Integrated Modeling of Observatories with Astronomical Coronagraphs using Hybrid Propagation Physics

Jaren N. Ashcraft[1], Ewan S. Douglas[2], Daewook Kim[1,2,3], A.J. Eldorado Riggs[4]
[1]Wyant College of Optical Sciences, University of Arizona. [2]Steward Observatory, University of Arizona.
[3]Large Binocular Telescope Organization, [4]NASA Jet Propulsion Laboratory

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Introduction

Integrated models of optical observatories are highly beneficial to their use and design [1]. Open-source packages have been widely used to simulate the performance of high-contrast imaging instrumentation [2]. As observatories become larger and more aspheric, the paraxial assumption becomes less valid. To accurately simulate the observatory PSF, we must look to methods of diffraction modeling that do not rely on the paraxial approximation. We are currently investigating Gaussian Beamlet Decomposition as a candidate propagation module for POPPY to perform nonparaxial diffraction calculations with ray data.

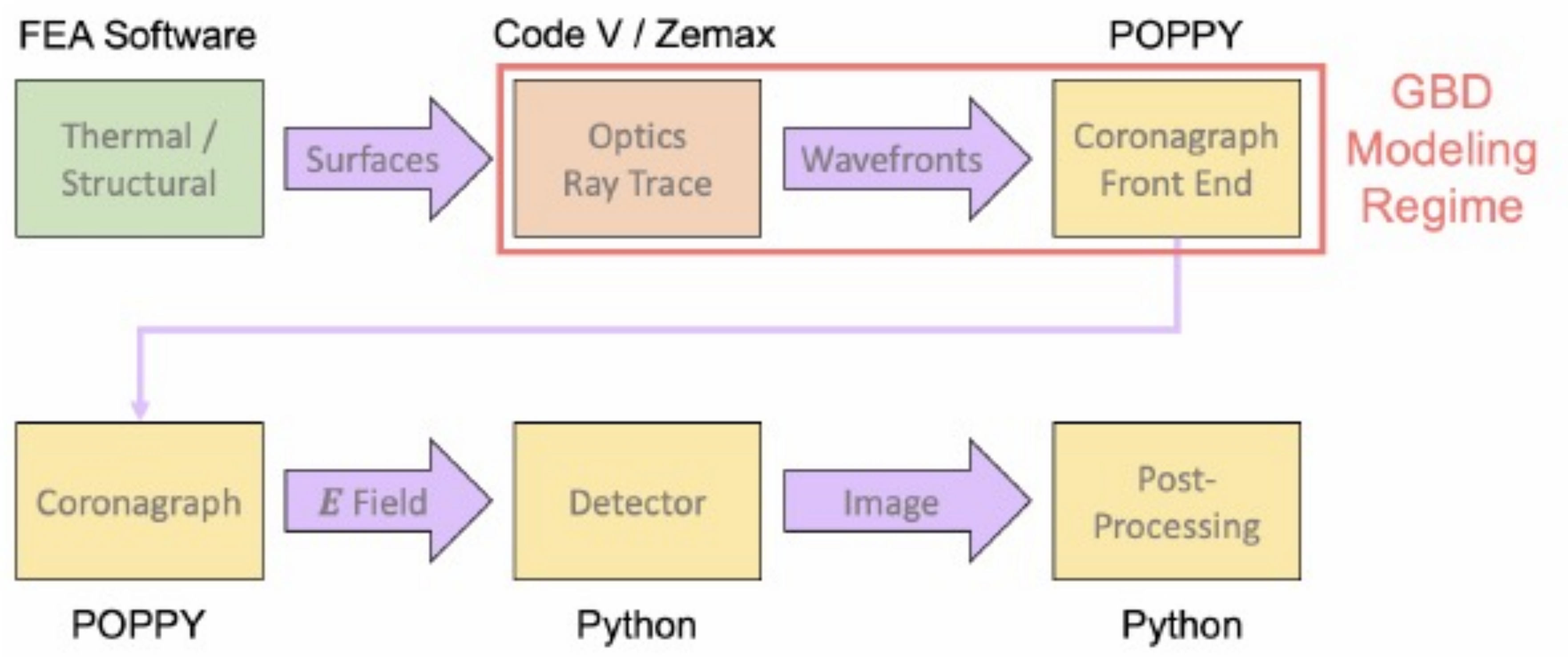

Figure 1: STOP Modeling flow for observatories outfitted with coronagraphs. The boxes in yellow are typically open-source. GBD aims to open-source the propagation physics of ray tracing engines by providing a better link between rays and waves.

