

Draft plan of telescope development for spectroscopic survey program

2025.01.22.

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[4]*Green Optics Co., Ltd.*
[5]*Hanwha System Co., Ltd.*
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[7]*Ajou University*
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1 Working Group Activities

- Participants: 박병곤, 한정열, 김윤종, 이충욱, 김재우, 홍성욱, 이지우 (KASI), 이형권, 경재현 (LeOSpace), 박상영, 김영수 (Hanwha System), 인정환 (KOPTI), 유정훈 (Green Optics)
- Date: 2024.3.21–22 (1st , Buyeo), 4.26 (2nd , Rahan, Kyeongju), 6.10 (3rd, On-line), 9.3 (4th, KASI), 10.22 (5th, KASI), 11.27–29 (6th, Forest Risom) , 2025.01.06 (7th, KASI)
- Key Agenda Items
  1) Sharing of Scientific Requirements and Project Status (L: SWHong)
  2) WBS: Update of Distributed Materials (L: JYHan)
  3) Updates to Optical Conceptual Design Based on Proposed Parameters (L: JHKyeong)
  4) Impact Assessment: Scientific, Technological, Social, and Economic (L: YSKim)
  5) Material Manufacturing: Feasibility of Domestic Production / Updates on International Trends (L: JHIn)
  6) Polishing and Coating: Updates on Domestic Capabilities (including other companies) or Overview of Overseas Capabilities (L: JHRyu)
  7) Current Status of Large-Scale Optomechanical Technology (L: IKMoon)
  8) Fiber Positioner (L: YMChoi)





1 Scientific Goals and Requirements

- Scientific Goals

  1) Study of the 3D positions and properties of approximately 140 million relatively nearby galaxies with redshift below 1 (적색이동 1 이하의 상대적으로 가까운 은하 1.4억 개의 3차원 위치 및 특성 연구)

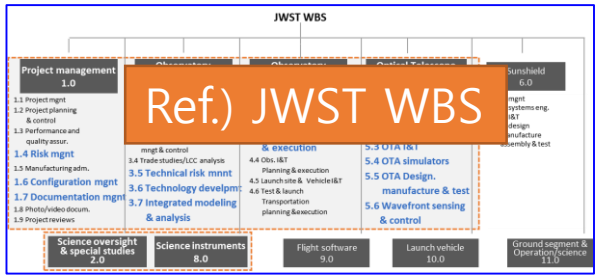
  2) Investigation of the formation and evolution of stars in the vicinity of the Milky Way and the formation processes of the Milky Way itself through follow-up spectroscopic observations of LSST data. (LSST 후속 분광관측을 통한 우리 은하 주변에 있는 별의 형성/진화 및 우리 은하의 형성 과정 연구)

- Requirements

Primary Mirror	Optical aperture 6.5 m (6.5m 2ea or 10 m 1ea)
Survey Area	Southern Hemisphere
Field of View	2.5 deg^2 = Φ 1.8 degree
Number of Objects (1회 관측 가능한 천체의 수)	10,000 ~ 13,000 (Low Spectral Resolution Option: LSR) 2,500~3,000 (High Spectral Resolution Option: HSR)
Wavelengths	370 ~ 1800 nm
Spectroscopic resolution	40,000 (HSR), 6,000 (LSR)
Plate Scale	0.1 ~ 0.15 mm/arcsec (650 ~ 980 mm for 1.8 degree)
Additional Information	Fiber Positioner Required Single Fiber per Target (MOS) or Fiber Bundle (IFS) Available

1 WBS(Draft)

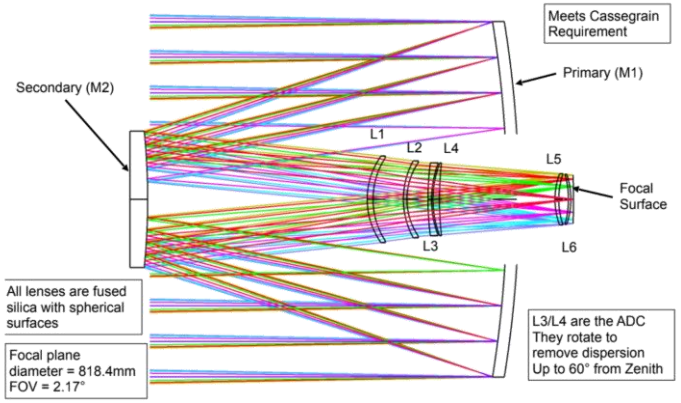
WBS for KLST



- 분광탐사 망원경(Draft) (KLST)
  - PM team
  - Project Scientist Team
  - SE team
  - Telescope (TEL)
    - Primary Mirror Optics System (M1)
    - Telescope Mount Structure (MSTR)
    - Instrument Rotator (InRo)
    - Wide Field Corrector (WFC) / Atmospheric Dispersion Corrector (ADC)
    - Telescope Safety System (TSS)
  - Science Instrument Package (SIP)
    - Positioner System (PoS)
    - Fiber Transmission System (FiTS)
    - Science Calibration System (Scal)
    - Spectrographs and Integral Field Unit (S/IFU)
  - Observatory Execution System Architecture (OESA)
    - Common Software (CSW)
    - Data Management Sysstem (DMS)
    - Observatory Control Sequences (OCSe)
    - Computing Services (CpS)
    - Data Reduction and Pipelines (DRP)
    - Data Archieves and Distribution (DAD)
    - Environment Conditi on Monitoring Syste m (ECMS)
  - Enclosure (ENCL)
    - Enclosure Structure (STR)
    - Enclosure Control System (ECS)
    - Enclosure Utilities (UTI)
    - Enclosure Safety System (ESS)
  - Observatory Building and Facilities (OBF)
    - Outer Building (OB)
    - Inner Pier (PIER)
    - Thermal Management System (THE)
    - Handling and Accessibility (ACC)
    - Shops and Labs (SHO)
    - Other Spaces and Facilities (OTSp)

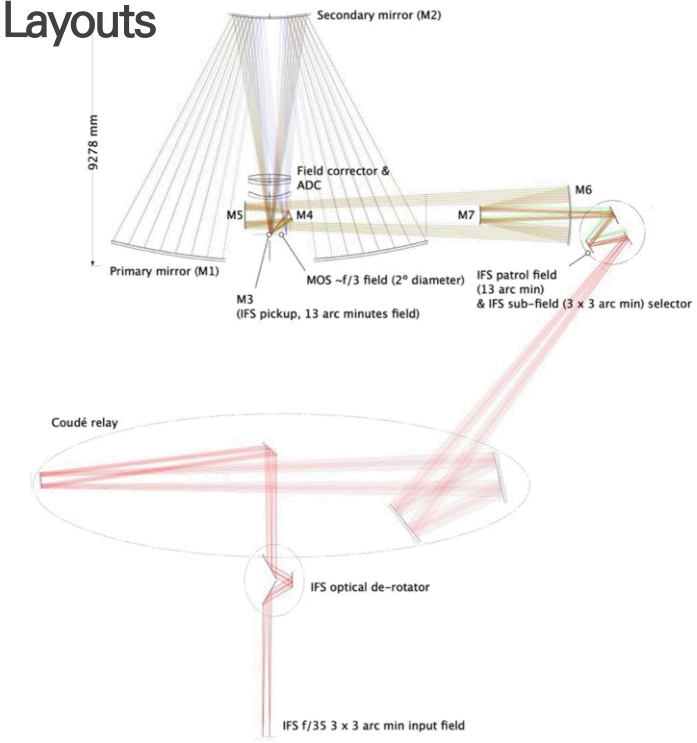
2 Optical Conceptual Design

Examples of Spectroscopic Survey Telescope Layouts



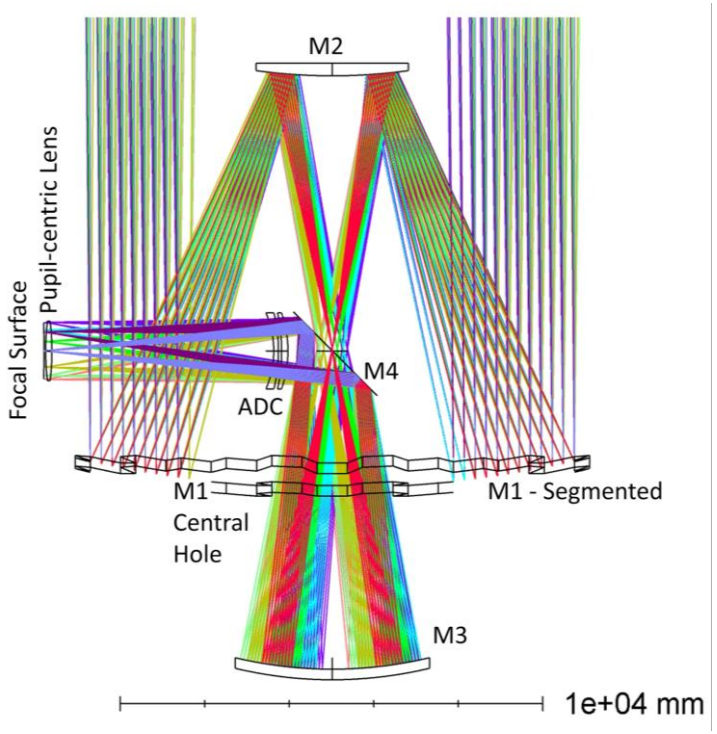
Spec-S5 (Old: MegaMapper)

- Aperture : 6m
- FOV: 2.17°
- F/# : 3.6
- Type : Cassegrain
- Wavelength : 360 – 980 nm



WST (Wide-field Spectroscopic Telescope)

- Aperture : 12m
- FOV : 2°
- F/# : 3 (MOS) / 35 (IFS)
- Type : Cassegrain (MOS) / Nasmyth (IFS)
- Wavelength : 350 – 1600 nm

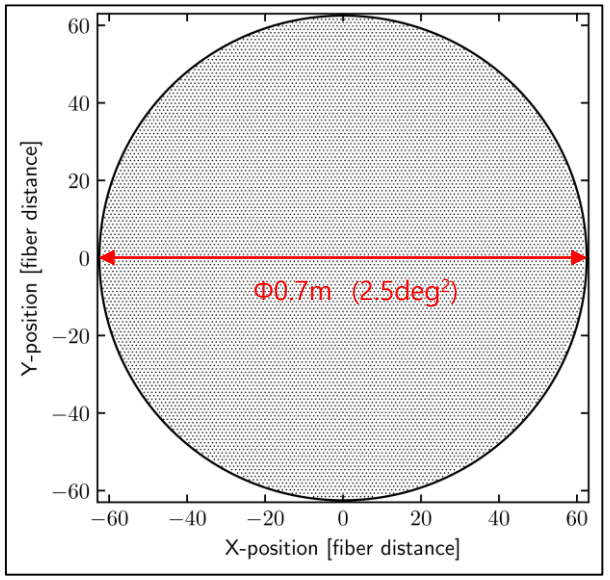


MSE (Maunakea Spectroscopic Explorer)

