Hybrid Propagation Physics for The Design and Modeling of Astronomical Observatories Outfitted with Coronagraphs

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Abstract.

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1 Introduction

1.1 Astrophysical Motivation

1.2 Survey of Design Software

1.3 Hybrid Propagation Physics

1.4 Gaussian Beamlet Decomposition

Traditional diffraction modeling regimes consider the optical system to be paraxial and the electromagnetic field to be essentially scalar.

Gaussian Beamlet Decomposition (GBD) is a ray-based method of diffraction calculation that approximates an optical field as a superposition of Gaussian beams. Gaussian beams are unique in that they can be propagated along ray paths. In their seminal paper, Harvey et al[1] reviews the theory of complex ray tracing used to propagate Gaussian beams.

The Gaussian Beam takes the form:[2]

$$V = \frac{V_o}{q(z)} exp[ik\frac{r^2}{2q(z)}] \tag{1}$$

Where V_o is the amplitude, k is the wavenumber, r is the radial coordinate in the plane perpendicular to propagation, and $q(z)$ is the complex valued constant that describes the beam's $1/e$ field size (the "waist" w_o) and curvature. This constant is referred to as the *complex beam parameter*.

$$q(z)^{-1} = \frac{1}{R(z)} + i\frac{\lambda}{\pi w(z)^2} \tag{2}$$

$q(z)$ is a convenient expression of the Gaussian beam because it fully encapsulates the information required to describe the transverse electric field of the beam as it propagates. The real part of $q(z)$ is related to the radius of curvature ($R(z)$) of the wavefront.

$$R(z) = z(1 + (\frac{Z_o}{z})^2) \tag{3}$$

Where Z_o is the rayleigh range and z is the longitudinal propagation distance. The imaginary part of $q(z)$ is related to the beam waist radius ($w(z)$)

$$w(z) = w_o\sqrt{1 + (\frac{z}{Z_o})^2} \tag{4}$$

In the paraxial regime $q(z)$ can be propagated using the ABCD matrices of geometrical optics.

$$q(z)_o^{-1} = \frac{C + D/q_i}{A + B/q_i} \tag{5}$$

For the generally astigmatic case, $q(z)$ is a 2x2 matrix that encodes the complex curvature in two orthogonal directions.[3,4]

2 Methods

2.1 POPPY

2.2 Gaussian Beam Parameters

2.3 Entrance Pupil Spatial Decomposition

2.4 Paraxial Model w/ Arbitrary WFE

3 Results

3.1 Paraxial Model

3.2 Real Model

4 Conclusion

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