Gaussian Beamlet Decomposition (GBD)

GBD is a ray-based method of diffraction simulation used in optical design software [3,4]. It works by decomposing the entrance pupil into a finite sum of Gaussian Beams, which can be propagated along ray paths [5,6]. With GBD a coherent calculation can be made using ray data for generally non-paraxial optical systems [6]. However, the method only produces accurate results with sufficient sampling [5]. We aim to evaluate GBD's suitability for high-contrast imaging simulations to provide a better connection between the ray model of the observatory and the wave model of the coronagraph, and ultimately publish it into an open-source library.

$$U(\boldsymbol{r}) = U_o \exp\left(-\frac{\boldsymbol{r}^2}{2q(z)}\right) \quad q'(z) = \frac{Aq+B}{Cq+D}$$

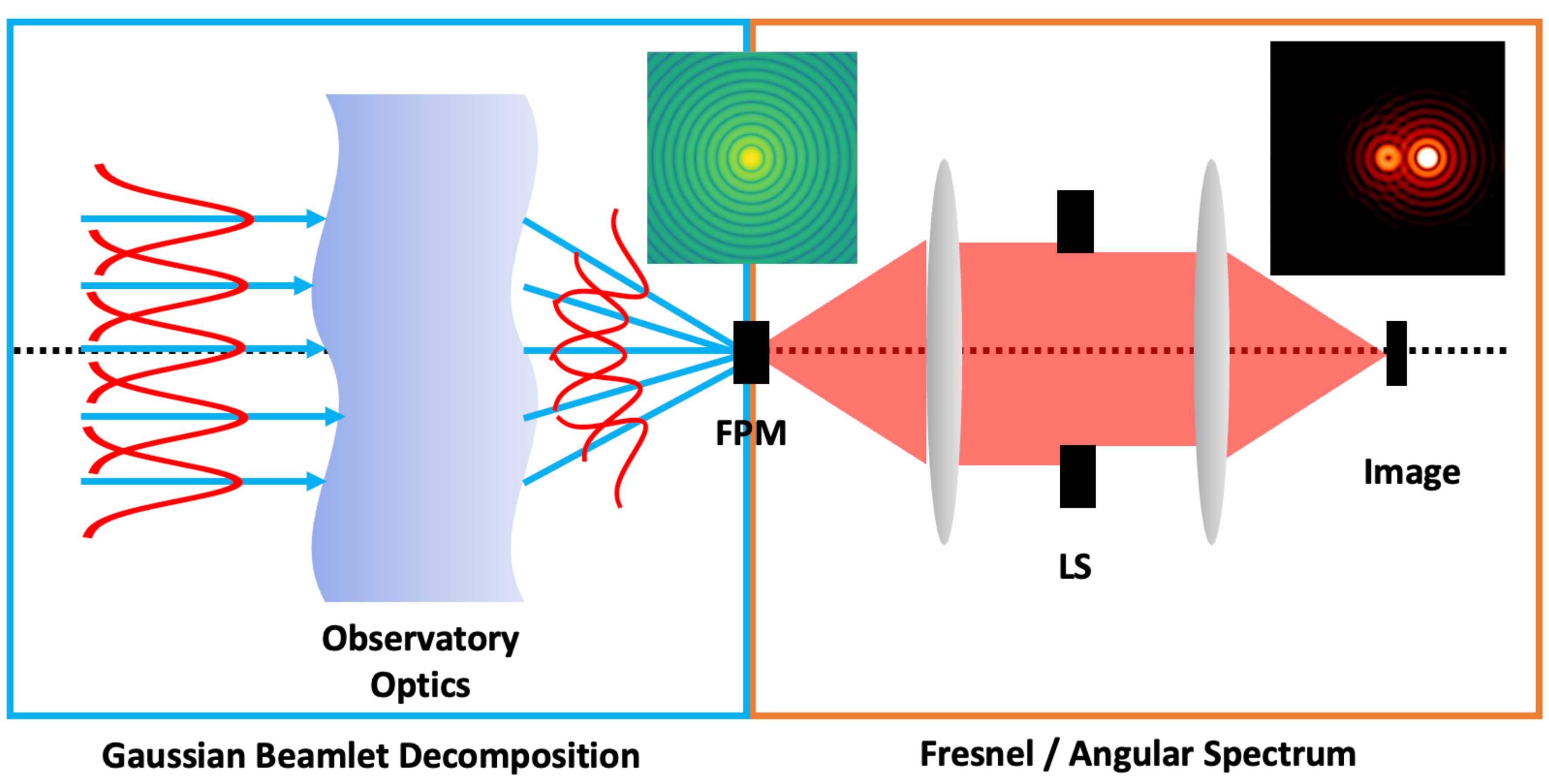

Figure 2: Diagram of modeling an observatory outfitted with a coronagraph with GBD and Fresnel diffraction in a "Hybrid" propagation scheme. The observatory PSF is generated with GBD from the ray trace model, and this is handed to a Fresnel diffraction model of a coronagraph after the focal plane mask (FPM).