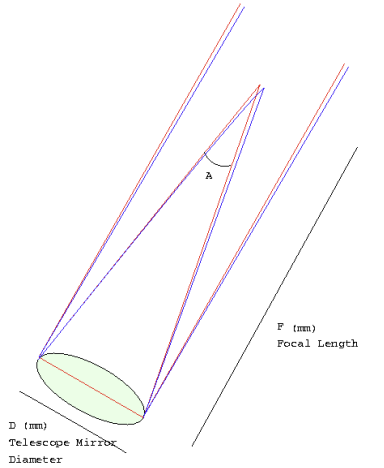
- Aperture : 12.5m
- FOV : 1.4°
- F/# : 4
- Type : Quad-mirror Nasmyth
- Wavelength : 360 – 1800 nm

Focal Plane and Plate Scale relative to Key Specifications of the Optical System

- **Optical Specification**
  - **M1: Φ6.5 m**
  - **Focal Plane: Φ0.7 m(2.5 deg^2)**
  - **F/3.51 → f=22.8 m**
  - **FOV 1.76 deg**
  - **Wavelength : 0.37-1.8 ㎛**



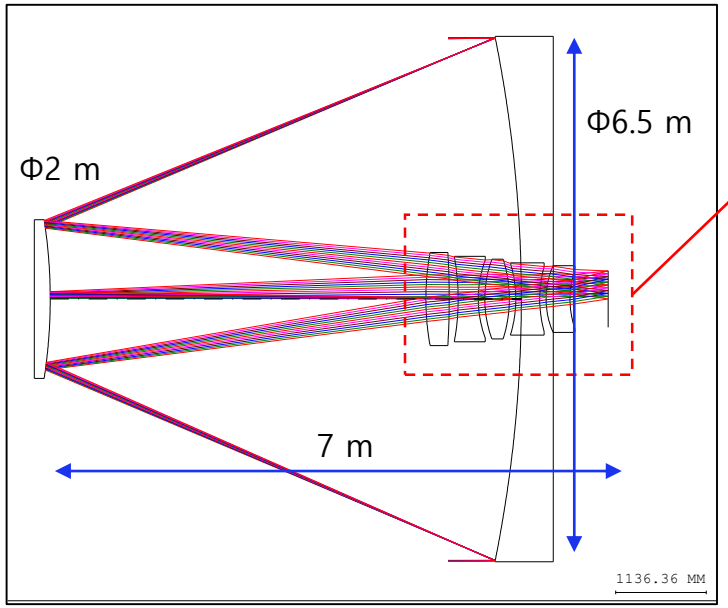
Focal plane

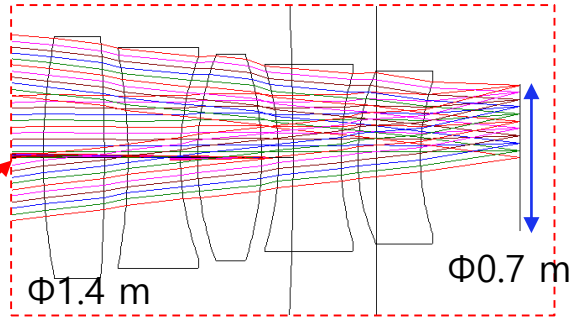


$$\text{PlateScale} = \frac{206265}{D \times f/\#} \left(\text{arc seconds / mm}\right)$$

Plate Scale(M1 6.5m) = 9.052arcsec/mm
= 0.110mm/arcsec

Conceptual Design of a Cassegrain-Type Telescope



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   BFL         479.0692
   FFL      -0.1613E+06
   FNO          3.5165
   IMG DIS    478.3697
   OAL        610.8305
   PARAXIAL IMAGE
    HT        351.0897
   ANG          0.8800
   ENTRANCE PUPIL
    DIA      6500.0000
    THI         0.0000
   EXIT PUPIL
    DIA       920.9190
    THI     -2759.3414
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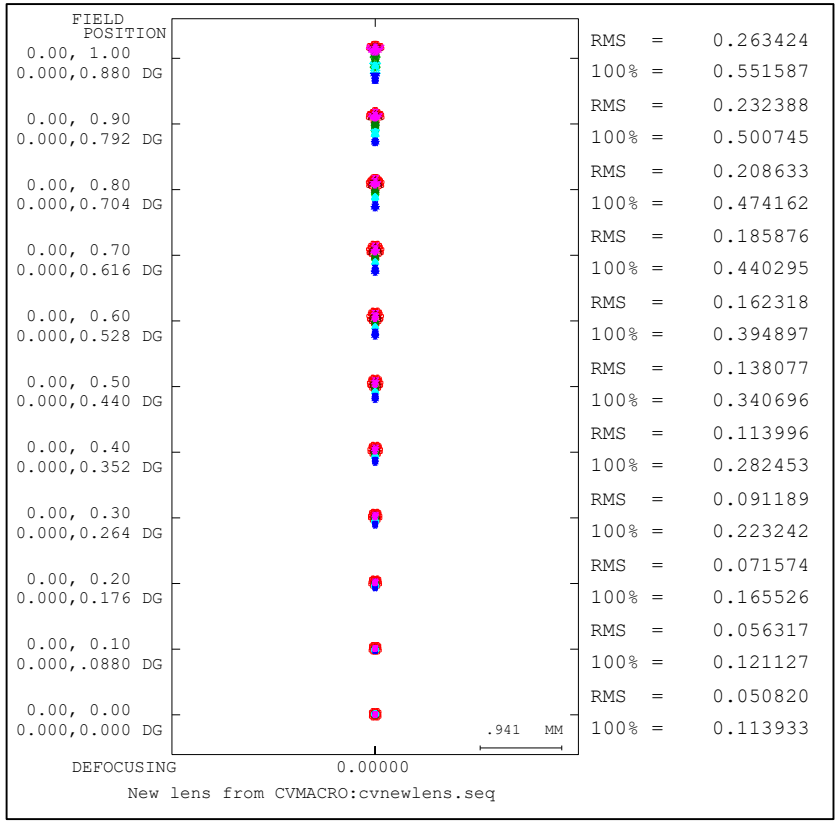
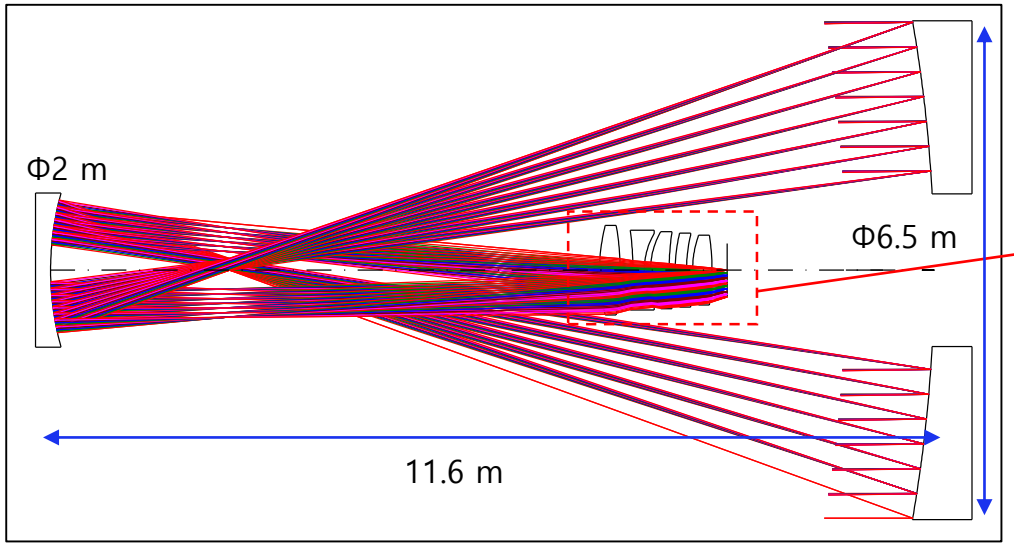
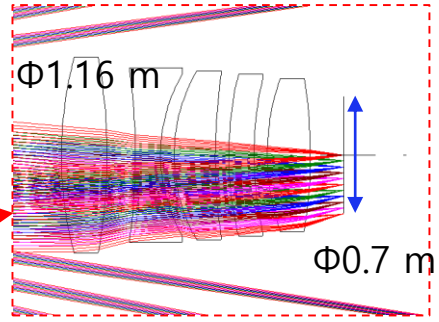


- **Advantages**: **Shorter distance between the primary and secondary mirrors enhances structural stability**.
- **Disadvantages**: **Manufacturing difficulty of the convex secondary mirror** (approximately Φ2m in diameter).

