DOING THE TANGO: ENHANCING JWST WITH AN OCCULTER

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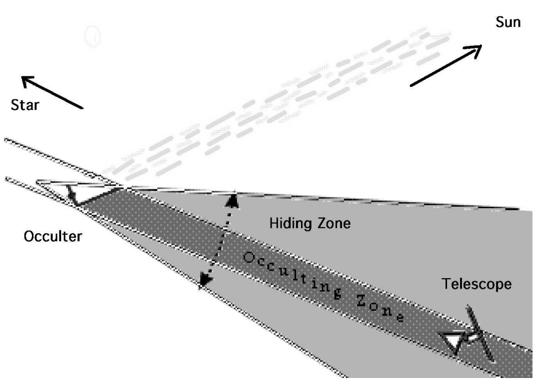
Abstract

Spatially resolving an exoplanet from its host star allows spectral separation of the planet's reflected starlight and thus characterization of its atmosphere and orbital parameters. We outline a method for direct planet detection that has the distinct advantage of relaxing the very demanding tolerances on the telescope optics that are required by traditional coronographic designs. This approach is based on using a free-flying occulter spacecraft in conjunction with a space-based telescope, such as the JWST. Here we discuss the potential advantages of using an external occulter with JWST and showcase some of the recent ground test data illustrating the feasibility of using an occulter-space telescope system.

Introduction to External Occulters

An external, free-flying occulter is a spacecraft designed to fly tens of thousands of kilometers from a space-based observatory. The occulter is interposed between the telescope and the target star in order to reduce the light from the star, enabling the telescope to image any faint companions in orbit about that star. A typical 5-year occulter mission designed to perform extrasolar planet detection, orbit determination, and atmospheric characterization about 50-100 or more stars within 15-40 parsecs could be conducted in concert with JWST. Simulations show that a 6.5-m telescope and a 45-m occulter at 20,000 km could detect terrestrial planets in the near-IR about stars out to ~5 parsecs. Moving the occulter to larger distances from the telescope increases the stellar distance for planet detection.

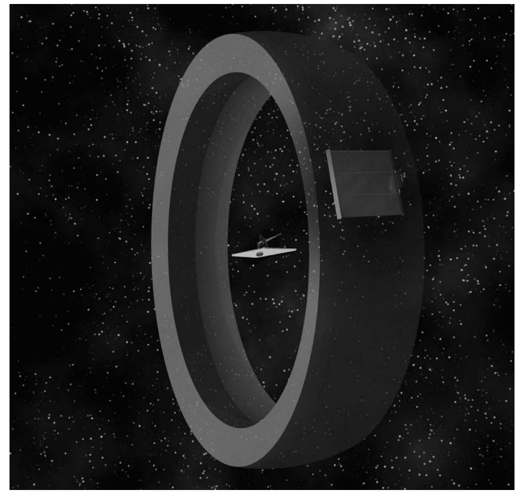


JWST Science

The James Webb Space Telescope (JWST) will be a 6.5-m telescope optimized for the near- and mid-infrared (1-5 um) with capability out to 20 um. The telescope will operate at the Sun-Earth second Lagrange point (L2). At 1 um, the resolution limit will be ~0.03" (Nyquist sampling is ~0.015"). A goal of JWST is to observe how planets form and evolve.

External Occulter Advantages

A free-flying external occulter spacecraft offers a number of advantages that an internal coronagraph does not. Importantly, star light is reduced before it enters the telescope, and thus reducing scattered light within the telescope, making the detection of extrasolar giant planets (EGPs) less sensitive to polarization effects of optical surfaces. There are no secondary coronagraphic optics to reduce the throughput or introduce additional diffraction effects or light scattering. Coronagraphs are specific to a given instrument. An occulter would allow all instruments aboard JWST to be used without any redesign of the telescope, instruments, or added mechanics (additional coronagraphs) to the instruments. Only modest enhancements to flight software and communications would be necessary to operate with an occulter. See next section.



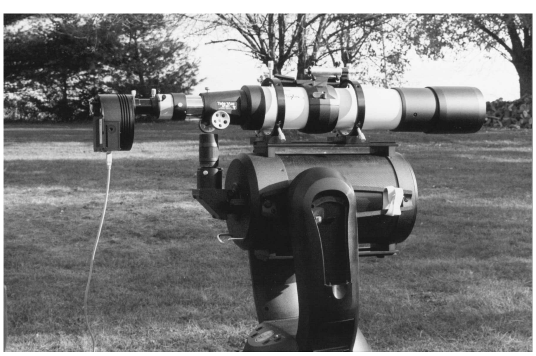
Operational Constraints and Requirements

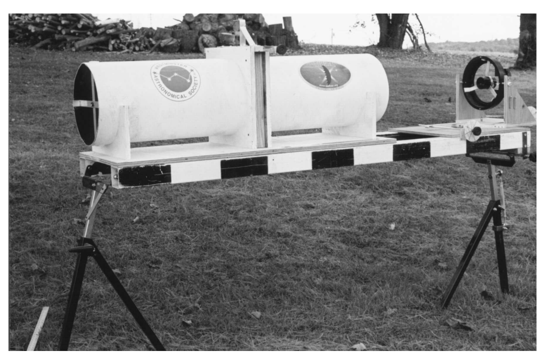
The critical mission constraint is alignment of the occulter on the target-telescope line-of-sight (TTLOS) while the occulter is at a distance of 10-20,000 km from the telescope. Formation Flying control will be dependent upon telescope flight software and sensor systems to detect and locate the occulter and a communication link between telescope and occulter (Kochte et al. 2004).