Results

GBD can produce accurate observatory PSFs without infringing on Coronagraph models. Below is a Vector Vortex Coronagraph point-response function to illustrate GBD's influence on coronagraphic simulations.

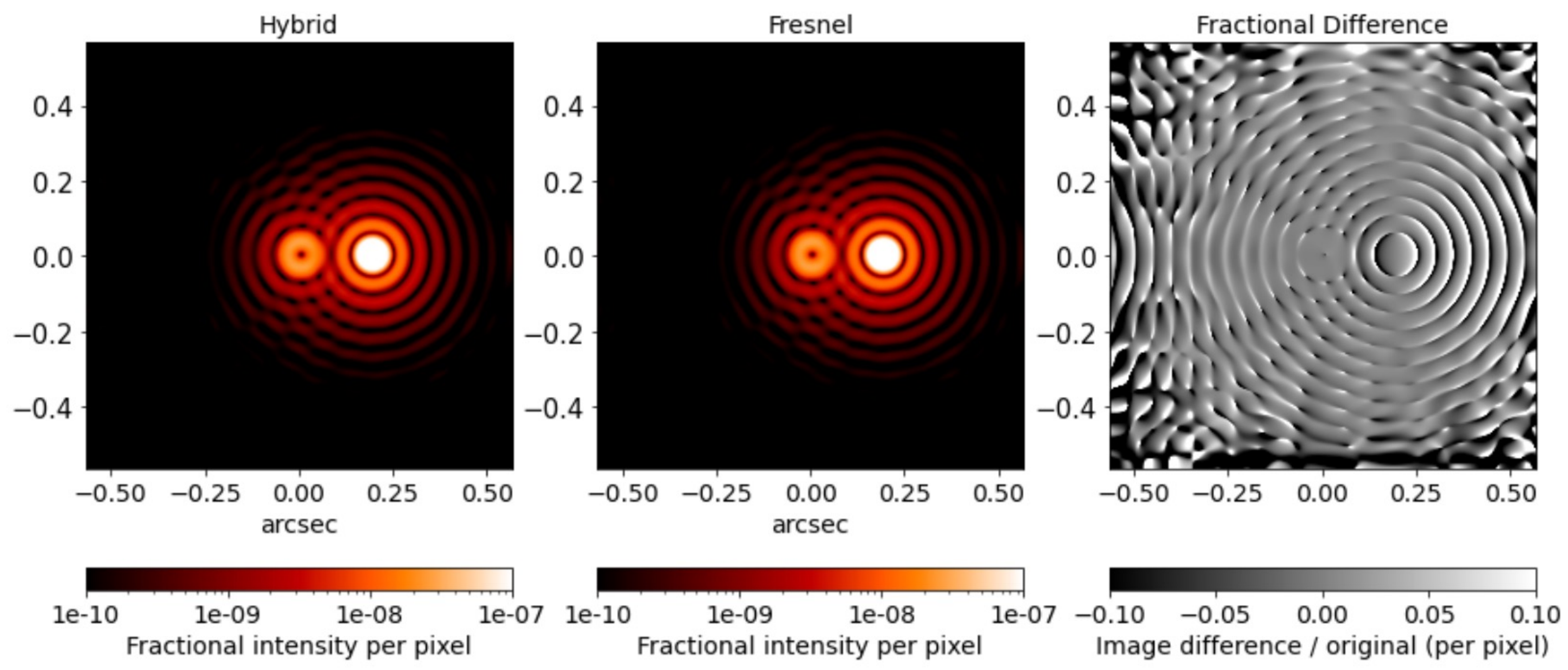

Figure 3: Comparison of the coronagraphic PSF produced by the proposed Hybrid propagation scheme (left) and Fresnel diffraction (middle). The fractional difference (right) reveals the consistency between the two simulations. The RMS difference is on the order of 3×10^{-11}.

