Introduction to China Space Station Telescope (CSST)

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Vice President of CIOMP
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CIOMP Brief Introduction

Overview

- Founded in 1952
- China's first optics institute
- Founding institute of several other optics institutes

Xian Institute of Optics, 1962

Beijing Institute of Mechanics, 1967

Shanghai Institute of Optics, 1965

Suzhong Ins. Of Bio-medical devices, 2008

Chengdu Institute of Optics, 1973

Anhui Institute of Optics, 1960

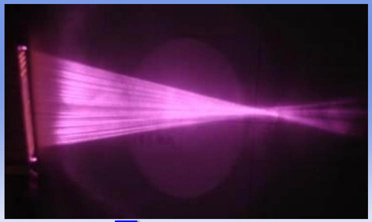
Prof. Wang Daheng
1915~2011

Up to 2017

–2087 employees

–229 research professors and 587 associate research professors

Funding in 2015-16 FY: 262 million US $



Energy

Space

The main research areas:

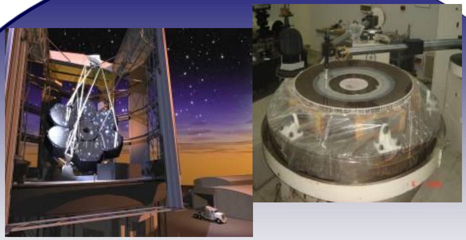
– Luminescence

–Applied Optics

–Optical Engineering

–Precision Mechanics

Industry

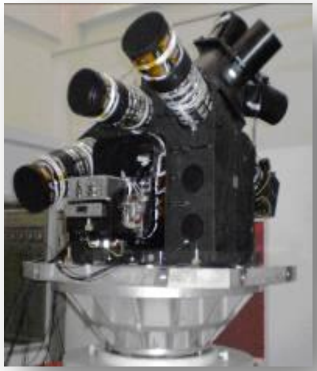


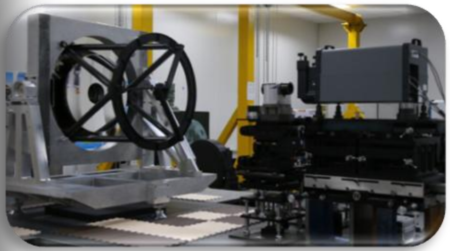
Astronomy

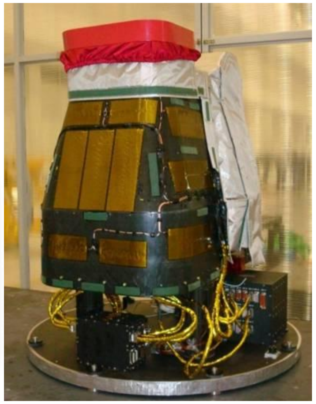
The new working area started operation in 2003

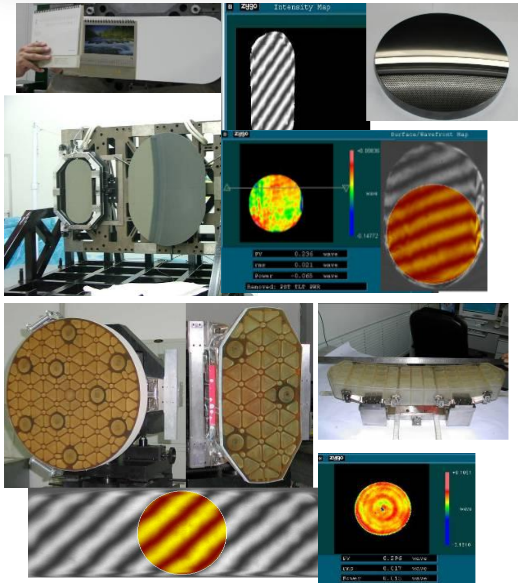
- Construction area = 260,000m^2
- Research & Development sector
- Production sector
- Education sector

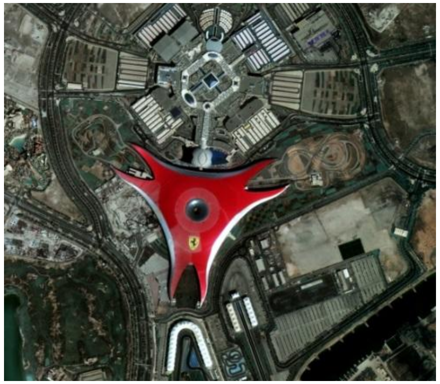
As a major space optical payload supplier, CIOMP can offer component and system level solutions.

