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“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. . . The observational challenge is great, but armed with new technologies. . . astronomers are poised to rise to it.”

—New Worlds, New Horizons, 2010
Starshade Concept
Separation distance 37,000 km ±250 km

±1 m lateral control

Inner Working Angle (IWA)

Starshade Concept

Starshade diameter 34 m

Telescope diameter 1.1 m

- Contrast and inner working angle are decoupled from the telescope aperture size
- A simple space telescope can be used
- No wavefront correction is needed
- No outer working angle
Exo-S Baseline Design Overview

<table>
<thead>
<tr>
<th>Band</th>
<th>Blue</th>
<th>Green</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelengths (nm)</td>
<td>400–630</td>
<td>510–825</td>
<td>600–1,000</td>
</tr>
<tr>
<td>IWA (mas)</td>
<td>75</td>
<td>95</td>
<td>115</td>
</tr>
<tr>
<td>Separation (Mm)</td>
<td>47</td>
<td>37</td>
<td>30</td>
</tr>
</tbody>
</table>

Off-the-shelf on-axis optical telescope (1.1-m NextView)
Heliocentric, Earth-drift away orbit (Earth-Sun L2 is also a possibility)
Move telescope, not starshade for retargeting
Instrumentation: imager and low-resolution spectrograph
Single launch vehicle
Science Goal #1: Photometric Search for New Exoplanets

- Discover planets from Jupiter-like planets down to rocky planets orbiting nearby Sun-like stars
- Image rocky planets in a Sun-like star’s habitable zone
- Discover multiple planets and circumstellar dust, around target stars
Science Goal #2: Spectral Characterization of New Exoplanets

- Spectra of newly discovered planets from 400–1000 nm, with a spectral resolution $R = 70$
- Spectra of mini Neptunes to ascertain the very nature of the low-density, extremely common, yet mysterious planets
- Potential for rocky planet spectra, for a handful of favorable target stars
Science Goal #3: Spectroscopy of Known Jupiters

- Spectra of 17 known Jupiter-mass exoplanets
- Spectral characterization from 400–1000 nm, with a spectral resolution $R = 70$
- Molecular composition and presence of clouds or haze will inform us of the diversity of giant planet atmospheres
- Comparative planetology with a variety of Jupiter-type exoplanets

The known Jupiters are detectable by virtue of extrapolated position in 2024 timeframe
Preliminary Observing Strategy

- The prime mission is 3 years; a 22 month example observing schedule is shown with targets sequential in longitude; an additional year is available for revisits and spectroscopy.
- Observation times are approximately 1 to 5 days and retargeting times are about one week.
- Observations include multi-color imaging to identify planet candidates and spectroscopy for known Jupiters and newly discovered planets.
- Disk science and search for Jupiter analogs around all stars.
- The observing schedule is adaptable to real-time discoveries.
Launch Configuration

- Telescope and starshade fit in the low cost intermediate-class L/V 5-m fairing
- Total launch mass is 2,140 kg vs. 3,550-kg launch capacity for 66% launch margin
- Starshade carries loads through existing central cylinder
- Two spacecraft separate on-orbit
Summary of Critical Technologies

Optical Model Validation
• Experimentally demonstrate that models predict performance to $10^{-11}$ contrast

Precision Deployment and Shape Control
• Build structure that meets shape requirements
• Deploy accurately and with high reliability
• Maintain shape during on-orbit disturbances such as jitter and thermal gradients

Long Distance Formation Flying
• Sense cross-track alignment errors between starshade and telescope
• Control relative position of starshade and telescope line of sight

Stray Light Control
• Mitigate scattering of sunlight off edge of starshade petals
• Control transmission of sunlight and starlight through membrane
Lab experiments at Princeton and NGST have demonstrated contrasts close to flight levels for large flight versions.

Optical Model Validation

Lab experiments at Princeton and NGST have demonstrated contrasts close to flight levels for large flight versions.

NASA funded effort is directed at larger-scale experiments closer to flight geometry and in broadband light to completely verify the propagation models.
Petal Prototype and Deployment

Full-scale petal prototype with the petal width profile manufactured to required tolerances. JPL facility.

Subscale (2/3) partial starshade prototype. 25 deployment cycles demonstrated deployed positions to within required tolerances. NGC facility.
Starshade Stowage and Deployment
STDT Next Steps

Baseline Probe Design
- Refine Design Reference Mission and science yield simulations
- Complete trades for the baseline design of starshade + telescope system

“Starshade Ready” Design
- Starshade design for a future or existing telescope (e.g., NRO)
- Starshade readiness of telescope

Technology Development
- Priorities recommended by STDT
- Where technology development will continue by the community through competed NASA technology programs; some STDT members participating
The starshade probe-class mission has the capability to discover rocky exoplanets around two dozen stars with a relatively small space telescope.

The planet-star flux contrast and IWA are nearly independent from the telescope aperture size.

Technology progress is on track for a new start in 2017.