Apodized Square Aperture Plus Occulter Concept for TPF

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Abstract:

TPF approaches have often relied upon using a limited number of different techniques to achieve the required level of star-light suppression. Deployment of a low- or medium-performance external occulter as the first stage of starlight suppression reduces manufacturing challenges, mitigates under-performance risks, lowers development costs, and hastens launch date for TPF. This paper describes the important aspects of a conceptual 4-metre apodized square aperture telescope system utilizing a low-performance external occulter. Adding an external occulter to such a standard TPF design provides a benefit that no other technique offers: scattered and diffracted on-axis starlight is suppressed by orders of magnitude before reaching the telescope. This translates directly into relaxed requirements on the remainder of the optical system.

Optical Performance = Starlight Suppression

Adding an external occulter reduces the on-axis starlight before entering the telescope thereby gaining optical performance and margin.

Why Fly an Occulter?

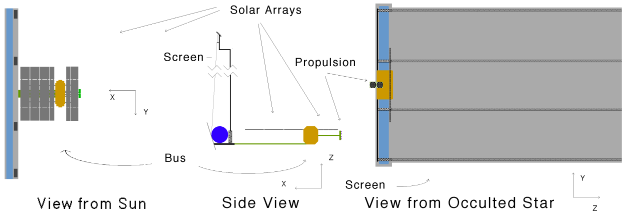
- ***Risk***: Underperformance in any stage of starlight suppression jeopardizes mission success and schedule. An external occulter can reduce requirements on the at-risk stage, lowering overall mission risk.
- ***Time***: If a TPF system cannot be launched until the technology reaches a certain performance level, then the relevant stage's performance requirements can be relaxed by using an occulter to make up the difference.
- ***Margin***: Integrating an opaque external occulter into operations gains several orders of magnitude of starlight suppression. This margin can be distributed appropriately among the individual optical stages, reducing their performance requirements.

What this study encompassed:

We leveraged previous investigations of combining external occulters with space telescopes as part of the UMBRAS project (Umbral Missions Blocking Radiating Astronomical Sources). The optical performance, spacecraft design, and mission design were examined for coupling an opaque external occulter with an apodized square aperture telescope combined with pupil apodization to shape and suppress the stellar PSF.

A review of the history of external occulter concepts allowed us to classify the different occulters based upon different metrics. An opaque occulter was picked for this study because of the manufacturing, packaging, and operating advantages.

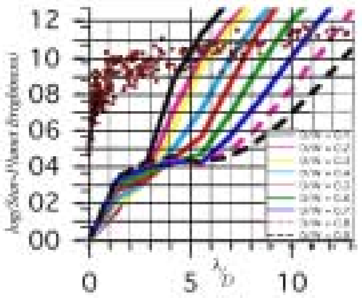
An apodized square aperture with a 4-metre diagonal diameter plus occulter (ASA4+O) was used as a reference mission to investigate the ability of the system to observe earth-analogues around nearby stars. The preliminary study showed that this system could potentially observe earth-analogues around F-stars and some of the nearby later-spectral-type stars.



Three orthogonal views of the occulter are shown above in its observing configuration. In transit configuration, the screen rotates 90-degrees around the y-axis to present a near-symmetric structure that can easily be controlled as it moves to the next target. An individual occulter craft would amass no more than about 1.5 tonnes.

Brightness limits of sources reflecting from the opaque occulter and their astronomical magnitude are provided below. Unwanted stray light from sources other than the target are significantly below the suppressed starlight. Suitably "sharp" radius of curvature (ROC) edges adequately suppress sunlight.

SourceEquivalent Stellar Brightness limit	**SourceEquivalent Stellar Brightness limit**
Scattered sunlight from edges	~ 14th magnitude diffuse beads (1-mm ROC).
Scattered earth/moon-shine from screen	~ 19th magnitude.
Doubly scattered sunlight telescope-->occulter	~ 33rd magnitude.



Parameterized ASA4+O System Performance. Colored curves show ideal (no wavefront error) ASA+O system performance (ratio of star central intensity to PSF) in the focal plane along a 45-degree diagonal to the diffraction spikes for a perfectly aligned ASA+O system at Fresnel number F_N=10 (=W^2/λz, where W is screen width, λ is observing wavelength, and z is telescope-occulter separation). Ideal ASA+O performance was simulated for various aperture-to-screen-width ratios (D/W) using GSFC's Optical Systems Characterization and Analysis Research (OSCAR) package. The overplotted data points show earth-analogues near quadrature in the habitable zone around several hundred nearby stars scaled to the 4-metre diagonal aperture observing at 0.5-microns wavelength.

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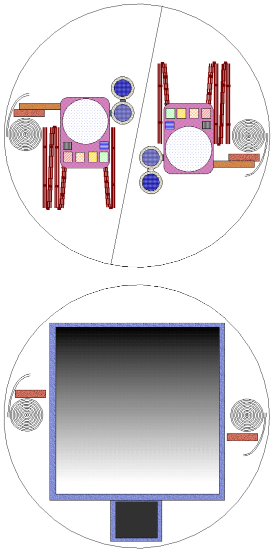
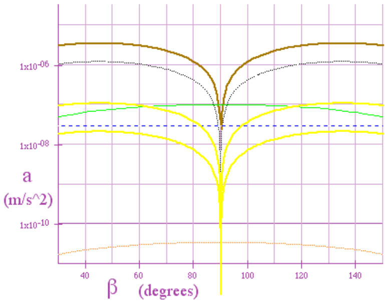


At the top of the above figure is a cross-section through the upper part of a 5-metre (4.6-m envelope shown) fairing containing two folded occulter spacecraft. On the bottom is a cross section through the same fairing several metres below passing through the 4-m diagonal square aperture, off axis telescope. The rolled screens of the two occulters can be seen projecting down the sides of the telescope. The two occulter spacecraft ride atop an adapter extending above where the telescope rides in the fairing. Approximately 9-metres of height in a 12-metre Delta IV fairing is available for the telescope in addition to its launch adapter.



Differential acceleration levels at Earth-Sun L2 for 20,000 km telescope-occulter spacecraft separation is plotted versus the sun-telescope-occulter angle. The highest acceleration levels are produced by Earth tides (brown) and solar tides (grey), while lunar tides vary between the yellow lines. The convex green line represents solar radiation pressure, while the faint dotted magenta line at bottom is solar wind pressure. The constant dotted blue line represents propellant leakage, above which mission duration would be impacted.