Conceptual Design of a Gregorian-Type Telescope



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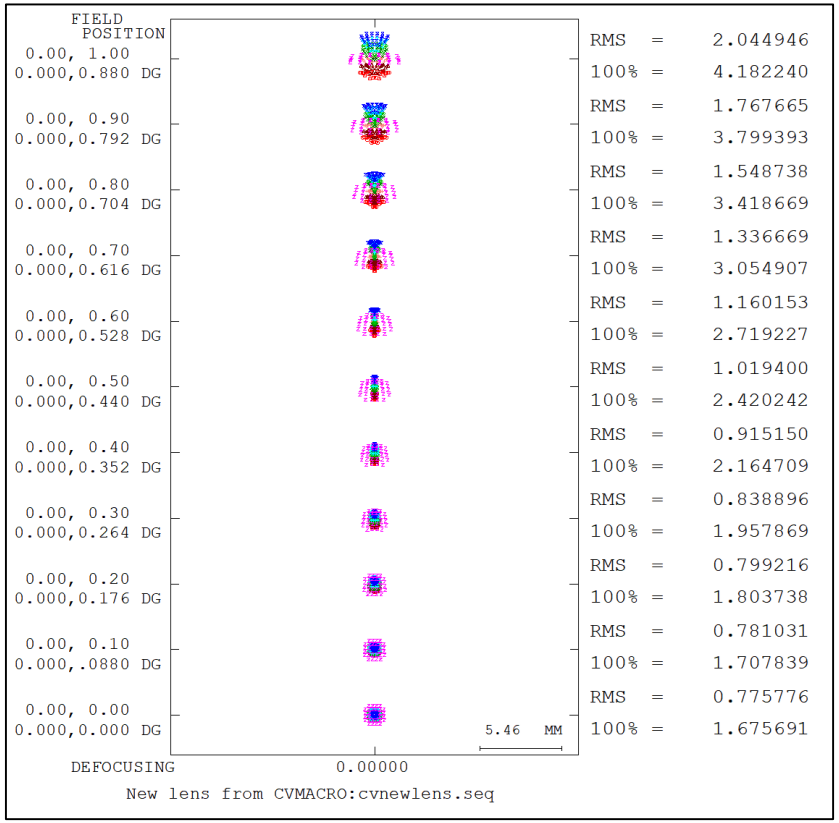
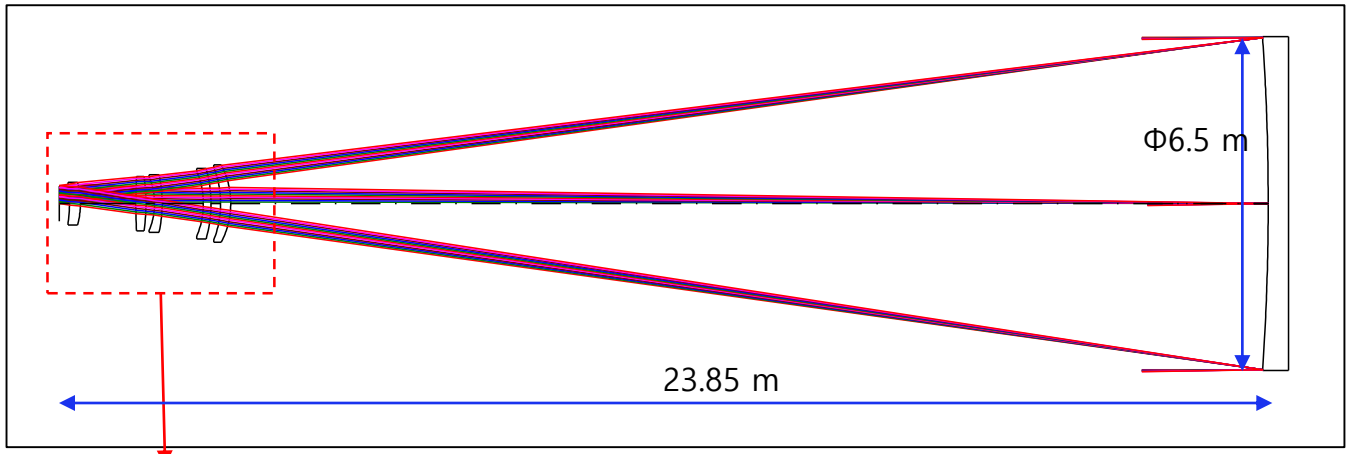
    BFL          479.0692
    FFL       -0.1613E+06
    FNO           3.5165
    IMG DIS     478.3697
    OAL         610.8305
    PARAXIAL IMAGE
     HT         351.0897
    ANG           0.8800
    ENTRANCE PUPIL
     DIA       6500.0000
     THI          0.0000
    EXIT PUPIL
     DIA        920.9190
     THI      -2759.3414
```

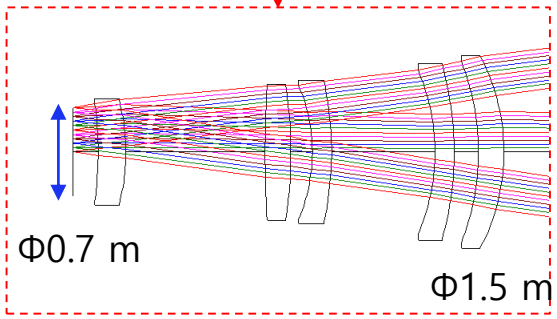


- **Advantages:**
  - Utilizing a concave shape for the secondary mirror instead of a convex shape is anticipated to **make manufacturing relatively easier.**
- **Disadvantages:**
  - The increased distance from the primary to the secondary mirror results in **a larger and more massive mount and structural framework.**

--Worst performance because it is optimized with a shorter secondary mirror and focal plane.

Conceptual Design of a Prime focus-Type Telescope





Advantages:
The absence of a secondary mirror in the optical system reduces the manufacturing burden.
Disadvantages:
Increased overall length may lead to **structural instability.**
Difficulty in replacing fibers (robots).
Anticipated challenges in constructing the enclosure.

INFINITE CONJUGATES	
EFL	-22393.9132
BFL	-200.1466
FFL	45498.4974
FNO	3.4452
IMG DIS	-200.0000
OAL	-23654.5859
PARAXIAL IMAGE	
HT	343.9729
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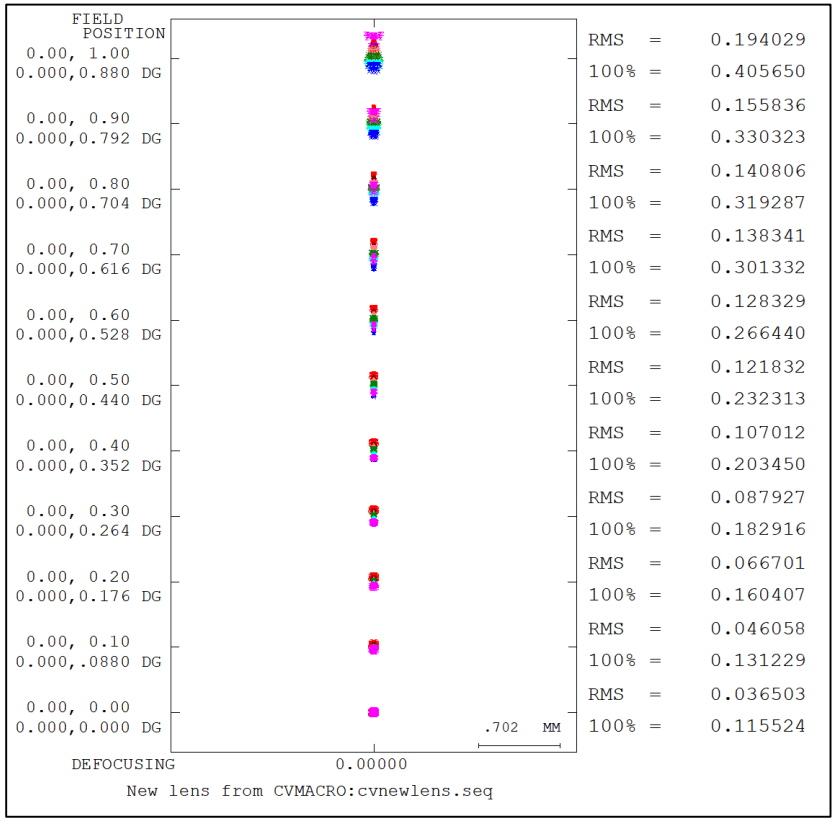
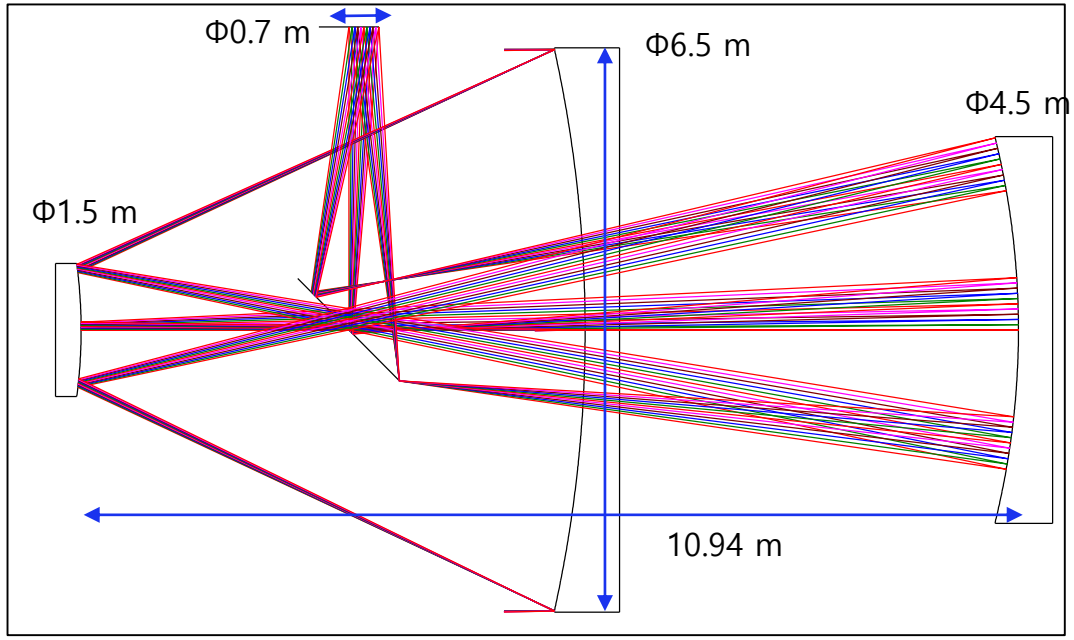


Conceptual Design of a Korsch-Type Telescope



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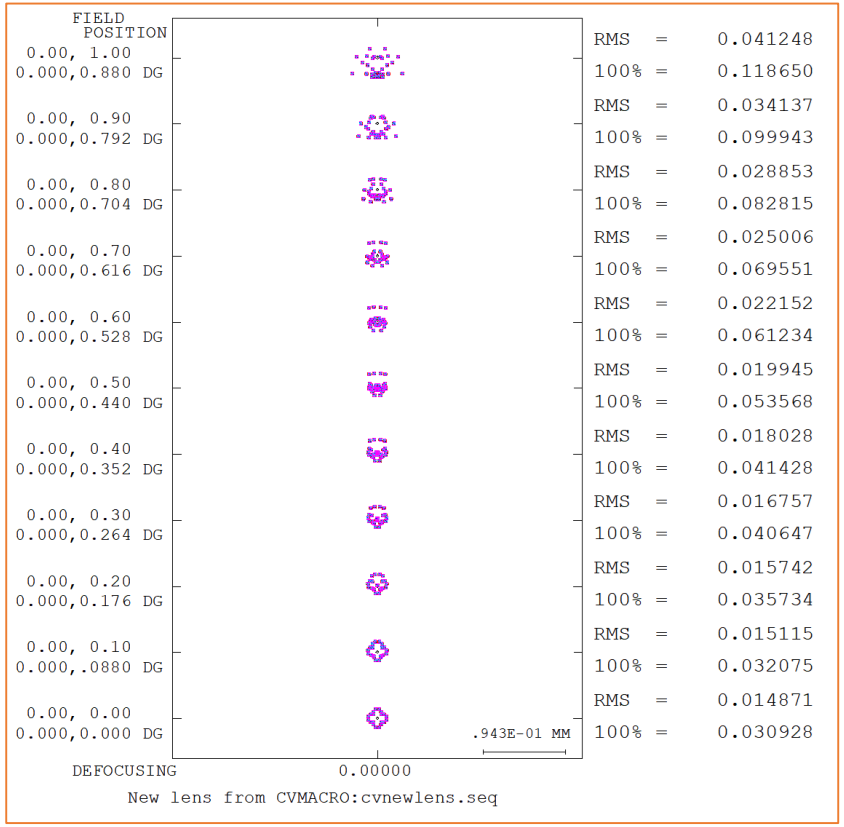
FFL	-0.1254E+06
FNO	-3.5048
IMG DIS	10.0000
OAL	742.4967
PARAXIAL IMAGE	
HT	349.9228
ANG	0.8800
ENTRANCE PUPIL	
DIA	6500.0000
THI	0.0000
EXIT PUPIL	
DIA	1180.3857
THI	-4126.9915



Advantages:

The telescope can be constructed using **only mirrors without lenses, effectively correcting chromatic aberrations.**

Among various telescope design concepts, it offers the **highest optical performance**.

By adding flat mirrors, the optical path can be altered, **allowing flexibility in modifying the telescope's structure.**

Disadvantages:

Manufacturing convex secondary mirrors is challenging (similar to the Cassegrain type); a concave design is being considered.

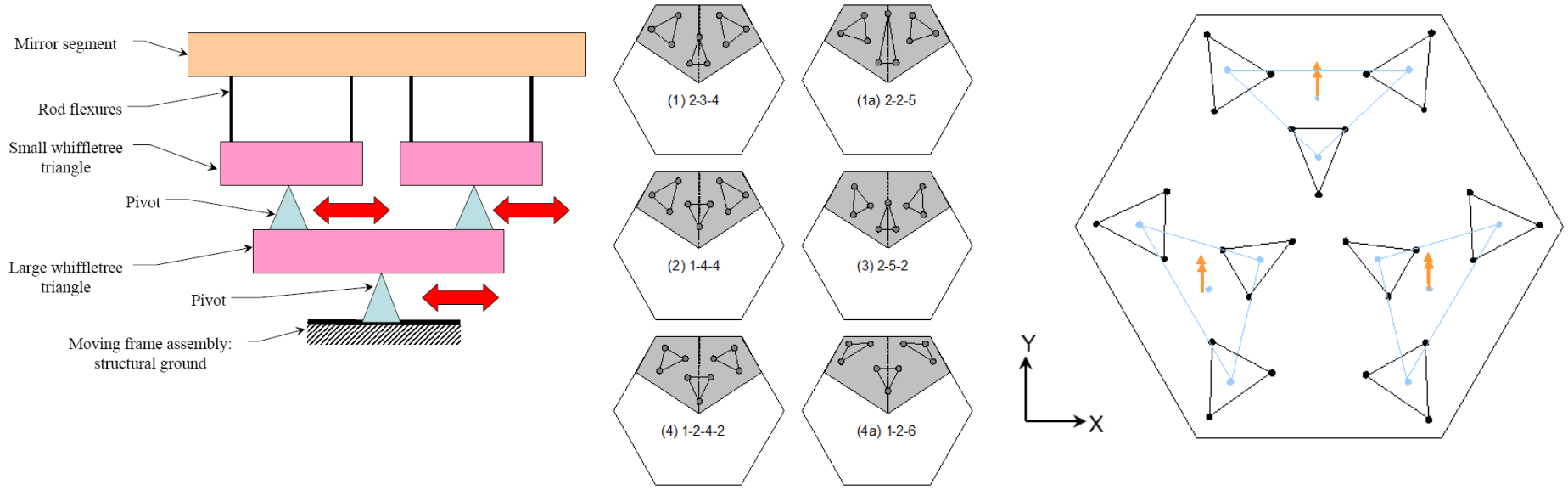
The size of the **tertiary mirror is large, posing additional design challenges.**

2 Optical Conceptual Design

Summary optical performances based on conceptual design of 6.5 and 10 m telescope configuration

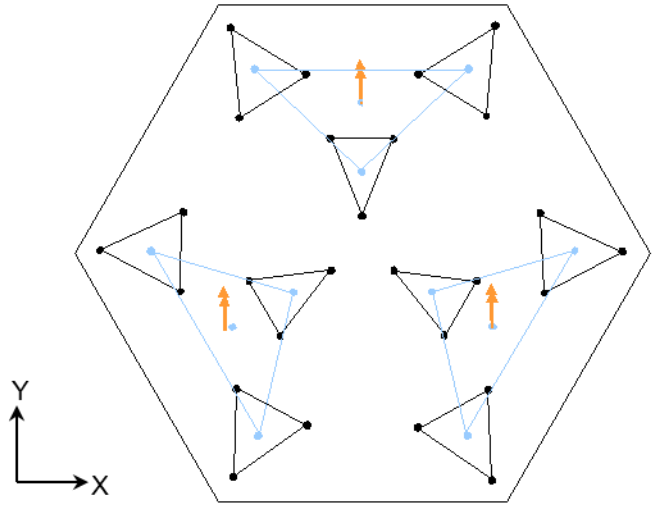
	Prime Focus	Cassegrain	Gregorian	Korsch	Prime Focus	Cassegrain	Gregorian	Korsch
M1 size	Φ10m				Φ6.5m			
Focal Plane	Φ1.2m				Φ0.7m			
OAL (max. distance)	23.17m	9.4m	14.3m	14.6m	23.85m	7m	11.6m	10.94m
