Unobscured Two-Mirror Confocal Optical System Analysis Using Application to Photon Simulator (PhoSim)

Sunwoo Lee[1], Woojin Park[2], Soojong Pak[1,3], Jimin Han[1], Dohoon Kim[3], Jaewon Yoo[2,4], Jongwan Ko[2,4], Dae-Hee Lee[2], Geon Hee Kim[5], Seunghyuk Chang[6], David Valls-Gabaud[7], and Dae Wook Kim[8,9]

[1]School of Space Research and Institute of Natural Science, Kyung Hee University, 1732, Deogyeong-daero, Yongin, Republic of Korea
[2]Korea Astronomy and Space Science Institute, 776, Daedeok-daero, Daejeon, Republic Korea
[3]Department of Astronomy & Space Science, Kyung Hee University, 1732, Deogyeong-daero, Yongin, Republic of Korea
[4]University of Science and Technology (UST), Gajeong-ro, Daejeon 34113, Republic Korea
[5]Korea Basic Science Institute, 169-148, Gwahak-ro, Daejeon, Republic Korea
[6]Center for Integrated Smart Sensors, Korea Advanced Institute of Science and Technology (KAIST), 291, Daehak-ro, Daejeon, Republic of Korea
[7]LERMA, CNRS, PSL, Observatoire de Paris, 61 Avenue de l'Observatoire, 75014 Paris, France
[8]Department of Astronomy and Steward Observatory, University of Arizona, 933 N. Cherry Ave., Tucson, Arizona 85721, USA
[9]James C. Wyant College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA

Author e-mail address: lsw@khu.ac.kr

Abstract: PhoSim is helpful for high accuracy observations thanks to its realistic simulation. Before testing three mirror confocal off-axis optical system, we confirmed the application of the confocal off-axis system to PhoSim using a Cassegrain system. (tel: +82 10.7763.0431, e-mail: lsw@khu.ac.kr).

1. Introduction

The Photon Simulator (PhoSim) platform was developed for the optical analysis of the Large Synoptic Survey Telescope (currently called as the Vera C. Rubin Observatory). It is specialized for a realistic optical modeling and simulation because it considers various physical effects including atmosphere and detector as indicated in the PhoSim algorithm flowchart in Figure 1 [1, 2]. Such realistic simulations become a powerful tool to model, evaluate, and predict high accuracy astronomical observations of low surface brightness objects [3]. One of the PhoSim simulations returns an expected image based on input image and a given optical system. This capability can be utilized for a wide-field imaging system (e.g., unmanned aerial vehicles) analysis, especially, to investigate the entire field of view.

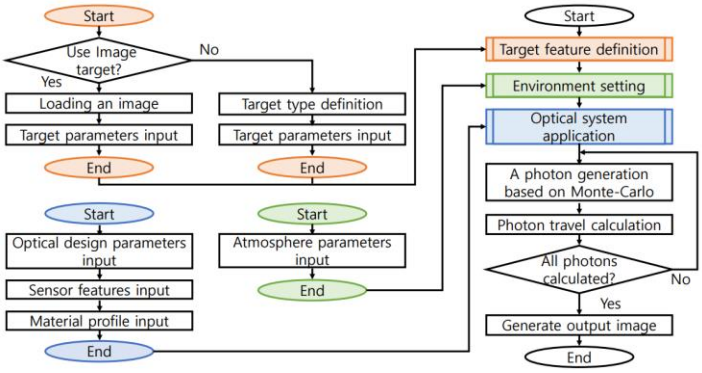

Fig. 1. Algorithm flowchart of PhoSim.

The obscuration from a secondary mirror and its supporting spiders, which generate diffraction effects at the focal plane, is one of the primary issues preventing high accuracy observations. A typical off-axis optical system solves the obscuration issues, but linear astigmatism aberration, which only occurs in off-axis systems, degrades the overall optical imaging performance. By letting the mirrors share their foci, the confocal off-axis configuration eliminates the linear astigmatism [4]. Confocal off-axis designs have been widely adopted because of their superb optical performance over the large field of view [5, 6]. Confocal off-axis Cassegrain telescope using two mirrors has been applied to PhoSim as a benchmark study and numerical verification before three-mirror off-axis confocal system analysis using PhoSim. The point spread function (PSF) simulation result was compared to that of CODE V.

