Starshade would take formation flying to extremes

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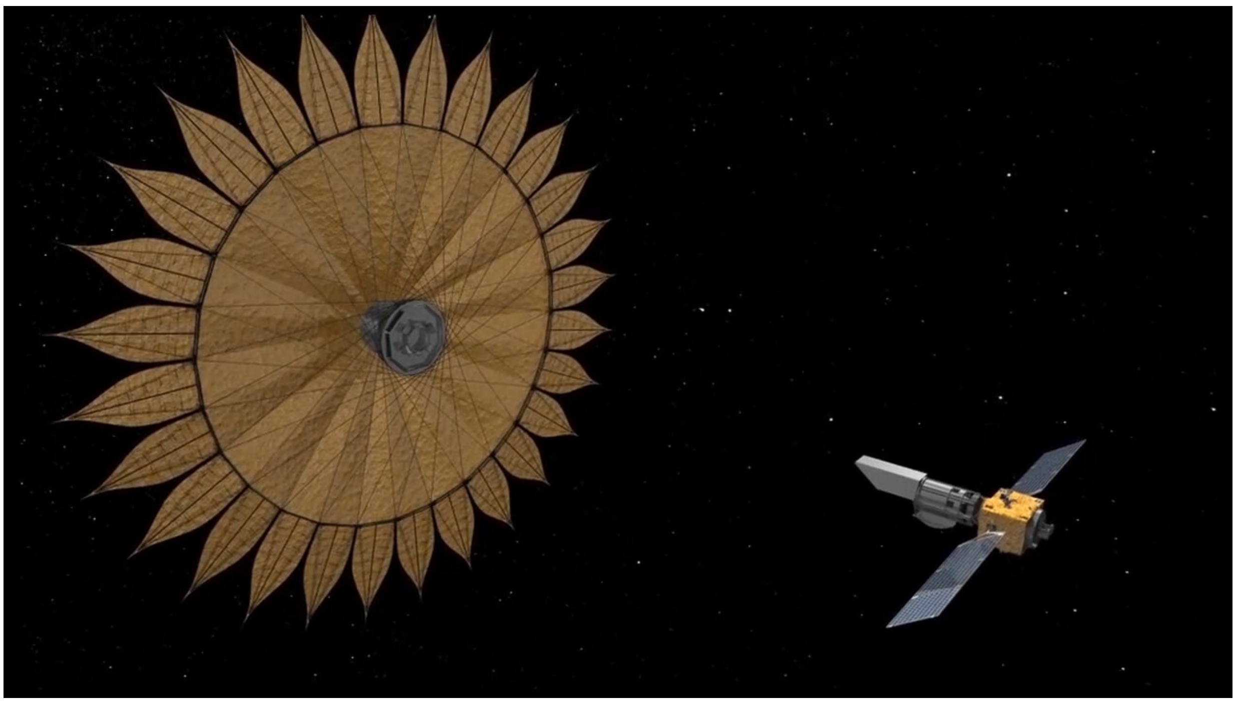

This artist's concept shows the geometry of a space telescope aligned with a starshade, a technology used to block starlight in order to reveal the presence of planets orbiting that star. Credit: NASA/JPL-Caltech

Anyone who's ever seen aircraft engaged in formation flying can appreciate the feat of staying highly synchronized while airborne. In work sponsored by NASA's Exoplanet Exploration Program (ExEP), engineers at the Jet Propulsion Laboratory in Pasadena, California, are taking formation flying to a new extreme.

Their work marks an important milestone within a larger program to test the feasibility of a technology called a starshade. Although starshades have never flown in space, they hold the potential to enable groundbreaking observations of planets beyond our solar system, including pictures of planets as small as Earth.

A future starshade mission would involve two spacecraft. One would be a space telescope on the hunt for planets orbiting stars outside of our solar system. The other spacecraft would fly some 25,000 miles (40,000 kilometers) in front of it, carrying a large, flat shade. The shade would unfurl like a blooming flower—complete with "petals—and block the light from a star, allowing the telescope to get a clearer glimpse of any orbiting planets. But it would work only if the two spacecraft were to stay, despite the great distance between them, aligned to within 3 feet (1 meter) of each other. Any more, and starlight would leak around the starshade into the telescope's view and overwhelm faint exoplanets.