M2 Diameter (type)	-	Φ2.8m (CV)	Φ3m (CC)	Φ2.9m (CV)	-	Φ2m (CV)	Φ2m (CC)	Φ1.5m (CV)
Spot size (max.)	1.92mm	0.20mm	3.44mm	0.04mm	0.19mm	0.26mm	2.04mm	0.01mm
Lens Diameter(max.)	Φ1.7m	Φ1.55m	Φ1.8m	-	Φ1.5m	Φ1.4m	Φ1.16m	-

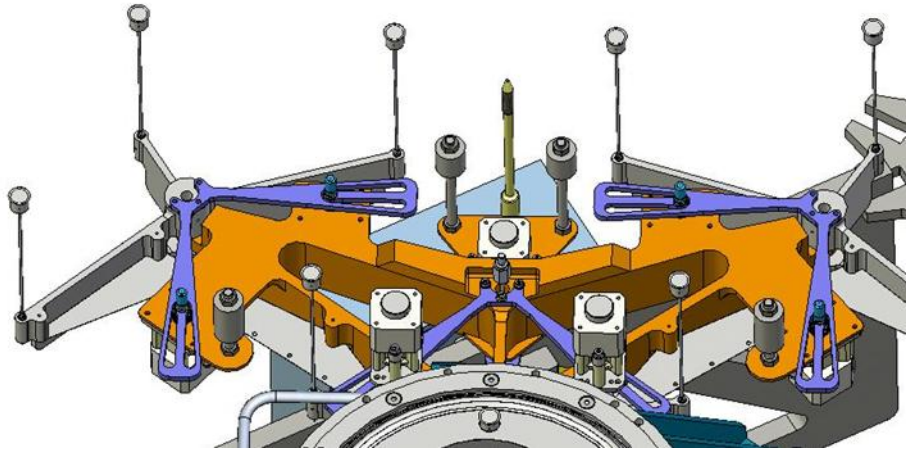
Conceptual Diagram of Axial Mount for Large Segmented-Mirror Telescope (Example)

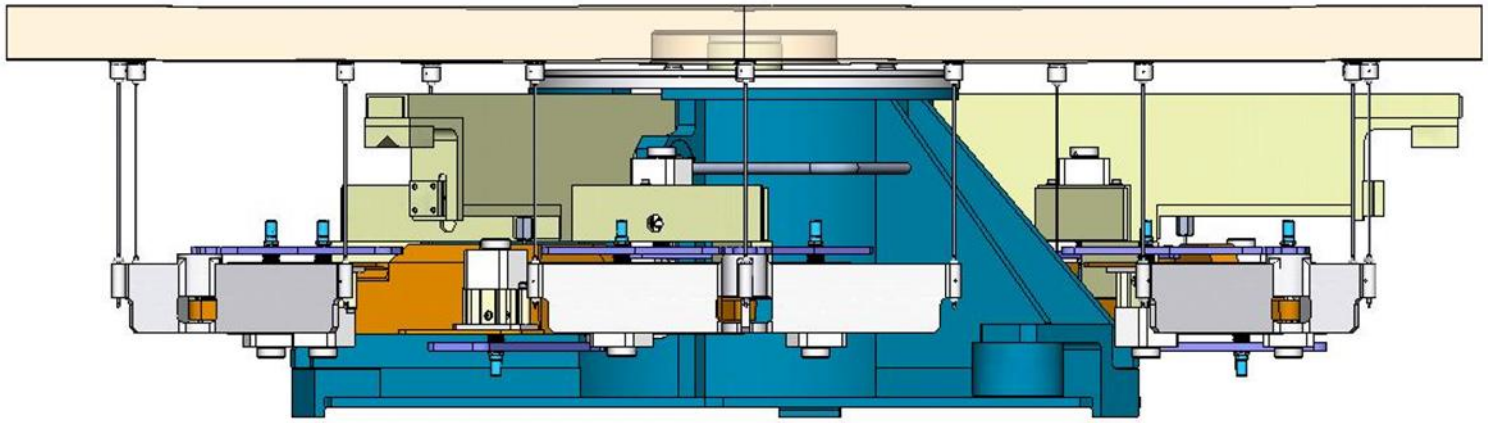


Topologies of support location

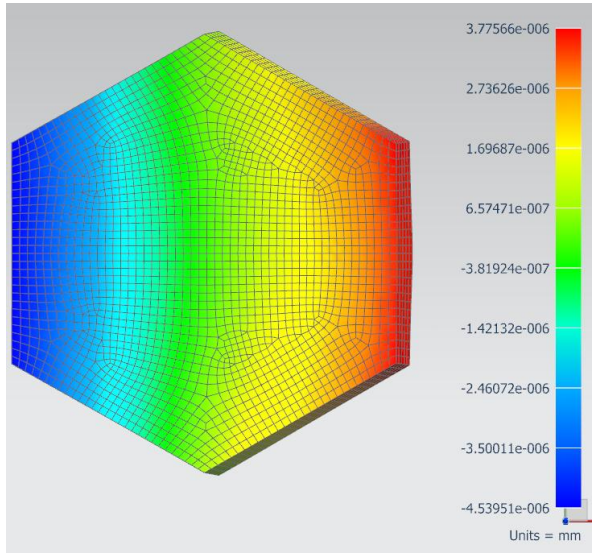
Layout of axial supports (Example)



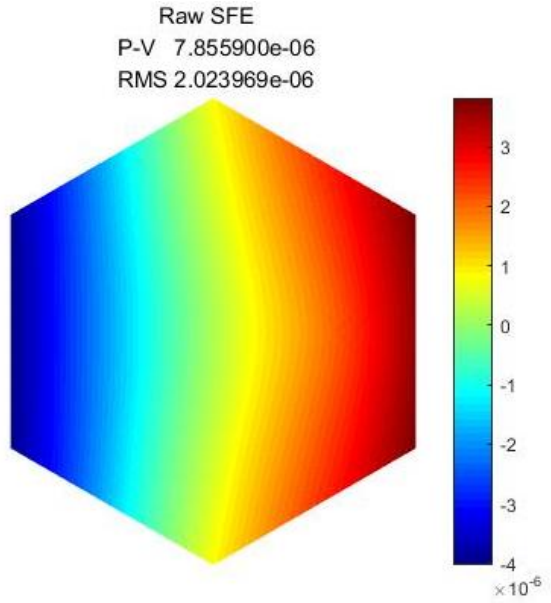




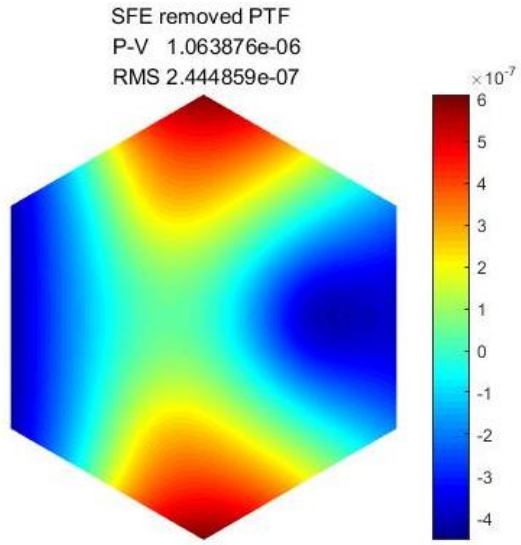
Segmented Mirror Analysis (1/2)



P-V 8.2 nm



Raw SFE
P-V 7.9 nm
RMS 2.1 nm

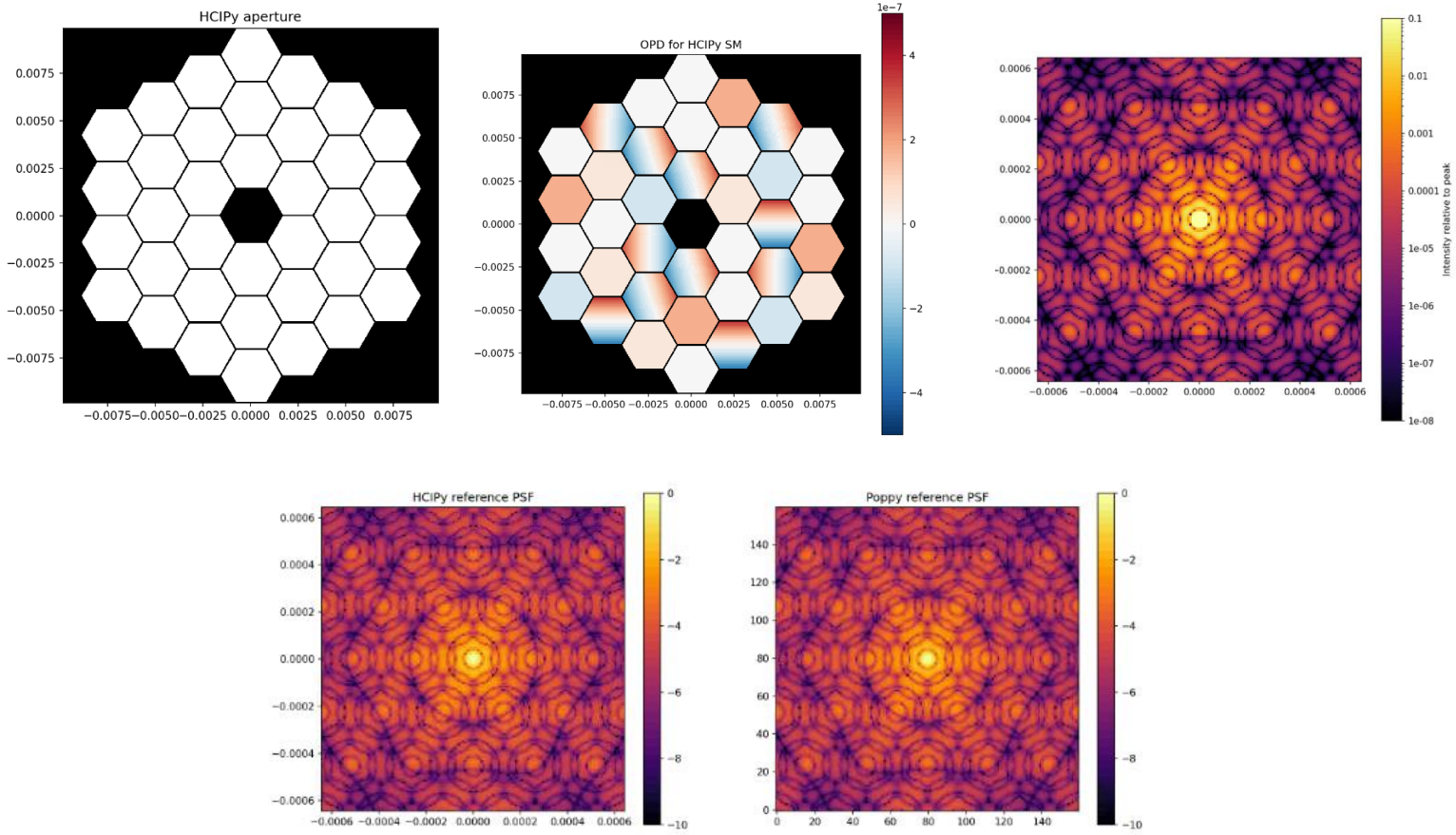


Removed PTF SFE
P-V 1.1 nm
RMS 0.2 nm

3 Optomechanical Design study

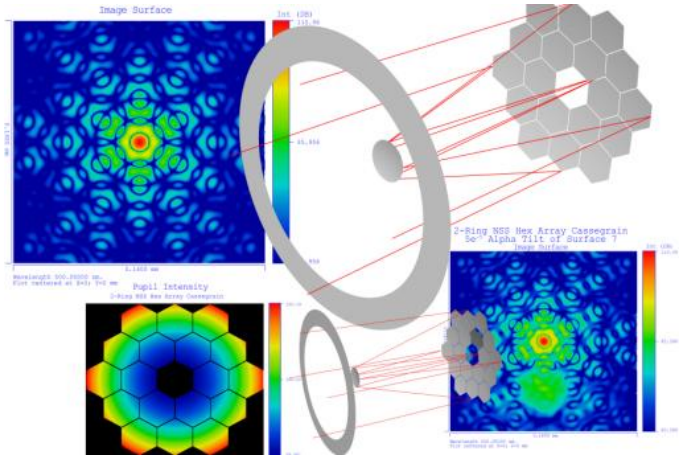
Segmented Mirror Analysis (HCIPy) – Development of Analysis Software for Segmented Mirrors

– Segment mirror analysis : HCIPy, hcipy.org

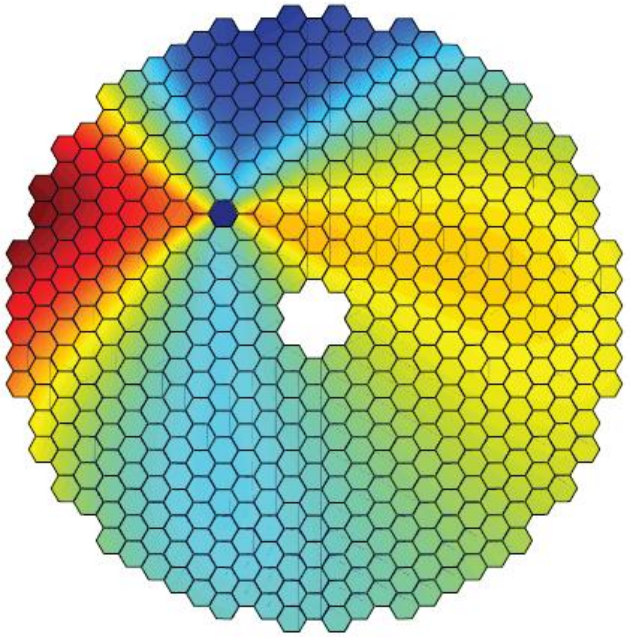


Example of System performance (1/2)

- Analysis of the Impact of Defects in Segmented Mirrors: Case Study Examples

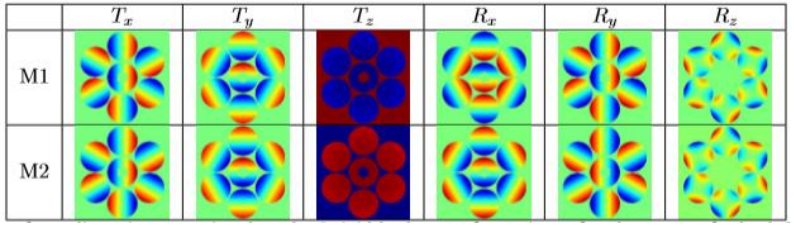


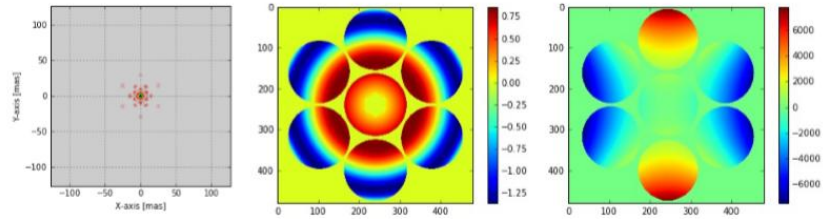
optical performance of segmented mirror



sample deformed shape

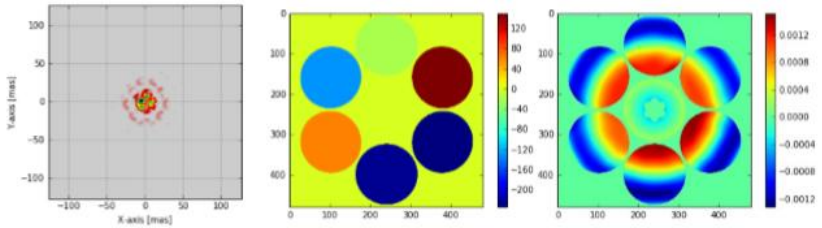
Example of System performance (2/2)



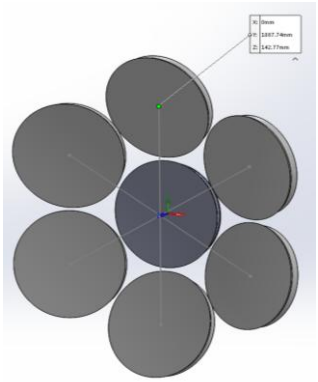


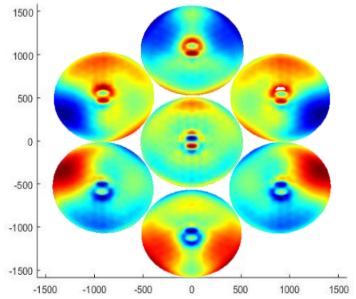
회절 한계 PSF　　축상 파면　　비축상 파면

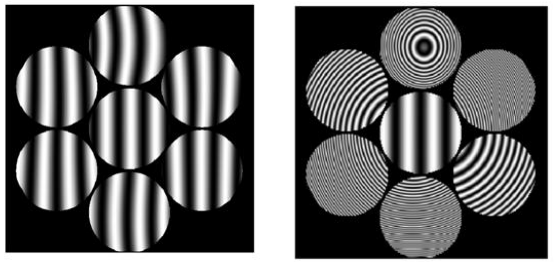
Proc.SPIE, vol.9909, 99091T-1



보정된 PSF　　축상 파면　　비축상 파면





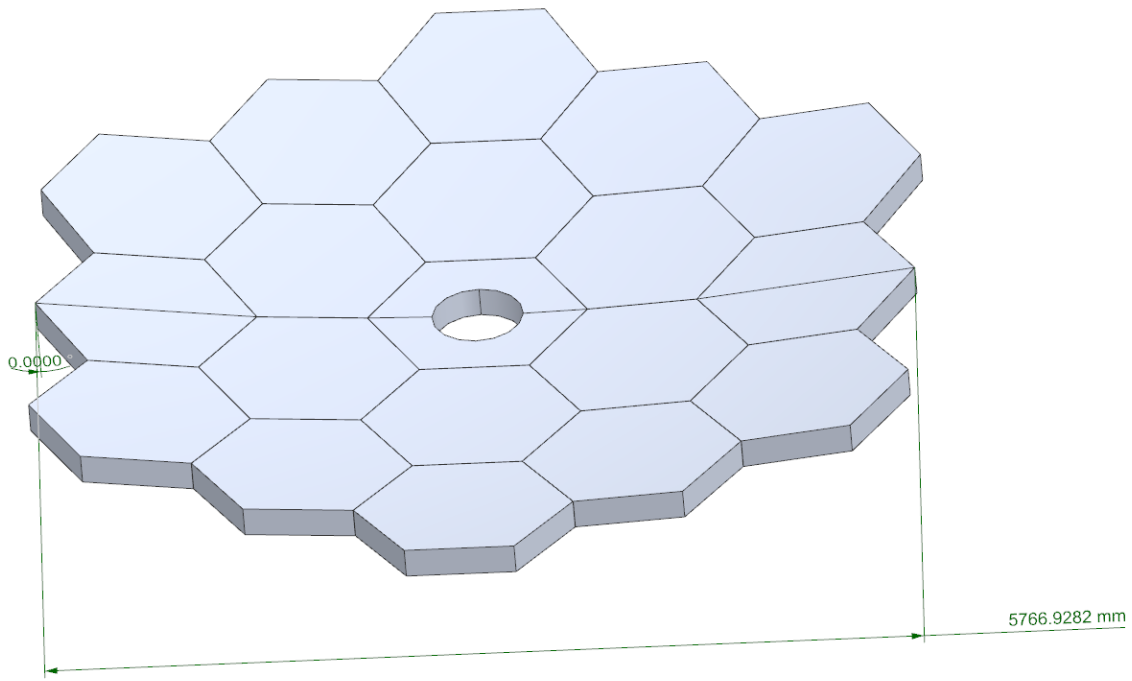


변형 전 파면

Analysis of Gravitational Deformation in Segmented Mirror Optical Systems (KRISS)

Drawing of 6.5 m Segmented Mirror

- Segment diameter 1.44 m ; thickness 75 mm edge gap 2 mm (Keck 3 mm)



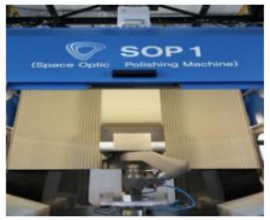
- Conceptual design and analysis of mirror assembly (3 ~ 4 Months)
  - Optimization of mirror
  - Axial and lateral support
- Conceptual design of telescope structure (2~3 Months)
- Performance estimation (2 ~ 3 Months)
  - Gravity, thermal load
  - Dynamic performance
  - Diffraction
- Collaborations
  - Co-works or share specialty for design and analysis

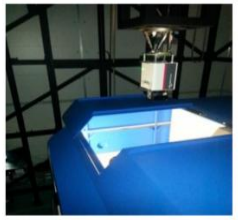
4 Optics fabrication

- 1.2 m optical fabrication capability at Green Optics

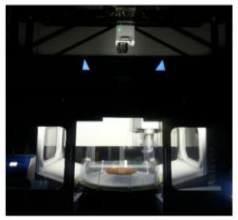
1.1m급 SiC 연마 특화 기술 - 직경 1.2m 6축 비구면 연마 장비 보유

1.2m 비구면 연마 장비를 보유 중입니다. (볼록 오목 비구면 비축비구면 자유비구면 연마 가능)
연마 중 장비 위에서 직접 측정 가능한 간섭계와 타워 CGH 장착된 측정 시스템 장착하여 30nm 이내 정밀 측정이 가능합니다.
SiC 소재의 강도와 형상에 최적화된 연마 공구와 최적의 Spot으로 보상 연마를 진행합니다.

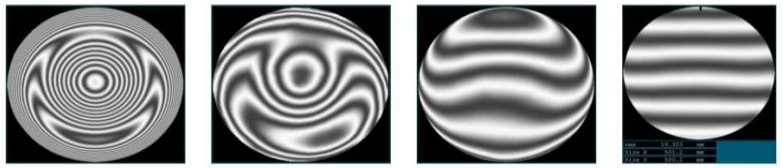








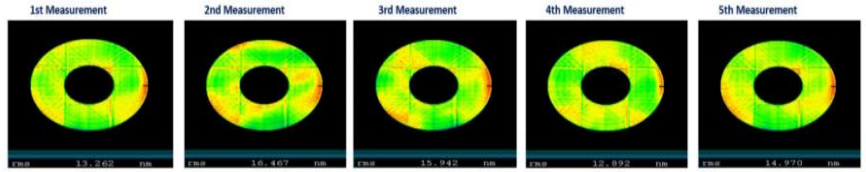
Aspherisation and Correction by CGHG Measurement



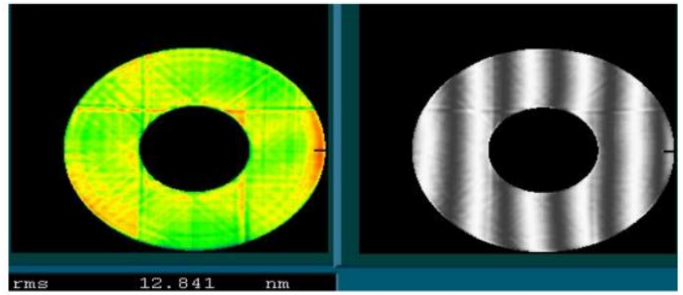
1.1m급 SiC 연마 특화 기술 - 초당 250 프레임 촬영 가능한 초고속 간섭계 적용

기계상에서 측정으로 반복 연마 회수를 최적화하여 제작 시간을 단축합니다.

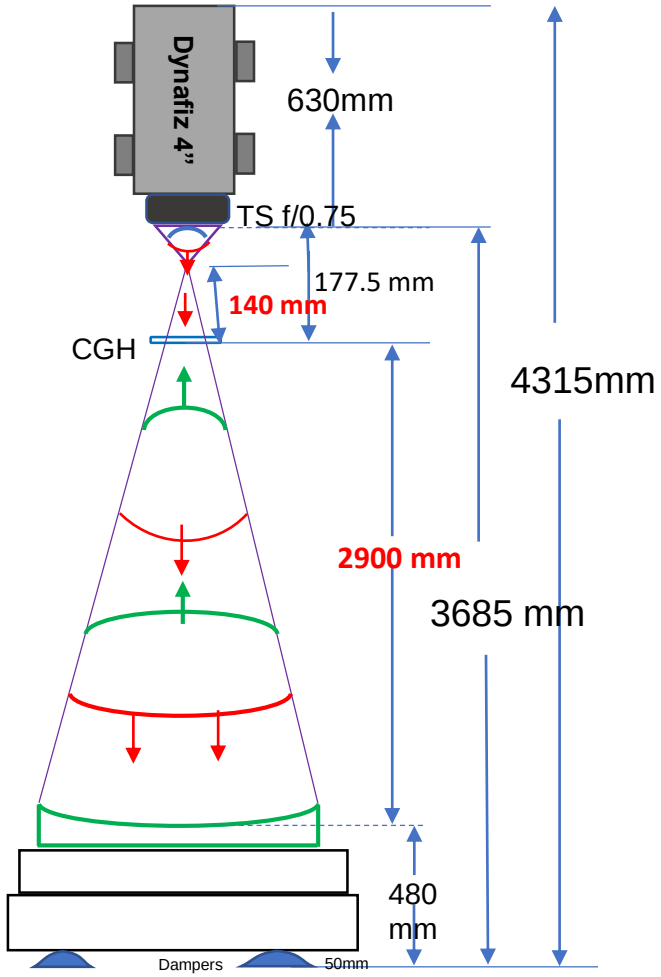