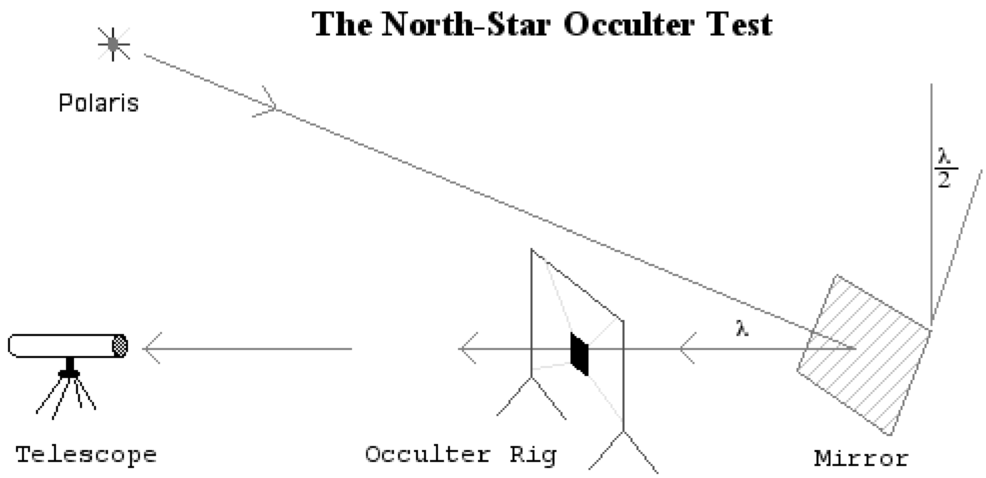
The Ground Test Configuration

In 2004 the UMBRAS team in collaboration with members of the Westminster Astronomical Society, Inc (WASI) constructed and tested the occulter design using a scale model occulter and masked-off telescope (the aperture scaled to distance and size of the occulter).

The scaled ground test configuration, illustrated in the diagram and images below, used a 540-mm focal length refractor masked down to 11 and 24 mm (below left) separated by 100 meters from an occulter, a 12-inch diameter light shroud tube with removable 1- and 2-inch square occulters and a mirror cell (below right). Optical alignment of the system was carried out by using green laser pointers. The star Polaris was allowed to drift across the field of view and behind the occulter. While none of the tests resulted in the imaging of Polaris B, a number of lessons were learned about how occulters operate and work during these tests, particularly with respect to alignment of the telescope, occulter, and target star. The test configuration is diagramed at the top of the next page.

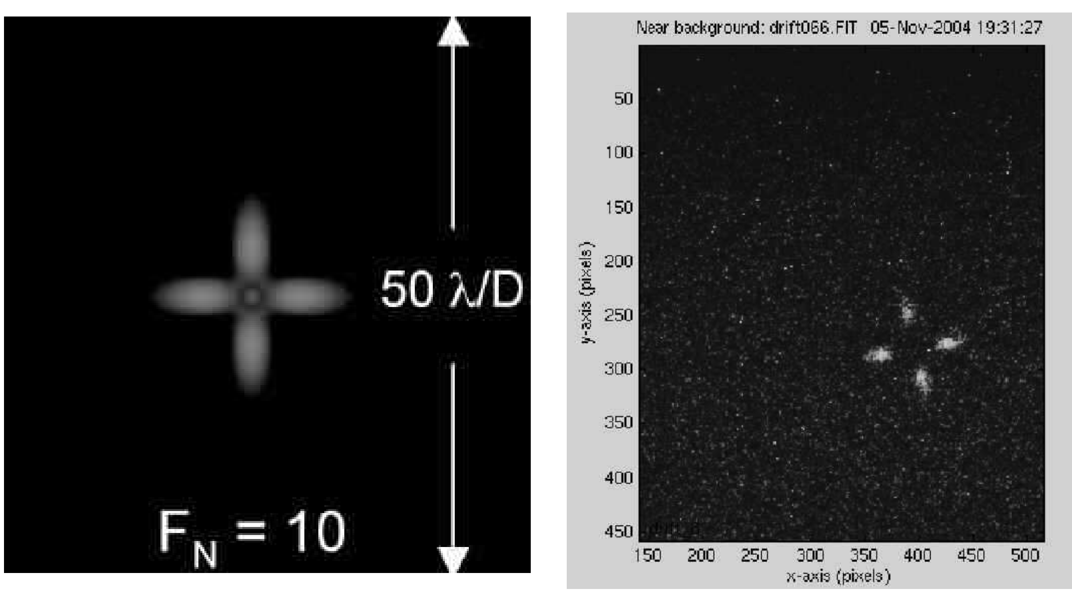






Is It Real?

The images below present a comparison of a theoretical model created by Rick Lyon (NASA/GSFC) and actual ground data obtained on November, 5, 2004. An optical design comprised of a telescope plus a square external occulter can be characterized by two parameters, the Fresnel number (F_N) and the ratio of the telescope diameter to the occulter width. The F_N is a dimensionless parameter used to describe the optical system without adopting specific model physical parameters (Schultz et al. 2003).



Above left is a computer simulation of a star behind an occulter compared with actual ground test data of Polaris (above right) taken on November 5, 2004. The diffraction lobes are distinctly visible in the computer simulation and in the image of Polaris.

Summary

The goal of a JWST-occulter pair would be to detect and study EGPs about stars to 15 parsecs. The ground test confirms the computer simulations for the telescope-occulter model. The concept of a free-flying occulter is a viable mission that can be enabled post-JWST design and construction as long as a communication link can be established between telescope and occulter and the flight software can be modified for formation flying control.

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References

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