PRINCETON UNIVERSITY

Starshade Earth Characterizer (SEC) Astrophysics

Jet Propulsion Laboratory
California Institute of Technology

Overview:

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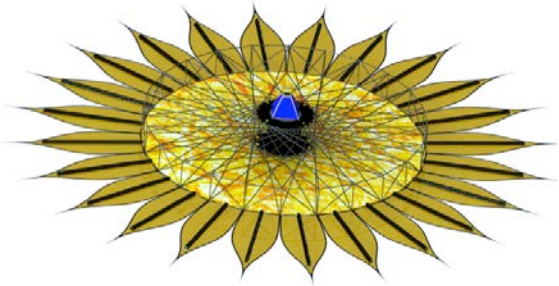
Goals:

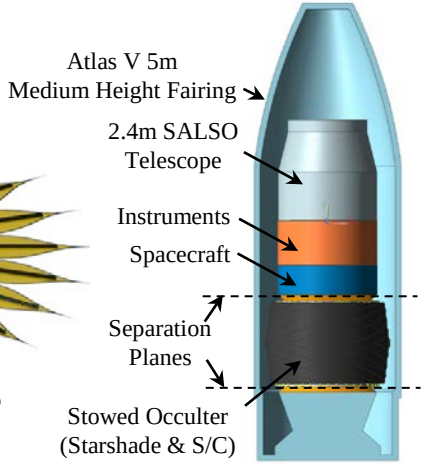
Search for and characterize Earth-like and larger exoplanets in the habitable zone and beyond of nearby stars.

Enable a rich program of pioneering general astrophysics experiments.

Graphic:



Occulter with 32m starshade with 30 6m long petals



Description:

Concept:

SEC is a NUV to NIR exoplanet mission operating at Earth-Sun L2 that will find and characterize earthlike exoplanets in the habitable zone around about 50 nearby F, G, or K stars.

SEC launches with the telescope, separates at L2, maneuvers into target alignment and maintains formation during observations.

SEC also includes instrumentation with minimal impact to the telescope: planet camera, spectrograph, occulter guide camera and inter-spacecraft communications.

Observations:

Search phase of about 500 days requires ≤ 2 days of telescope time every 10 days, on average.

Telescope is free for general astrophysics observations, while the occulter is repositioning for the next target.

Characterization phase revisits a select set of candidate Earths about 4 more times for orbit determination and spectroscopy.

Readiness:

ROSES NRA TDEMs are addressing key technology challenges. Current status is TRL 4/5. Aim is TRL-6 prior to 2018.

Value to NASA:

A starshade operating with the available telescope is fully capable of characterizing Earths within habitable zones around all target stars.

Characterizing Earthlike exoplanets is a NASA Strategic Goal (2.4) and a priority of the 2010 Decadal Survey, *New Worlds, New Horizons*.

This exoplanet instrumentation is highly compatible with a robust set of general astrophysics experiments and utilizes only a small fraction of observing time and other resources (mass, power and volume).

The occulter can launch together with the telescope on an EELV, saving the cost of a second launch vehicle.

Observing efficiency and science return can be enhanced by deploying additional starshades to operate with the same telescope.

Advancing innovative new space technologies to improve the future capabilities of NASA and to make NASA science and discovery missions more affordable are Strategic Goals (3.1, 3.2) of NASA.

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STARSHADE EARTH CHARACTERIZER

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Objective Category: Astrophysics

Can we find another planet like Earth orbiting a nearby star? To find such a planet would complete the revolution, started by Copernicus nearly 500 years ago, that displaced Earth as the center of the universe. . . . Astronomers are now ready to embark on the next stage in the quest for life beyond the Solar System–to search for nearby, habitable, rocky or terrestrial planets with liquid water and oxygen. . . . The observational challenge is great, but armed with new technologies. . . astronomers are poised to rise to it.

–New Worlds, New Horizons, 2010

Summary:

One of NASA's key science priorities, and a priority of the 2010 Decadal Survey, is the discovery and characterization of exoplanets about nearby stars, particularly Earth-sized planets in the habitable zone (HZ) that may harbor life. The Study on Applications of Large Space Optics (SALSO) offers a breakthrough opportunity to make these challenging observations with technologies that are implementation ready. We describe here SEC, an occulter based exoplanet mission operating at Earth-Sun L2 point with the capability to discover and characterize earthlike exoplanets and search for signs of life. The occulter provides the required starlight suppression for imaging earths (25 stellar magnitudes), inner working angle (IWA) to access the inner HZ of 100 nearby F, G and K stars (60 mas) and unlimited outer working angle (OWA) to study complete planetary systems. It does this with no telescope modifications and conventional imaging and spectroscopic instruments.

Implementation:

An external occulter flies in formation with a telescope and employs a carefully shaped screen, or starshade, to block starlight, creating a high contrast shadow that enables imaging of off-axis planets. While occulters do require operating a separate spacecraft, they offer many critical advantages, including: planet observations at small separation angles independent of telescope size, unlimited OWA for outer-planet observing, broadband near-UV to near-IR operation, and high throughput for efficient spectroscopy. Additionally, and most importantly, no special optical or wavefront control requirements are imposed on the telescope.