Fine Correction & Final Measuring



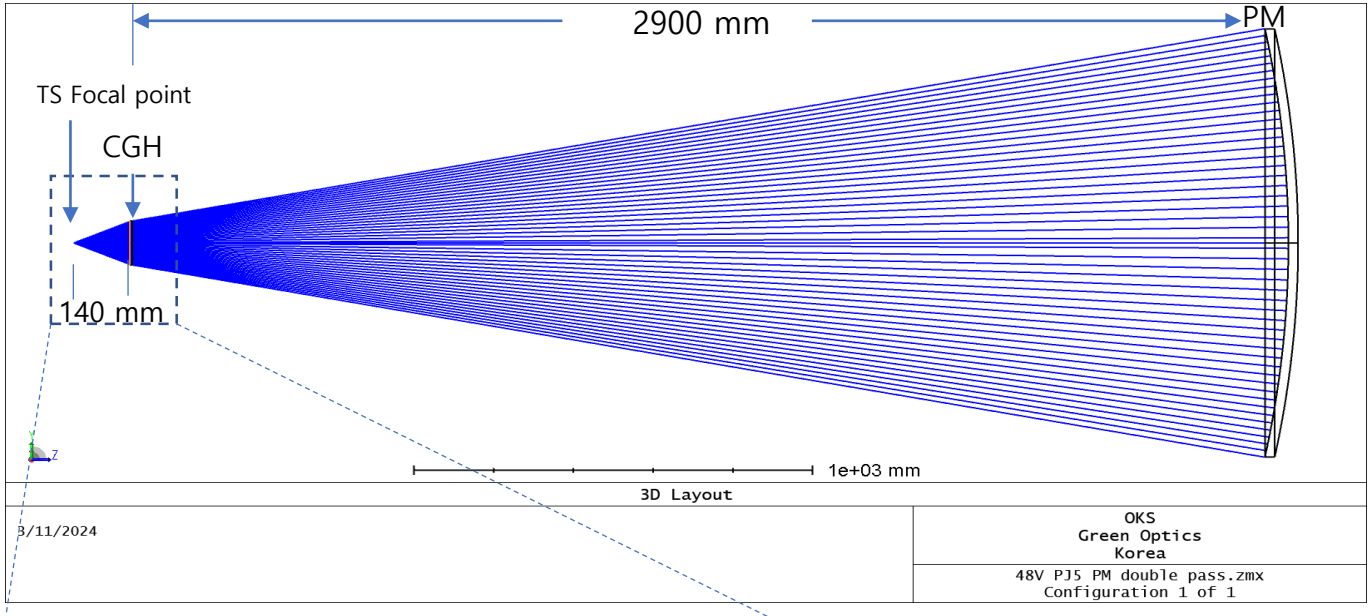
1st ~ 5th Averaging 진행

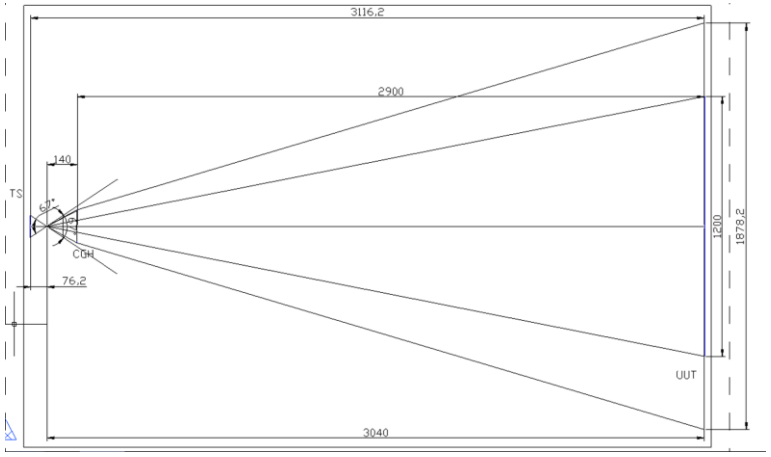


- 1.2 m optical metrology system layout at Green Optics



Optical height for metrology



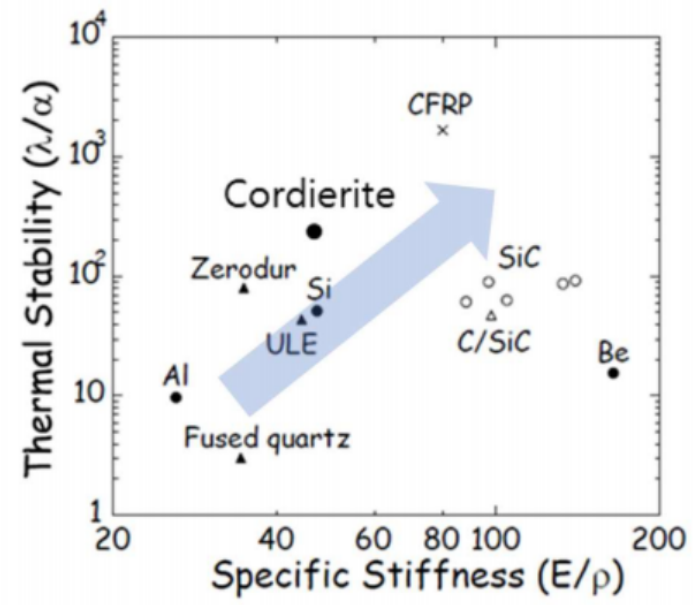


Measurement area:	1220 mm
Paraxial RoC:	3167 mm
Conic:	-0.98
Test wavelength:	632.82 nm
Transmission accessory:	F/0.75 TS
Focus to CGH distance:	140 mm
CGH to UUT distance :	2900 mm
CGH size:	6” x 6” x 0.25”

1. Physical Properties of Mirror Materials

KOPTI

◆ **Comparison of physical properties of several materials**



Type	Classification	Young's Modulus (E) GPa	CTE (α) ppm/K	Thermal Conductivity (λ) W/m·K	Specific Stiffness (E/ρ)	Thermal Stability (λ/α)
Be	Metal	303	11.4	180	164	16
Al	Metal	71	24	237	26	10
Sintered SiC	Ceramic	420	2.2	194	132	88
RB-SiC	Ceramic	400	2.3	140-150	132	61
Cordierite	Ceramic	140	0.02	4.68	55	234
Zerodur	Glass-Ceramic	89	0.02	1.52	35	76
ULE	Glass	66	0.02	1.27	30	64
CFRP	Carbon fiber reinforced plastic	120	0.03	50	80	1,667

Material for structure

◆ **Classification of Mirror Materials**

- **High specific stiffness** and **high thermal conductivity** (Be, SiC)
- **Low specific stiffness and extremely low thermal expansion material (Zerodur, ULE, Cordierite)**

3. SiC material – Cases

[SiC Mirror Cases for Space Application]

No.	Project	Purpose	Wavelength range	Mission start	M1 diameter (Arerial Density)	Operating Organization
1	Formosat-2	Earth	450-900nm	2004.05.19.	0.65m	NSPO (Taiwan)
2	AKARI	Space	1.7-180 μm	2006.02.21.	0.68m (29kg/m²)	JAXA
3	THEOS	Earth	UV-VIS-NIR	2008.10.01.	0.65m	GISTDA (태국우주국)
4	Herschel Space Obs ervatory	Space	70-700 μm	2009.05.14.	3.5m (31.2kg/m²)	ESA, NASA
5	COMS (천리안)	Ocean	400-900nm	2010.06.26.	-	KARI (한국항공우주연구원)
6	Gaia	Earth	320-1050 nm	2013.12.19.	1.45 x 0.5m	ESA
7	KazEOSat-1	Earth	UV-VIS-NIR	2014.04.30.	0.64m	카자흐스탄우주국
8	ASNARO	Earth	UV-VIS-NIR	2014.12.06	< 1m	JAXA
9	Sentinel-2	Earth	440-2200nm	2015.06.23.	0.54 x 0.27m	ESA
10	PeruSat-1	Earth	UV-VIS-NIR	2016.09.16.	0.64m	CONIDA (페루우주국)
11	Rosetta Osiris	혜성탐사	250-1000nm	2016.09.30.	0.14m	ESA
12	Aeolus Aladin	Earth	355nm	2018.08.22.	1.5m	ESA / ESOC (유럽우주운영센터)
13	Pleiades Neo-3,4,5,6	Earth	UV-VIS-NIR	2021.04.29.~2022.12.20.	0.65m	ESA
14	NIRSpec (James Webb)	Space observation	600nm-5500nm	2021.12.25.	0.3m x 0.3m	NASA / ESA
15	Euclid	Space observation	530-1850nm	2023.07.01.	1.2m (31.0kg/m²)	ESA
16	EarthCare	Earth	355nm	2024 예정	0.62m	ESA / JAXA / NICT

- SiC mirrors are widely used in space telescopes due to their lightweight capacity, thermal stability, and low thermal expansion rate at low temperatures

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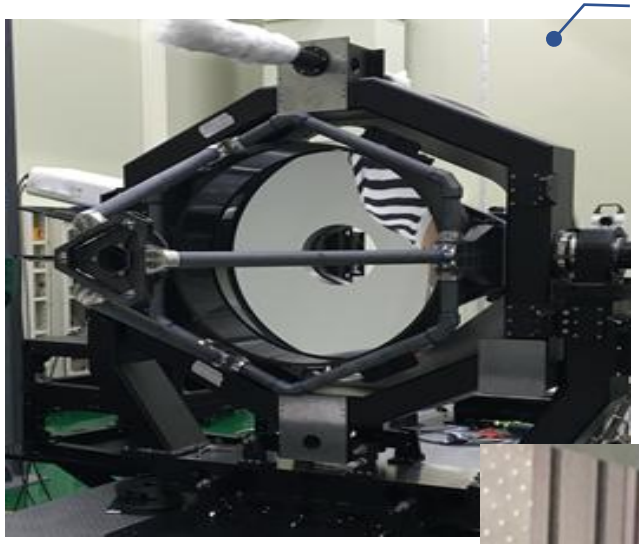
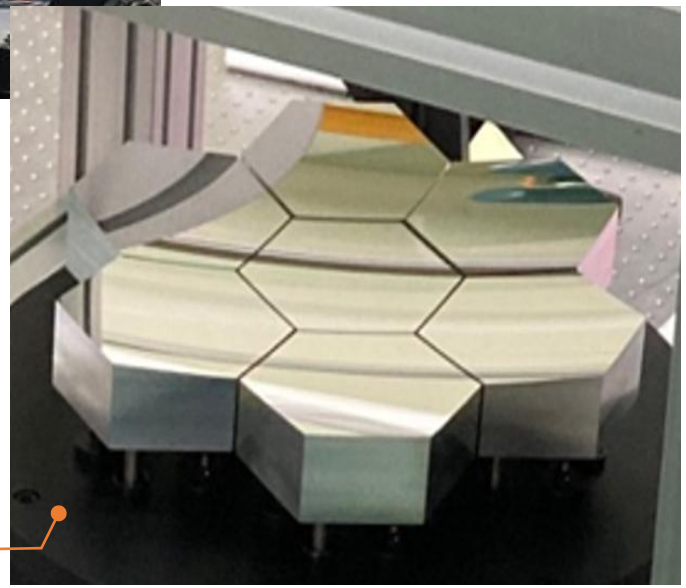
- SiC mirrors are widely used in space telescopes due to their lightweight capacity, thermal stability, and low thermal expansion rate at low temperatures