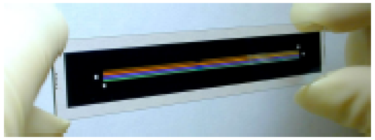






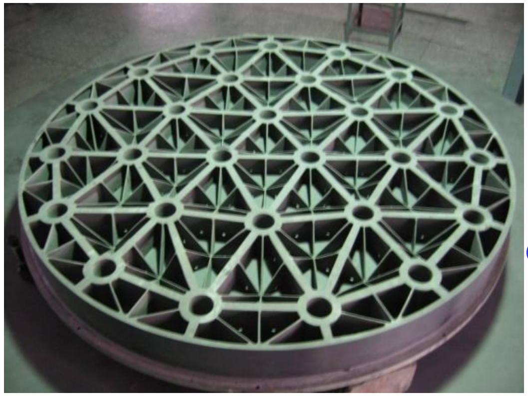




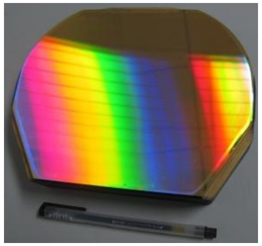


Stripe filters for CCD

CMOS sensor-GMAX3005



2.4m RB-SiC



Grating 400mm×500mm

Optical Module

CSST is the biggest space-based optical payload in China, surveying at the same orbit with China Space Station . Survey camera uses the telescope to achieve astronomical surveying.

surveying in orbit

Task and Features

- **Task of CSST surveying:** research on dark matter、dark energy 、cosmogony. Study the weak lensing effect.

- **Features:**
  - ✓ Aperture Φ2m
  - ✓ broadband spectrum：255nm~1700nm
  - ✓ FOV of survey:1.1 deg^2
  - ✓ 2.5 billion pixels
  - ✓ Angular resolution : ≤ 0.15″ (λ=0.6328μm， 1.1deg^2)
  - ✓ Survey image stabilization precision ≤0.05″ (3σ，@300s)
  - ✓ PSF Ellipticity max<15%,avg<5%