In a custom-designed mission to characterize earthlike planets, the relative merit of internal coronagraphs and starshades is a complex question, still debated within the community. However, with the SALSO assets, there is no question that a starshade has vastly higher scientific performance and is the only approach capable of detecting a significant number of Earth's in the habitable zone.

Figure 1: Fully deployed occulter

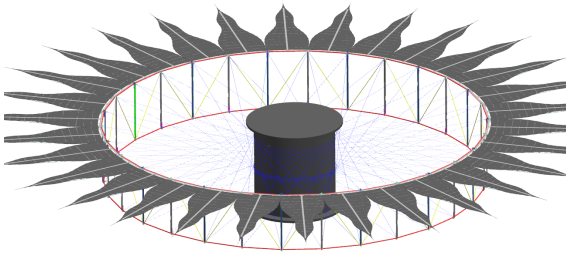


Figure 1 shows the fully deployed occulter with 32 m diameter starshade consisting of a 20 m inner disk and 30 petals of 6 m length. The specific shape of the petals is found via an optimization process that creates the smallest possible starshade meeting the contrast requirement. The geometrically defined IWA at the 50% transmission point inside the petals is 60 mas.

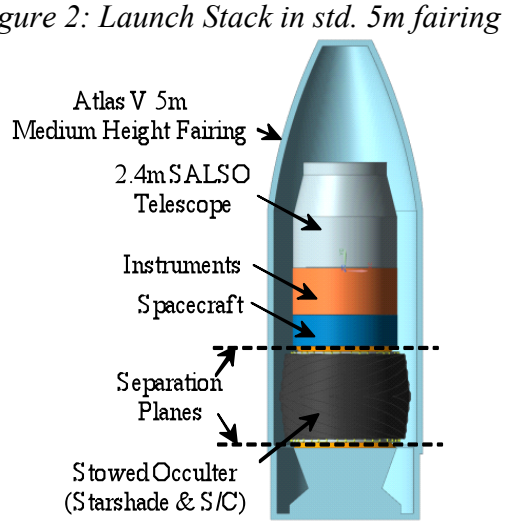
The occulter is positioned at two distances: 45,000 km for the 250-550 nm band and roughly half that for the 550 to 1000 nm band. It creates a shadow 2 m larger than the telescope diameter to allow a low-bandwidth controller for lateral sta-

tionkeeping using a conventional hydrazine propulsion system. Performance is largely insensitive to axial position.

The SEC operational concept includes an initial search phase that will observe roughly 50 of the most favorable targets. Each target requires ≤ 2 days of observatory time, including formation acquisition. A new target is observed on average every 10 days. The occulter is repositioned for the next target via commercially available Hall Effect thrusters and Xenon gas. During these maneuvers, the observatory is free for other astrophysical observations. A characterization phase will conduct repeat visits to select candidate earths and will utilize ≤ 25% of observatory time. Characterization includes spectroscopy and the multiple detections needed for orbit determination to place candidate Earths in the HZ with high confidence.

The starshade stows compactly around a load-carrying hub structure and can launch together with the telescope in a standard 5m launch fairing, as shown in Figure 2.

Figure 2: Launch Stack in std. 5m fairing



The occulter bus including propellant tanks installs inside the hub. Occulter launch mass is ≤ 2,000 kg and Atlas-551 launch capacity is 6,400 kg, such that 4,400 kg is available for all other flight systems.

The telescope instrument package includes the planet camera, an integral-field spectrometer, the occulter guide camera and a radio system to transmit guide camera derived starshade positions. Total experiment mass with the telescope is ≤ 250 kg and volume is < 1/4th the total available, leaving ample resources for other general astrophysics experiments and a robust overall mission.

A perimeter truss, with deployable antenna heritage, forms the inner disk and controls deployed petal positions. Petals are of graphite lattice construction with near-zero CTE carbon pultruded rods controlling the critical width. Pop-up ribs passively deploy to provide out of plane stiffness. Petals are sufficiently stiff to not participate in the dynamic response of the truss-dominated system. An opaque, low-reflectivity multi-layer blanket covers the occulter. Layers are spaced apart, such that only particles with trajectories in line with the target can create light paths to the telescope.

The occulter bus is spin-stabilized with a 5-minute spin period. Any imperfections in the starshade shape leading to starlight leakage are smeared into annular rings that are easily distinguishable from a planet. This significantly relaxes manufacturing, deployment, dynamic, and thermal tolerances to levels that are readily achievable.