Optical Lens Material Research Center

KASI heritage

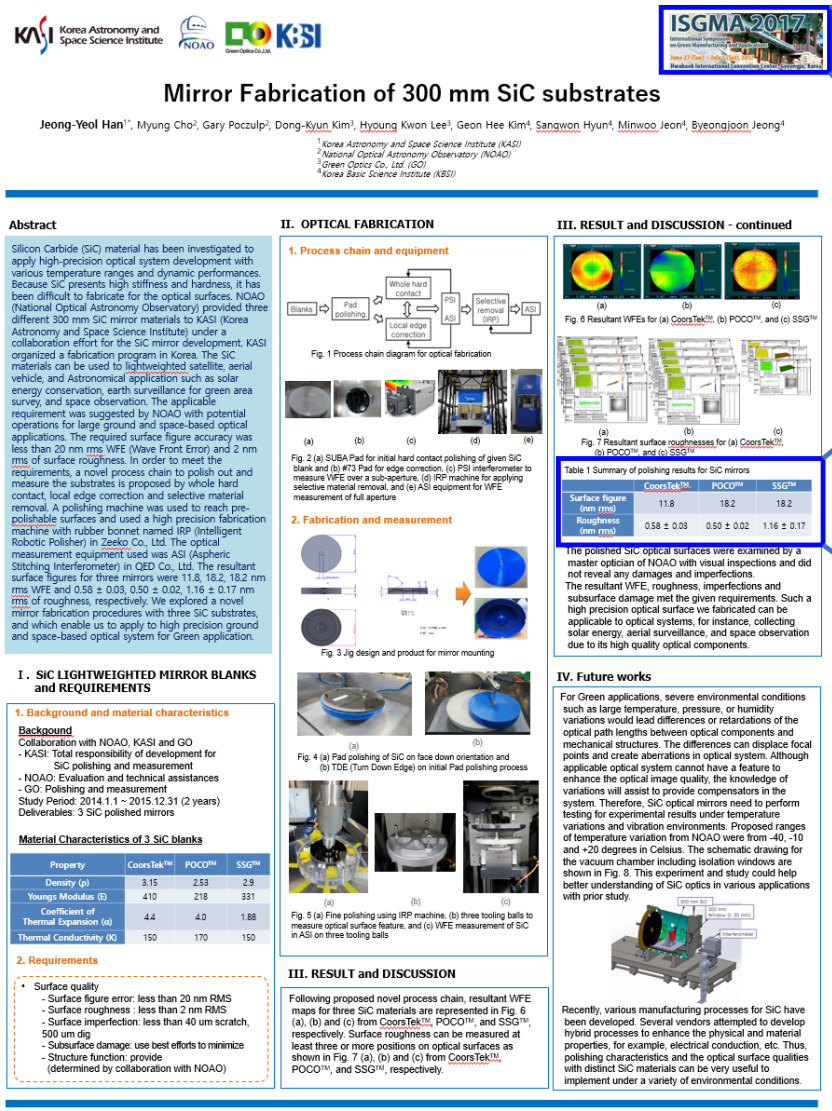


초경량 SiC 반사광학계 (2016)
(700 mm급 Optical Telescope)



Super Eye Bridge (2022)
(300 mm급 Segmented Mirror)

- **Excellency of SiC mirror fabrication**



Korea Astronomy and Space Science Institute | NOAO | GO | KASI

Mirror Fabrication of 300 mm SiC substrates

Jeong-Yeol Han[1*], Myung Cho[2], Gary Poczulp[2], Dong-Kyun Kim[3], Hyoung Kwon Lee[3], Geon Hee Kim[4], Sangwon Hyun[4], Minwoo Jeon[4], Byeongjoon Jeong[4]

[1] Korea Astronomy and Space Science Institute (KASI)
[2] National Optical Astronomy Observatory (NOAO)
[3] Green Optics Co., Ltd. (GO)
[4] Korea Basic Science Institute (KBSI)

Abstract

Silicon Carbide (SiC) material has been investigated to apply high-precision optical system development with various temperature ranges and dynamic performances. Because SiC presents high stiffness and hardness, it has been difficult to fabricate for the optical surfaces. NOAO (National Optical Astronomy Observatory) provided three different 300 mm SiC mirror materials to KASI (Korea Astronomy and Space Science Institute) under a collaboration effort for the SiC mirror development. KASI organized a fabrication program in Korea. The SiC materials can be used to lightweighted satellite, aerial vehicle, and Astronomical application such as solar energy conservation, earth surveillance for green area survey, and space observation. The applicable requirement was suggested by NOAO with potential operations for large ground and space-based optical applications. The required surface figure accuracy was less than 20 nm rms WFE (Wave Front Error) and 2 nm rms of surface roughness. In order to meet the requirements, a novel process chain to polish out and measure the substrates is proposed by whole hard contact, local edge correction and selective material removal. A polishing machine was used to reach pre-polishable surfaces and used a high precision fabrication machine with rubber bonnet named IRP (Intelligent Robotic Polisher) in Zeeko Co., Ltd. The optical measurement equipment used was ASI (Aspheric Stitching Interferometer) in QED Co., Ltd. The resultant surface figures for three mirrors were 11.8, 18.2, 18.2 nm rms WFE and 0.58 ± 0.03, 0.50 ± 0.02, 1.16 ± 0.17 nm rms of roughness, respectively. We explored a novel mirror fabrication procedures with three SiC substrates, and which enable us to apply to high precision ground and space-based optical system for Green application.

I. SiC LIGHTWEIGHTED MIRROR BLANKS and REQUIREMENTS

1. Background and material characteristics

Backgound
Collaboration with NOAO, KASI and GO
- KASI: Total responsibility of development for SiC polishing and measurement
- NOAO: Evaluation and technical assistances
- GO: Polishing and measurement

Study Period: 2014.1.1 ~ 2015.12.31 (2 years)
Deliverables: 3 SiC polished mirrors