GBD is also uniquely suited to parallelization to enable higher sampling. Preliminary use of parallel processing packages shows an encouraging decrease in computation time. We will explore GBD's suitability for GPU parallelization in future work.

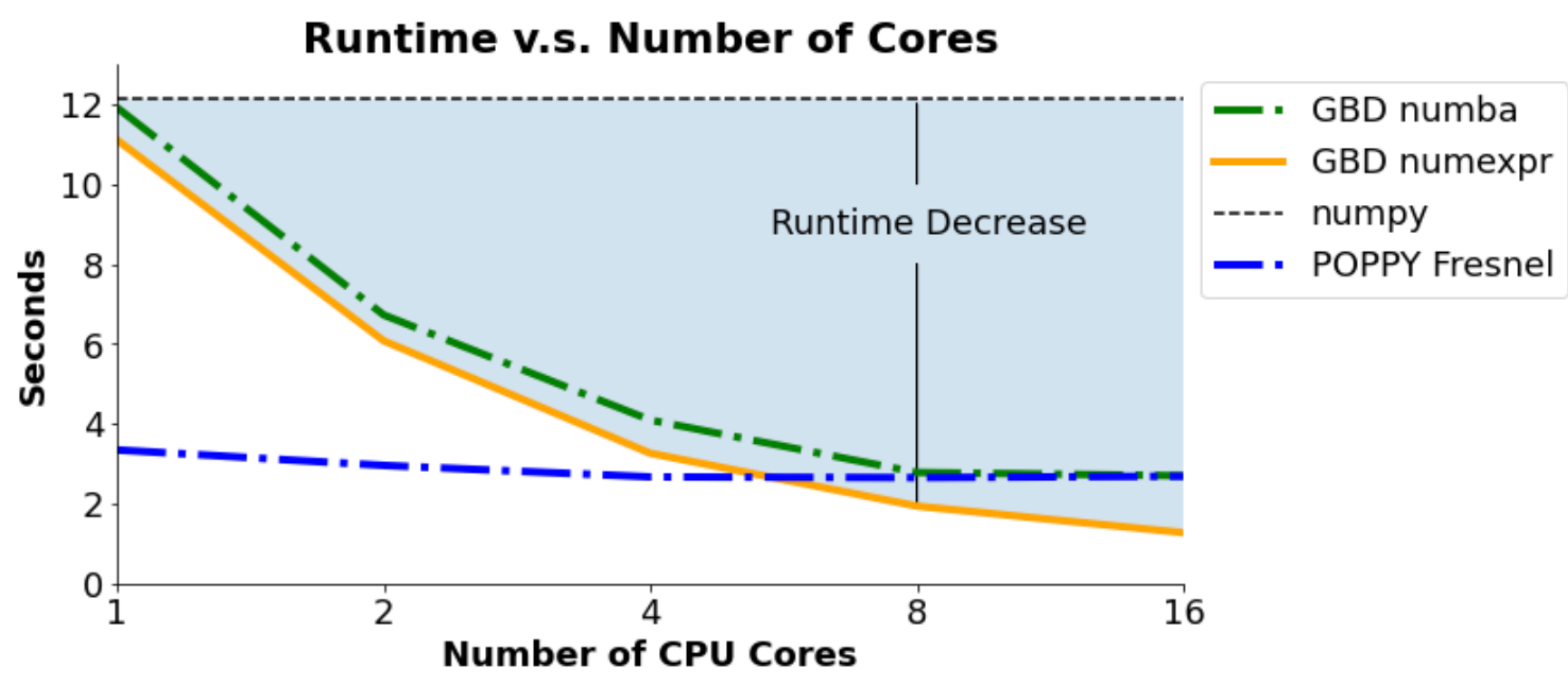

Figure 4: Runtime comparison using multi-threading packages for GBD simulations. GBD is uniquely suited to parallel processing because of the independence of each beamlet calculation.

Conclusion

GBD provides a compelling link between the ray model of the observatory and the wave model of the coronagraph without introducing significant additional numerical error. We aim to develop this module for open-source implementation as a design tool for observatories equipped with high - contrast imaging instrumentation. Future work entails using GBD on GPUs to further decrease the runtime and evaluating differences in paraxial and nonparaxial models of observatories. GBD will also be used in concert with Polarization Ray Tracing to integrate the vector behavior of the electric field and explore how this limits high-contrast imaging instruments.

References

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Acknowledgements

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Follow the package development at Github.com/Jashcraf/Gaussian-Beamlets