Ultradeep occultation for planet hunting

Webster Cash

A technique for suppressing diffraction makes the use of external occulters in conjunction with separate satellite telescopes an attractive option in the search for extra-solar planets.

As we learn more about the richness of planetary systems around other stars using indirect means, the desire for direct observation grows. Ideally, astronomers should have instruments that can see exoplanets directly, and fully apply the techniques of photometry, spectroscopy, imaging, and polarimetry to the analysis of alien systems. Direct spectroscopy, in particular, has the potential to carry observations beyond mere mapping of physical characteristics and into the search for extraterrestrial life.1

The overwhelming problem that has impeded direct observation of planets is the relative brightness of the central star. At 10 billion times the brightness of an Earth-like planet, stars simply swamp their planetary systems with stray light inside the telescopes. The technology to suppress diffraction and scattered light inside the optics has been pursued in some depth recently, but has remained an expensive and risky approach.

Spitzer suggested an alternative in 1962, at the start of the space age.2 He pointed out that by placing an occulter larger than your telescope on a separate spacecraft, you could artificially eclipse the central star without suppressing light from the planets. Keeping the starlight out of the telescope largely bypasses the issues of telescope performance. But Spitzer also recognized that diffraction around the edge of the occulter would limit such a system, concluding that one might search for Jupiter-class planets. In 1985 Marchal revisited the concept and reached similar conclusions.3

Recently, we have found that there is a practical way to suppress diffraction to a much higher level across small angles.4,5 To reveal Earth-like planets at 10 parsecs requires that starlight be suppressed by a factor of $10^{10}$ at 0.1 arcseconds of separation. It has now been shown that one can achieve very high levels of suppression in a minimal size shade at a minimal distance by creating an occulter with apodization (shaping) of the electric field given by

$$A(\rho) = \begin{cases} \frac{1}{(\rho/a)^{n}} & \text{for } \rho > a \\ 0 & \text{for } \rho < a \end{cases}$$

In a well-designed system, the strength of the radiation reaching the center of the shadow is given by

$$S \leq (n!)^2 \left( \frac{\lambda F}{2\pi ab} \right)^{2n}$$

Furthermore, it has been shown that the apodization function may be achieved in a binary way. By making the starshade flower shaped, as shown in Figure 1, the occulter may be made binary, sidestepping the problem of scattering in a partially transmitting membrane.

Figure 1. In this conceptual layout, the starshade’s petals are tapered to provide the needed apodization. The spacecraft is mounted in the center, which is fully opaque.

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Figure 2. A 38mm diameter starshade with 42 petals was etched in silicon to high precision.

Recent work at the University of Colorado, led by Douglas Leviton of the Goddard Space Flight Center, has demonstrated the principle of the starshade. We built a 40m-long dark tunnel and fed it with solar light through a heliostat. We put a 1:500 scale model starshade in the beam (see Figure 2), covering the same number of Fresnel zones as would be expected in a flight model. We were able to demonstrate $10^{-7}$ suppression of the direct beam in the center of the shadow. We believe the residual signal was mostly due to scattering from aerosols, since we were operating in air. These results are being readied for publication.

A system architecture study is being supported by the NASA Institute for Advanced Concepts, and has been completed with the help of Northrop-Grumman Space Technologies of Redondo Beach, CA, and Ball Aerospace of Boulder, CO. Identifying the technology drivers and addressing each of the major design issues has established that the smaller, lighter, faster starshades enabled by the new apodization function are affordable to NASA's space science program. A starshade just 50m in diameter, flying 50,000km from the telescope, could reveal planets as close to their suns as Venus is to our sun. Each shade could potentially visit hundreds of planetary systems at rates of up to one per week.

The occulter may turn out to be an enabling technology for the future. The first step is to build a small occulter capable of revealing Earth-like planets at 10 parsecs. Such a pathfinding mission might well make use of existing (or soon-to-be-existing) high-quality space telescopes such as the James Webb Space Telescope. Beyond that, an occulter with a 3m- to 10m-class telescope optimized for the job would be able to fully map planetary systems out to tens of parsecs and perform detailed spectroscopy and photometry. Planet imaging could eventually be achieved by building a large-scale interferometer in space, with each telescope of the array shielded by a starshade.

The excitement of the scientific return from any of these missions is exceptional. But perhaps the most exciting aspect of all is the potential of searching for life on alien planets. High-quality spectra of Earth-like planets should reveal signatures of life if it is there. We may now be within range of answering one of the most ancient and important of questions: Is there life elsewhere in the universe?

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References

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