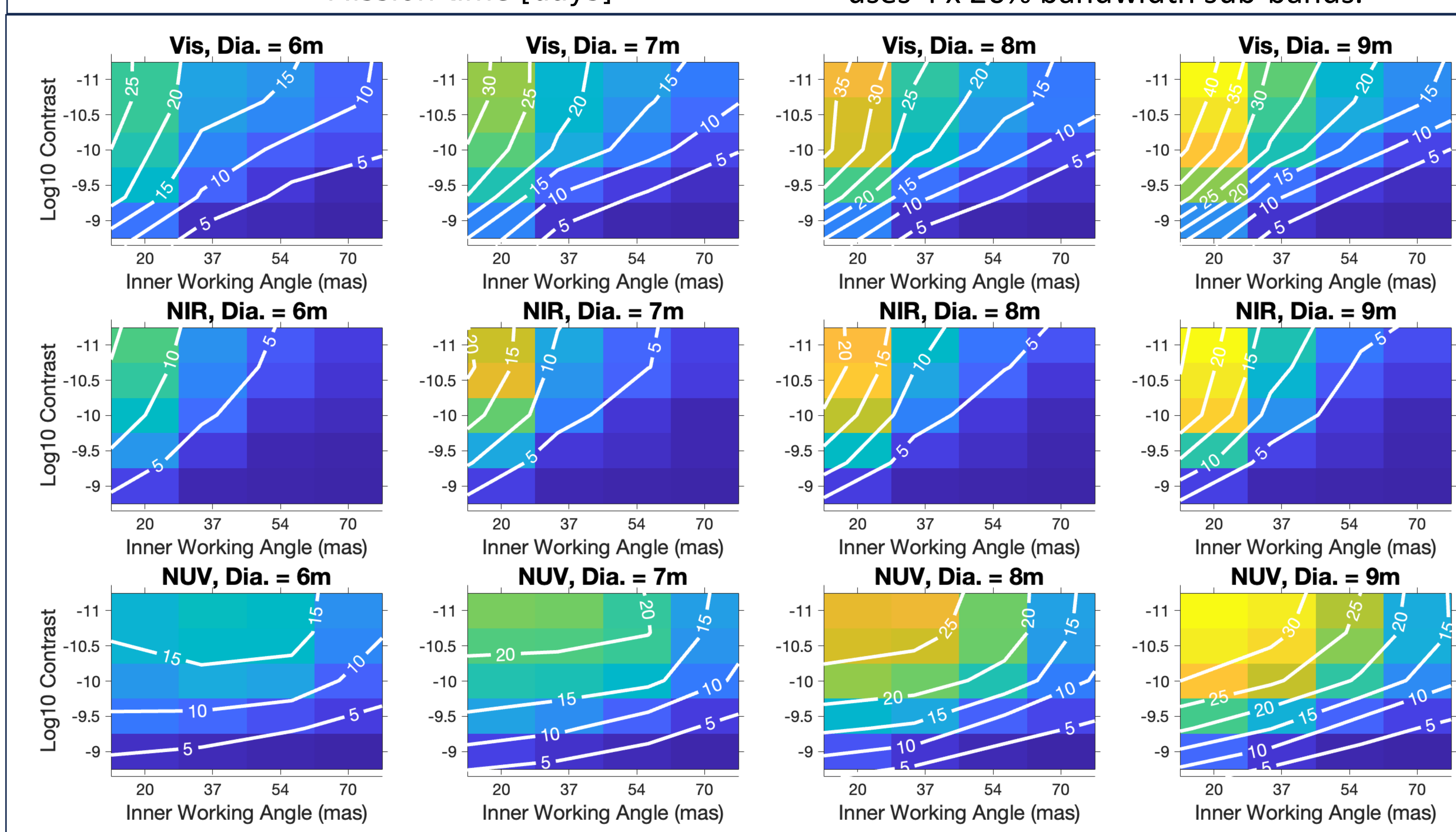


Figure 5. Yield for contrast and IWA is shown for the four diameters and 3 wavelength bands: visible, near infrared (NIR), and near ultraviolet (NUV). The parameter sweep over a likely HWO architecture space shows that yield sensitivity has joint-dependency for contrast, IWA, diameter, and wavelength. These are the first yield sensitivities calculated for the NIR and NUV, which was enabled by significant upgrades to EXOSIMS funded by this SURP.

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Reference: R. A. Brown and R. Soummer. "New completeness methods for estimating exoplanet discoveries by direct detection," The Astrophysical Journal, 715:122, 2010

Publications:

A. Morgan, R., Savransky, D., Turmon, M., Damiano, M., Hu, R., Mennesson, B., ... & Tokadjian, A. (2024, August). HWO yield sensitivities in the NIR and NUV. In *Space Telescopes and Instrumentation 2024: Optical, Infrared, and Millimeter Wave* (Vol. 13092, pp. 1836-1854). SPIE. DOI: 10.1117/12.3020858

B. Savransky, D. (2024, August). Efficient methods for computing dynamic completeness. In *Space Telescopes and Instrumentation 2024: Optical, Infrared, and Millimeter Wave* (Vol. 13092, pp. 2022-2028). SPIE. DOI: 10.1117/12.3020181

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