Comparison of Specifications

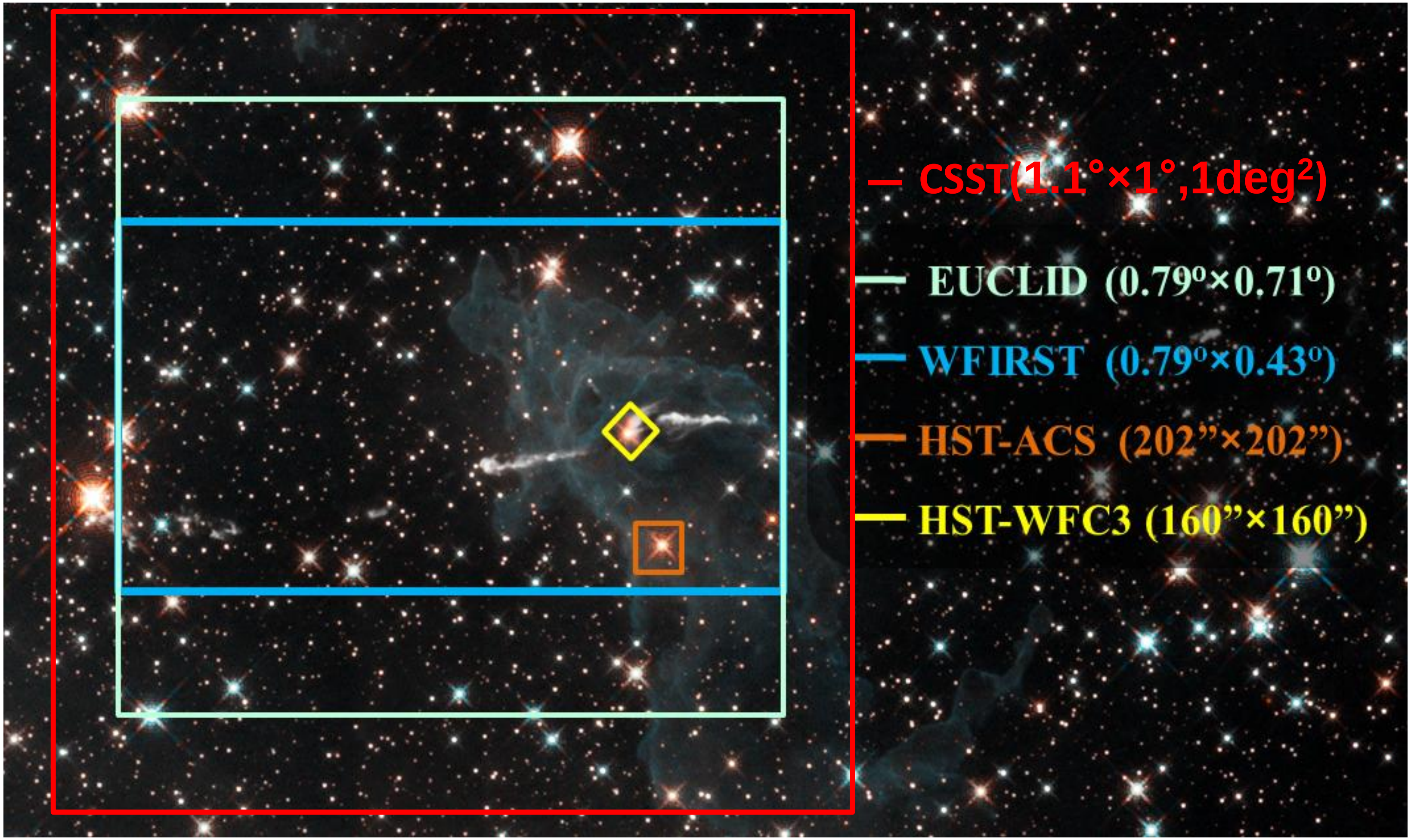
	HST[1]	Euclid	WFIRST[2]	CSST
				
Orbit	LEO(600km)	L2	L2	LEO(400km)
Aperture	2.4m	1.2m	2.4m	2m(no CO)
FOV	0.17deg^2	0.55deg^2	0.28deg^2	1.1deg^2
Angular Resolution	0.1″	>0.2″	>0.2″	0.15″
Optical System	R-C	On-axial TMA	Re-designed On-axis TMA	Off –axis TMA

[1]: 《The Hubble Space Telescope Optical Systems Failure Report》
[2]:https://wfirst.ipac.caltech.edu/sims/Param_db.html