Technology Status:

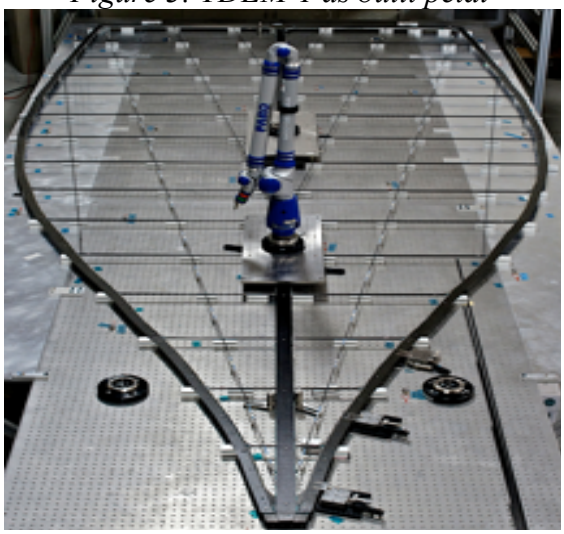
We have addressed key starshade technology challenges via NASA grants for Technology Development of Exoplanet Missions (TDEMs) with a goal to establish TRL-6 prior to 2018. The first TDEM was completed Spring 2012 and demonstrated that a flight-like petal could be built to the required tolerances for an Earth finding mission. Figure 3 shows the current manufactured petal. The current TDEM will demonstrate required deployed position tolerances with a 60% scale truss and four petals. Thermal and structural stability performance has been verified by analysis and optical edge scatter requirements are also under investigation. Table 1 summarizes the overall technology plan. We are soon approaching a point where a larger effort is needed to address the remaining engineering challenges.

Our laboratory testing of cm-size starshades has validated optical propagation models by achieving starlight suppression to a few parts in 10^{-10}. Several independently developed models predict contrast levels agreeing to within 10^{-12}, giving high confidence that a properly constructed starshade will perform as predicted on-orbit.

Science Goals:

The primary goal of SEC is to find and characterize Earth analogs: an Earth-size planet in an Earth-like orbit about a Sun-like star. Our group has carried out extensive mission modeling of occulter exoplanet searches using realistic parameters. For each star we evaluate search *completeness* – the probability an Earth analog would be detected in the HZ if present. DRM studies point to 100 candidate targets with minimum and average search completeness of 30% and 50%, respectively. What if Earths are rare? These completeness calculations show that if only 10% of the nearest suns have Earth-like planets in the habitable zone, SEC has a 95% chance of finding at least 3 of them. SEC's high throughput also enables spectroscopic characterization of detected planets over a broad wavelength range. A spectrum of even a single earthlike planet would be an epochal event for humanity; this mission provides the first realistic chance of obtaining one.

Figure 3: TDEM-1 as built petal



During its search for other Earths, SEC will also automatically find planets that are larger, have higher albedo, and/or have larger orbits, giving it the most complete exoplanet science portfolio of any mission. In fact, approximately 15 known extrasolar giant planets fall within the SEC detection space, affording a unique opportunity to "ground truth" the observatory's discovery capabilities while conducting comparative exoplanet science (see Figure 4).

SEC will also image transitional and debris disks, providing important diagnostics as to the dynamics of these systems, including unseen planetary bodies that influence disk structure.

Figure 4: Known and modeled exoplanets among nearby stars.

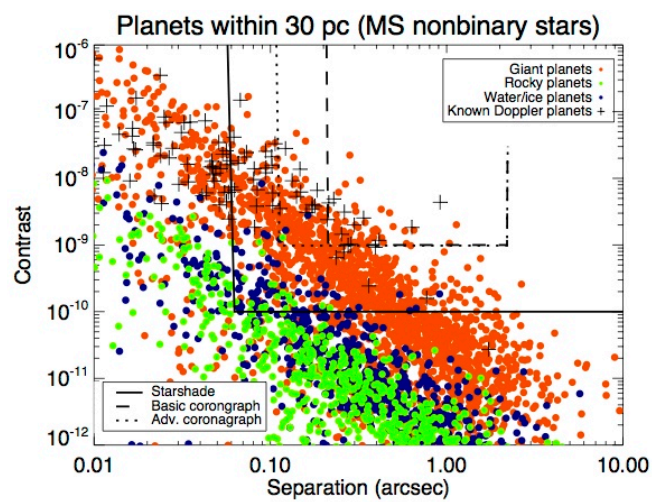


Table 1: Summary of technology status and plans

Key Challenges	Driving Spec	Technology Status
Dynamic Stability	Deformations ≤ 15 ppm, after 10s	Verified by analysis with large margins.
Thermal Stability	Non-uniform deformations ≤ 15 ppm	Verified by analysis with large margins.
Manufacturing tolerance	Petal width ≤ 25 μm (1 mil)	Demonstrated per TDEM-1
Deployment tolerance	In-plane petal root position ≤ 0.5 mm	Demonstration in progress per TDEM-2
Edge scattered sunlight	Edge radius of curvature ≤ 0.5 μm	Demonstration in progress per JPL RTD
Petal design for deploy	Pass deploy cables through petals	To develop 2nd gen. petal per TDEM-3
Deploy control system	Avoid petal contact	Requires significant engineering effort
Launch restraint	Axial Loads ≤ 10 g's	Requires significant engineering effort
Facilities	Gravity offload fully deployed starshade Metrology for petal production	Partners with required facilities. Petal metrology planned as capital equip.