Material Characteristics of 3 SiC blanks

Property	CoorsTek™	POCO™	SSG™
Density (ρ)	3.15	2.53	2.9
Youngs Modulus (E)	410	218	331
Coefficient of Thermal Expansion (α)	4.4	4.0	1.88
Thermal Conductivity (K)	150	170	150

2. Requirements

- Surface quality
  - Surface figure error: less than 20 nm RMS
  - Surface roughness : less than 2 nm RMS
  - Surface imperfection: less than 40 um scratch, 500 um dig
  - Subsurface damage: use best efforts to minimize
  - Structure function: provide (determined by collaboration with NOAO)

II. OPTICAL FABRICATION

1. Process chain and equipment

Fig. 1 Process chain diagram for optical fabrication

Fig. 2 (a) SUBA Pad for initial hard contact polishing of given SiC blank and (b) #73 Pad for edge correction, (c) PSI interferometer to measure WFE over a sub-aperture, (d) IRP machine for applying selective material removal, and (e) ASI equipment for WFE measurement of full aperture

2. Fabrication and measurement

Fig. 3 Jig design and product for mirror mounting

Fig. 4 (a) Pad polishing of SiC on face down orientation and (b) TDE (Turn Down Edge) on initial Pad polishing process

Fig. 5 (a) Fine polishing using IRP machine, (b) three tooling balls to measure optical surface feature, and (c) WFE measurement of SiC in ASI on three tooling balls

III. RESULT and DISCUSSION

Following proposed novel process chain, resultant WFE maps for three SiC materials are represented in Fig. 6 (a), (b) and (c) from CoorsTek™, POCO™, and SSG™, respectively. Surface roughness can be measured at least three or more positions on optical surfaces as shown in Fig. 7 (a), (b) and (c) from CoorsTek™, POCO™, and SSG™, respectively.

III. RESULT and DISCUSSION - continued

Fig. 6 Resultant WFEs for (a) CoorsTek™, (b) POCO™, and (c) SSG™

Fig. 7 Resultant surface roughnesses for (a) CoorsTek™, (b) POCO™, and (c) SSG™

Table 1 Summary of polishing results for SiC mirrors

	CoorsTek™	POCO™	SSG™
Surface figure (nm rms)	11.8	18.2	18.2
Roughness (nm rms)	0.58 ± 0.03	0.50 ± 0.02	1.16 ± 0.17

The polished SiC optical surfaces were examined by a master optician of NOAO with visual inspections and did not reveal any damages and imperfections.
The resultant WFE, roughness, imperfections and subsurface damage met the given requirements. Such a high precision optical surface we fabricated can be applicable to optical systems, for instance, collecting solar energy, aerial surveillance, and space observation due to its high quality optical components.

IV. Future works

