Optical Design and Tolerance Analysis of a Three-Mirror Freeform Telescope for the MESSIER Surveyor Mission

Seunghyuk Chang[1*], Jimin Han[2], Sunwoo Lee[2], Soojong Pak[2], Woojin Park[3], Dae Wook Kim[4], Geon Hee Kim[5], Dae-Hee Lee[3,6], and David Valls-Gabaud[7]

[1]*Center for Integrated Smart Sensors, Kim Byung-ho IT Convergence Building (N1) No. 312., 291, Daehak-ro, Yuseong-gu, Daejeon, Republic of Korea 34141*

[2]*School of Space Research and Institute of Natural Science, Kyung Hee University, 1732 Deogyeong-daero, Giheung-gu, Yongin-si, Gyunggi-do , Republic of Korea 17104*

[3]*Korea Astronomy and Space Science Institute, 776 Daedeok-daero, Yuseong-gu, Daejeon, Republic of Korea 34055*

[4]*James C. Wyant College of Optical Sciences, University of Arizona, 1630 E. University Blvd., Tucson, AZ 85721-0094*

[5]*Korea Basic Science Institute, 169-148, Gwahak-ro, Yuseong-gu, Daejeon, Republic of Korea 34133*

[6]*Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology (KAIST), aehak-ro 291, Yoosung-gu, Daejeon, Republic of Korea 34141*

[7]*Observatoire de Paris, LERMA, 61 Avenue de l'Observatoire, 75014 Paris, France*

[*] *chang@offaxis.co.kr*

Abstract: The optical design and the tolerance analysis of a 400mm-aperture, f/3, three-mirror freeform telescope for the MESSIER surveyor mission is presented. Due to its linear-astigmatism-free characteristic, the telescope provides a wide field of view. Also, the tolerance analysis indicates the manufacturing and the alignment of the telescope is achievable.

1. Introduction

The MESSIER surveyor mission is a small space mission to survey extremely low surface brightness universe at wavelength range from 200nm to 1000nm [1]. Since a low PSF wing level is important, an obstruction-free optics is essential for this mission. Also, an all-reflective telescope with a wide field of view is desirable because scattering problem related lens systems can be avoided. Considering all these requirements, a linear-astigmatism-free three-mirror freeform telescope design was selected for the mission [2].

2. Optical design

Figure 1 shows the side view of the telescope and the RMS spot size over a 4.5° x 1.5° field of view. The aperture diameter and the focal ratio of the telescope are 400mm and f/3, respectively. The aperture stop is located at M2 and the optical design satisfied the linear-astigmatism-free condition [3]. All three mirrors are freeform and symmetric with respect to the plane of paper.

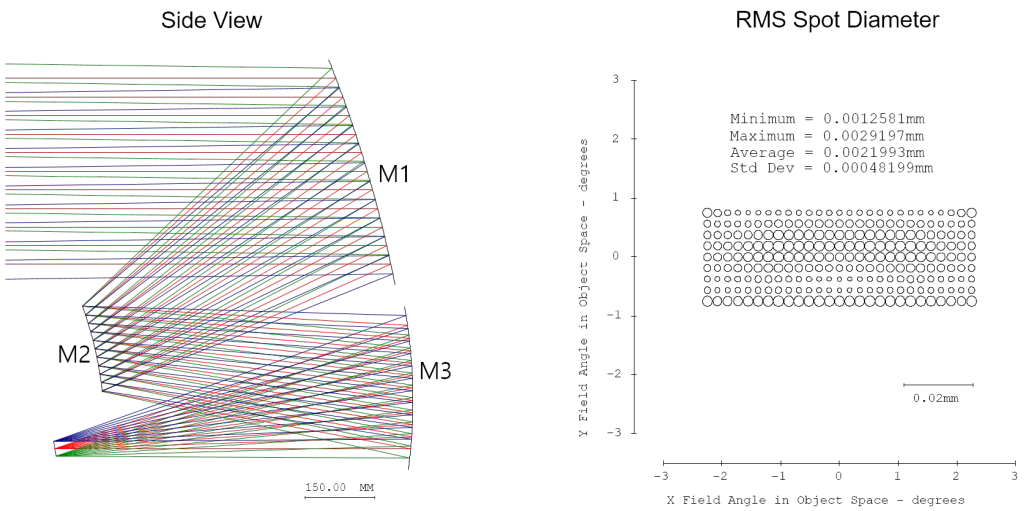

Figure 1. Side view and RMS spot diameter of the MESSIER telescope.