New Trends in Astronomy Community

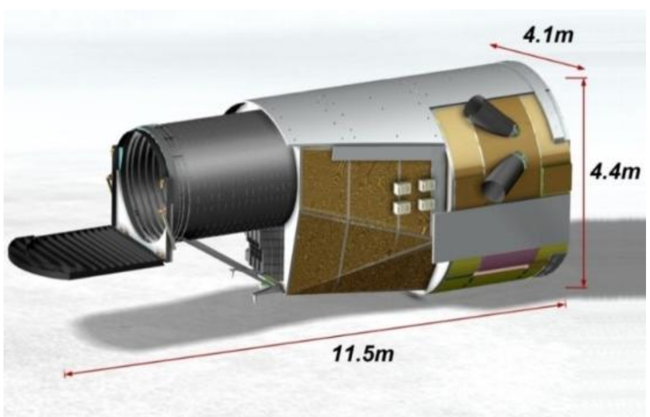
Large FOV & High Resolution

Area of FOV 350 times larger than HST

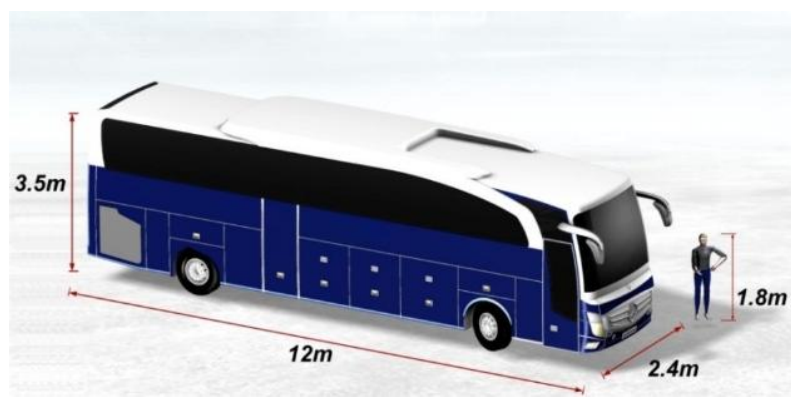


CSST Features

- The main optical system--Off-axis TMA
- Fast steering mirror-- image stabilization
- Secondary mirror --Active optical adjustment
