Scaling relation for occulter manufacturing errors

Dan Sirbu\textsuperscript{1,2}, Stuart B. Shaklan\textsuperscript{3}, N. Jeremy Kasdin\textsuperscript{4}, Robert J. Vanderbei\textsuperscript{5}
\textsuperscript{1}Princeton University, \textsuperscript{2}NASA JPL, \textsuperscript{3}NASA ARC

OBJECTIVE

For directly imaging exoplanets, NASA is considering space mission designs that use an external occulter as the principal starlight suppression system. These occulter designs range in diameter from 16 to 40 m and separation distance from 8,000 to 60,000 km for telescopes with primary diameters of 0.5 to 4 m (1-2).

Occluder shapes are solutions to an optimization problem (3) which seeks to maximize suppression in the shadow subject to constraints such as size, separation, and wavelengths. These designs are based on scalar diffraction theory and must be verified experimentally to demonstrate predicted on-orbit performance. Due to the large sizes and separations involved the experiment must be scaled to lab size (4-5).

We are currently expanding the existing experimental testbed at Princeton to enable scaling of occulters operating at flight Fresnel sizes. Here we examine the effect on suppression performance of edge defects and their scaling to testbed size.

OCCULTER SCALING

For a plane wave incident on the space occulter, the electric field downstream at the telescope can be computed assuming an apodization function \(A(r)\):

\[
E_x(r') = E_0 \exp\left( -\frac{k}{\lambda} \left( \int_0^{r'} \left( A(r') - A(r) \right) dr' \right) \right)
\]

We can introduce scaling relationships that maintain the Fresnel numbers \(r^2/\lambda z\) and \(p^2/\lambda z\) constant via a scaling factor \(a\):

\[
E_x(r') = E_0 \exp\left( -\frac{k}{\lambda} \left( \int_0^{r'/a} \left( A(r') - A(r/a) \right) dr' \right) \right)
\]

where in the above \(r' = r/a, z' = z/a\).

MASK DESIGN

We compare the design of the space occulter with other existing designs. We also design an outer ring to minimize the diffraction effects from a finite-size occulter.

![New Experiment Mask Apodization Profile](image)

![Sample propagations for increasing feature sizes](image)

An optimized occulter mask was designed for realistic space mission parameters. This was then scaled to a laboratory size maintaining a constant Fresnel number. Optical propagations were performed that verified the suppression and contrast performance under scaling for finite feature sizes, and also the effect of random manufacturing errors along the petal edges.

We have also developed an analytical model that can be used to more easily ascertain the effect of defects without using the full optical propagations.

REFERENCES

(2) NJ Kasdin et al. G. The Occulting Ozone Observatory. AAS 2010.