"The distances we're talking about for the starshade technology are kind of hard to imagine," said JPL engineer Michael Bottom. "If the starshade were scaled down to the size of a drink coaster, the telescope would be the size of a pencil eraser and they'd be separated by about 60 miles [100 kilometers]. Now imagine those two objects are free-floating in space. They're both experiencing these little tugs and nudges from gravity and other forces, and over that distance we're trying to keep them both precisely aligned to within about 2 millimeters."

Researchers have found thousands of exoplanets without the use of a starshade, but in most instances scientists have discovered these worlds indirectly. The transit method, for example, detects the presence of a planet as it passes in front of its parent star and causes a temporary drop in the star's brightness. Only in relatively few cases have scientists taken direct images of exoplanets.

Blocking out starlight is key to performing more direct imaging and, eventually, to carrying out in-depth studies of planetary atmospheres or finding hints about the surface features of rocky worlds. Such studies have the potential to reveal signs of life beyond Earth for the first time.

Seeking Shade

The idea of using a space-based starshade to study exoplanets was initially proposed in the 1960s, four decades before the discovery of the first exoplanets. And while the ability to point a single spacecraft steadily at a distant object is not new, either, keeping two spacecraft aligned with each other toward a background object represents a different kind of challenge.

Researchers working on ExEP's Starshade Technology Development, known as S5, have been tasked by NASA with developing starshade technology for possible future space telescope missions. The S5 team is addressing three technology gaps that would need to be closed before a starshade mission could be ready to go to space.

The work done by Bottom and fellow JPL engineer Thibault Flinois closes one of those gaps by confirming that engineers could realistically produce a starshade mission that met these stringent "formation sensing and control" requirements. Their results are described in the S5 Milestone 4 report, available on the ExEP website.

Get Into Formation

The specifics of a particular starshade mission—including the exact distance between the two spacecraft and the size of the shade—would depend on the size of the telescope. The S5 Milestone 4 report looked primarily at a separation range of between 12,500 to 25,000 miles (20,000 to 40,000 kilometers), with a shade 85 feet (26 meters) in diameter. These parameters would work for a mission the size of NASA's Wide Field Infrared Survey Telescope (WFIRST), a telescope with a 2.4-meter-diameter primary mirror set to launch in the mid-2020s.

WFIRST will carry a different starlight-blocking technology, called a coronagraph, that sits inside the telescope and offers its own unique strengths in the study of exoplanets. This technology demonstration will be the first high-contrast stellar coronagraph to go into space, enabling WFIRST to directly image giant exoplanets similar to Neptune and Jupiter.

Starshade and coronagraph technologies work separately, but Bottom tested a technique by which WFIRST could detect when a hypothetical starshade drifted subtly out of alignment. A small amount of starlight would inevitably bend around the starshade and form a light-and-dark pattern on the front of the telescope. The telescope would see the pattern by using a pupil camera, which can image the front of the telescope from inside—akin to photographing a windshield from inside a car.

Previous starshade investigations had considered this approach, but Bottom made it a reality by building a computer program that could recognize when the light-and-dark pattern was centered on the telescope and when it had drifted off-center. Bottom found that the technique works extremely well as a way to detect the starshade's movement.

"We can sense a change in the position of the starshade down to an inch, even over these huge distances," Bottom said.

But detecting when the starshade is out of alignment is an entirely different proposition from actually keeping it aligned. To that end, Flinois and his colleagues developed a set of algorithms that use information provided by Bottom's program to determine when the starshade thrusters should fire to nudge it back into position. The algorithms were created to autonomously keep the starshade aligned with the telescope for days at a time.

Combined with Bottom's work, this shows that keeping the two spacecraft aligned is feasible using automated sensors and thruster controls. In fact, the work by Bottom and Flinois demonstrates that engineers could reasonably meet the alignment demands of an even larger starshade (in conjunction with a larger telescope), positioned up to 46,000 miles (74,000 kilometers) from the telescope.

"With such an unusually large range of scales at play here, it can be very counterintuitive that this would be possible at first glance," Flinois said.

A starshade project has not yet been approved for flight, but one could potentially join WFIRST in space in the late 2020s. Meeting the formation-flying requirement is just one step toward demonstrating that the project is feasible.

"This to me is a fine example of how space technology becomes ever more extraordinary by building upon its prior successes," said Phil Willems, manager of NASA's Starshade Technology Development activity. "We use formation flying in space every time a capsule docks at the International Space Station. But Michael and Thibault have gone far beyond that, and shown a way to maintain formation over scales larger than Earth itself."

Provided by Jet Propulsion Laboratory