- Fold mirror-focusing\image stabilization
- Scientific instruments orbital upgrade or maintenance

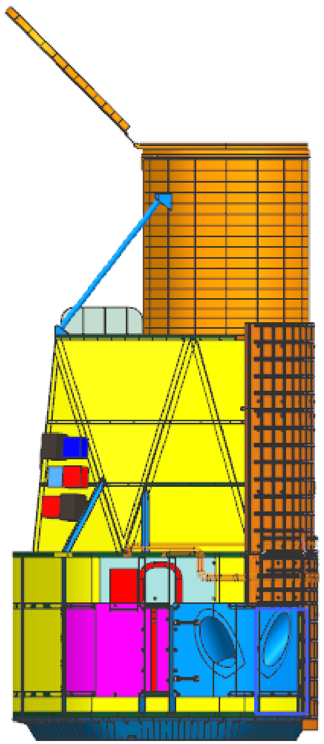


CSST



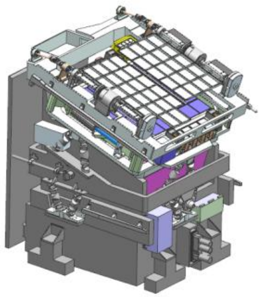
Tour bus

CSST Components



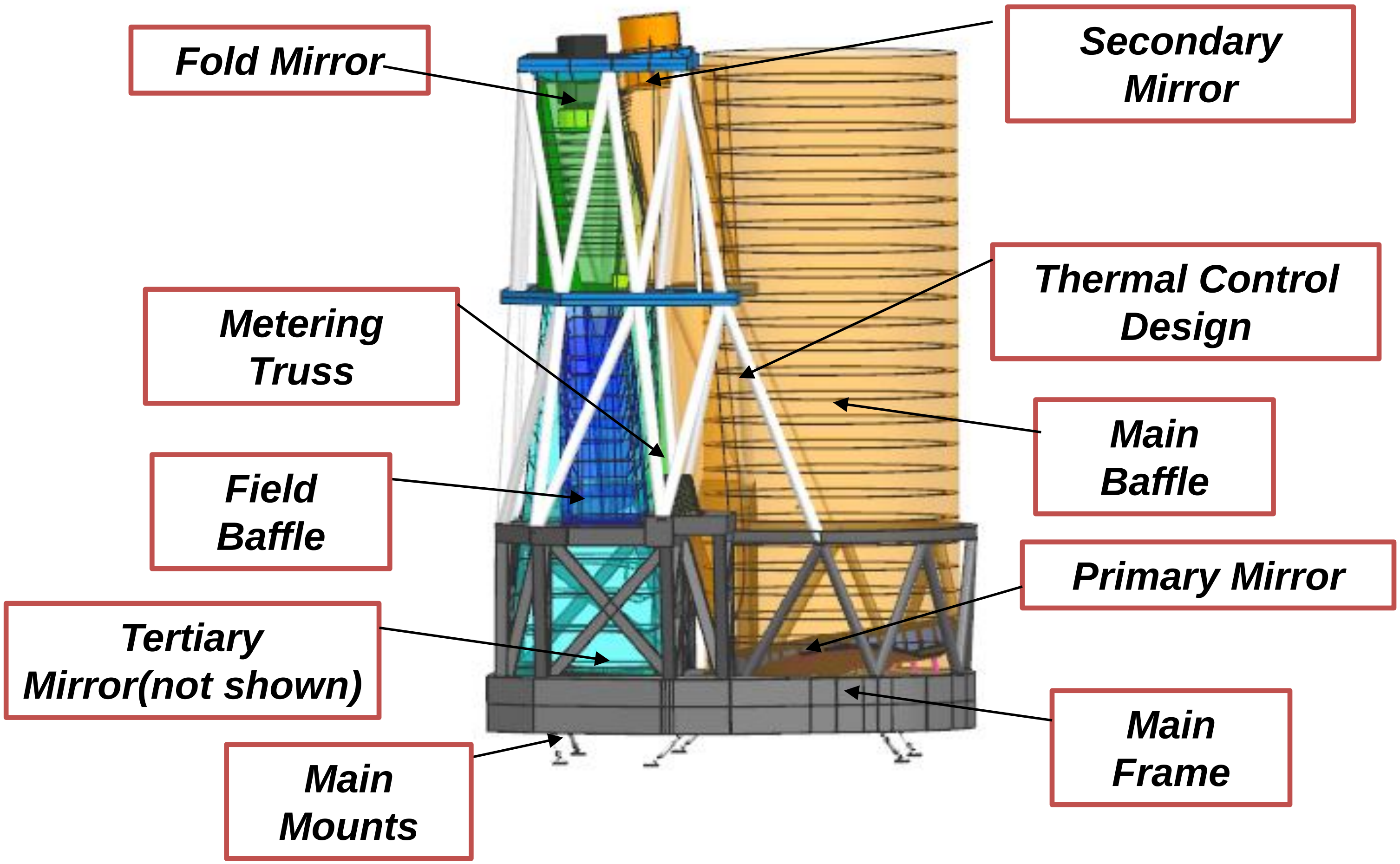
Outer Barrel Assembly (OBA)