For Green applications, severe environmental conditions such as large temperature, pressure, or humidity variations would lead differences or retardations of the optical path lengths between optical components and mechanical structures. The differences can displace focal points and create aberrations in optical system. Although applicable optical system cannot have a feature to enhance the optical image quality, the knowledge of variations will assist to provide compensators in the system. Therefore, SiC optical mirrors need to perform testing for experimental results under temperature variations and vibration environments. Proposed ranges of temperature variation from NOAO were from -40, -10 and +20 degrees in Celsius. The schematic drawing for the vacuum chamber including isolation windows are shown in Fig. 8. This experiment and study could help better understanding of SiC optics in various applications with prior study.

Recently, various manufacturing processes for SiC have been developed. Several vendors attempted to develop hybrid processes to enhance the physical and material properties, for example, electrical conduction, etc. Thus, polishing characteristics and the optical surface qualities with distinct SiC materials can be very useful to implement under a variety of environmental conditions.



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Surface figure (nm rms)	11.8	18.2	18.2
Roughness (nm rms)	0.58 ± 0.03	0.50 ± 0.02	1.16 ± 0.17

SiC material is very stiff and difficult to polish, but we have secured optical surface polishing technology that allows observation in the ultraviolet region beyond visible light.

6 Summary and Future Plans

Summary of Current Activities

Working Group Operations:

Conducted discussions on the **optical, optomechanical, material, polishing, and fiber positioner** aspects of next-generation spectroscopic survey telescopes from a technical perspective.

Initial WBS Identification:

Defined the optical system configuration and task segmentation in the early phase.

Optical Conceptual Design:

Performed optical conceptual design referencing domestic scientific goals for spectroscopic surveys, **corresponding requirements**, and planned overseas spectroscopic survey telescopes.

Segmented Mirror Mount Design:

Developed **basic concepts and conceptual designs for segmented mirror** mounts.

Optical Fabrication: 1.2 m machining capability in Korea

Development of advanced mirror materials:

SiC, Cordierite, Zerodur, ULE, etc. are being considered for optical mirrors, and **SiC** materials and polishing are **expected to be available in Korea.**

6 Summary and Future Plans

Future Directions

Refinement of Telescope Optical and Optomechanical Conceptual Designs:

Further development of **detailed designs for the optical and mechanical systems**.

Optical fabrication and advanced material development

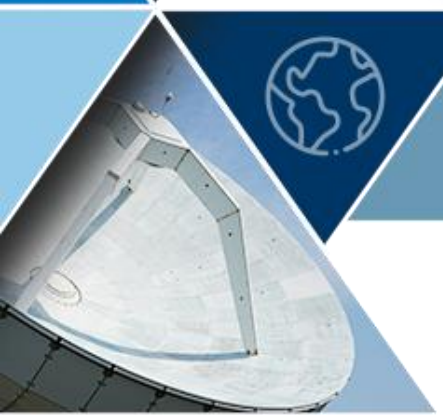
Progressing efforts **to expand fabrication capabilities and securing material development cases**

Expectations and impact

Referring to the **6.5 m telescope planning materials** proposed last time and **securing practical industrialization cases**

Thank you for your attention









KASI 한국천문연구원
Korea Astronomy & Space Science Institute