3. Tolerance analysis

Sensitivity analysis result is shown in table 1. Also, Fig. 2 shows Monte-Carlo simulation result. The requirement for the analysis is 80% encircled energy diameter less than 10 micrometers.

Table 1. Sensitivity analysis result of the MESSIER telescope

Parameter	Tolerance Limit	Parameter	Tolerance Limit	Parameter	Tolerance Limit
M1 α–tilt	±0.290 arcmin	M3 β–tilt	±0.618 arcmin	M3 y-decenter	±0.296 mm
M1 β–tilt	±0.312 arcmin	M3 γ–tilt	±4.388 arcmin	M1-M2 despace	±0.711 mm
M1 γ–tilt	±1.074 arcmin	M1 x-decenter	±0.107 mm	M2-M3 despace	> ±1 mm
M2 α–tilt	±2.073 arcmin	M1 y-decenter	±0.109 mm	M1 surface error	0.121 μm RMS
M2 β–tilt	±2.090 arcmin	M2 x-decenter	±0.157 mm	M2 surface error	0.080 μm RMS
M2 γ–tilt	±1.229 arcmin	M2 y-decenter	±0.159 mm	M3 surface error	0.150 μm RMS
M3 α–tilt	±0.598 arcmin	M3 x-decenter	±0.284 mm		

Parameters		Tolerance Range
Tilt	M1	±0.12 arcmin
	M2	±0.60 arcmin
	M3	±0.30 arcmin
Decenter		±0.05 mm
Despace		±0.10 mm
Surface RMS error		50.0nm
Focus		±1.00 mm
80% EED		9.83 μm

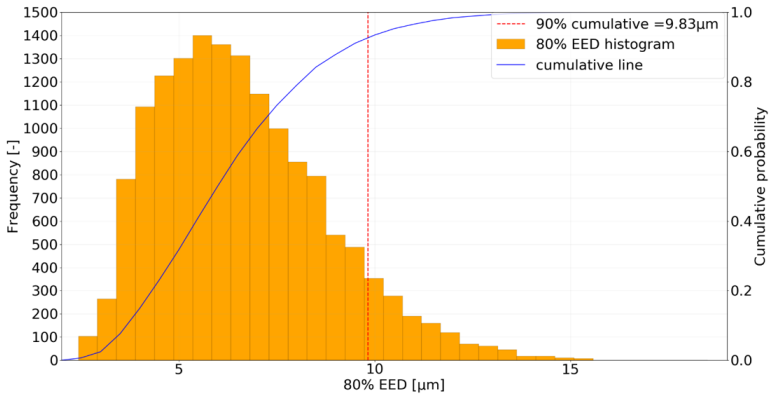

Figure 2. Monte-Carlo simulation result of the MESSIER telescope.

Acknowledgement: This research was supported by the International Research & Development Program of the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (Grant number: 2020K1A3A1A2104184711).

[1] D. Valls-Gabaud, and MESSIER Collaboration, “The MESSIER surveyor: unveiling the ultra-low surface brightness universe,” Proc. Int. Astron. Union 321, 199–201 (2017).

[2] S. Chang, "A Design Method of Linear-Astigmatism-Free Three-Mirror Freeform Imaging Systems," in Optical Design and Fabrication 2019 (Freeform, OFT), OSA Technical Digest (Optical Society of America, 2019), paper FM2B.6.

[3] Seunghyuk Chang, "Linear astigmatism of confocal off-axis reflective imaging systems with N-conic mirrors and its elimination," J. Opt. Soc. Am. A 32, 852-859 (2015).