2. Unobscured two-mirror confocal optical system

For reliability test of the confocal off-axis system analysis using PhoSim, we simulated a confocal off-axis Cassegrain telescope with 1,000 mm entrance pupil diameter and 8,000 mm effective focal length. The optical layout of the unobscured Cassegrain telescope is shown in Figure 2. The three critical optical prescriptions defining the confocal off-axis system are distance between the mirrors (d), distance between sensor and the secondary mirror (l_2'), and the reflection angle of the chief ray at the primary mirror (i_1). Those three parameters are set to 1,400 mm, 2,400 mm, and 15°, respectively.

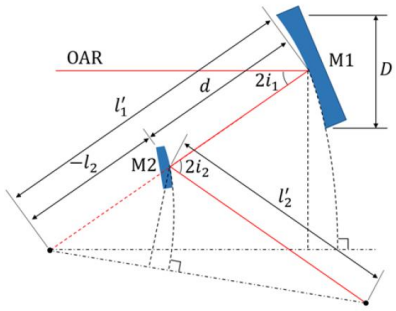

Fig. 2. Optical layout of the unobscured two-mirror confocal Cassegrain optical system.

3. PSF accuracy cross-verification

The PSF simulation result of PhoSim was compared to and cross-verified with that of the CODE V result to obtain the reliability. For this purpose, atmosphere effect, phenomena occurring in the detector and the other non-optical effects are ignored in PhoSim to simulate the identical condition in CODE V. The wavelength was set to 532 nm. The simulated two PSFs are plotted in log scale for a clear comparison of the center width of PSF as presented in Figure 3. The PSF central peak widths for both cases match well to ~8 μm.

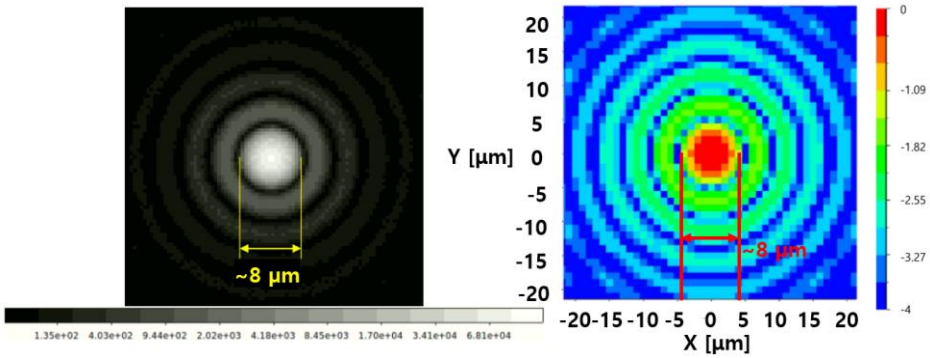

Fig. 3. Log scaled PSF simulation result of PhoSim (left) and CODE V (right).

Based on the PSF simulation comparison between the PhoSim and CODE V, the accuracy and reliability of the PhoSim analysis for confocal off-axis optical system application is well verified. We will model and analyze more complex three-mirror confocal off-axis system using freeform optical surfaces (expressed in XY decic polynomials with 66 coefficients) on the PhoSim platform.

Reference

[1] J. R. Peterson, “Sensor Distortion Effects in Photon Monte Carlo Simulations”, ApJ 889, 182 (2020).

[2] Angeli, G. Z., “An integrated modeling framework for the Large Synoptic Survey Telescope (LSST)”, SPIE 9911, 1-20 (2016).

[3] Simona Lombardo, “Next-generation telescopes with curved focal surface for ultralow surface brightness surveys”, MNRAS 488, 5057-5064 (2019).

[4] Chang Seunghyuk, “Linear astigmatism of confocal off-axis reflective imaging systems and its elimination”, AO 45, 484 (2006).

[5] Hammer Arvid, “Wide-field off-axis telescope for the Mesospheric Airglow/Aerosol Tomography Spectroscopy satellite”, OSA 58, 1393-1399 (2019)

[6] Park Woojin, “Development of Linear Astigmatism Free—Three Mirror System (LAF-TMS)”, PASP 132, 1-26 (2020)