Optical Telescope Assembly(OTA)

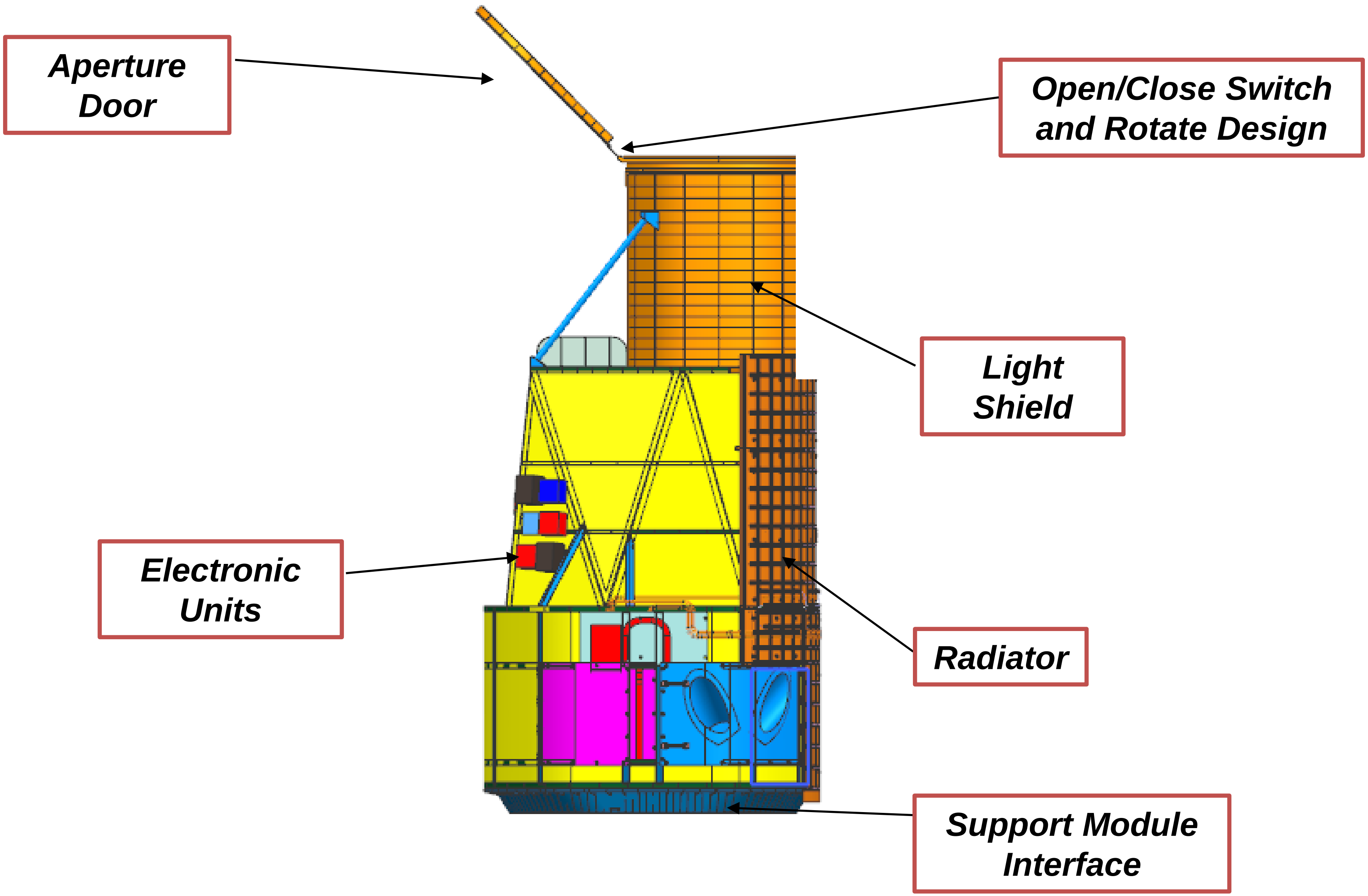


Survey Camera(SC)

Optical Telescope Assembly(OTA)

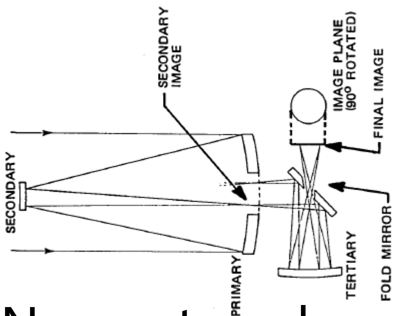


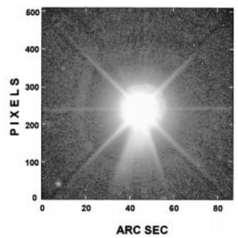
Outer Barrel Assembly (OBA)



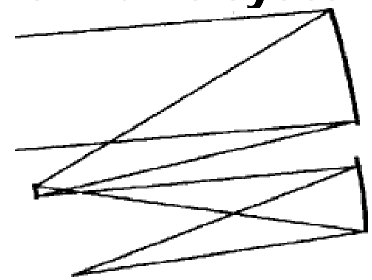
Optical System Selection

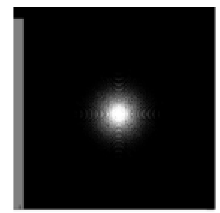
Coaxial system(Korsch TMA)



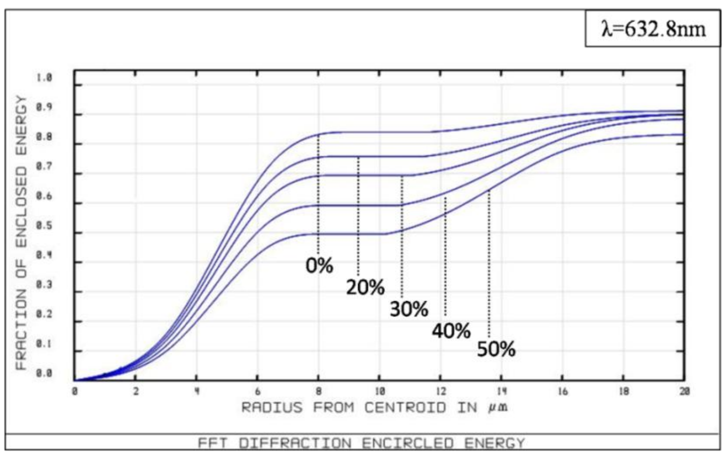


Off-axis system(COOK TMA)

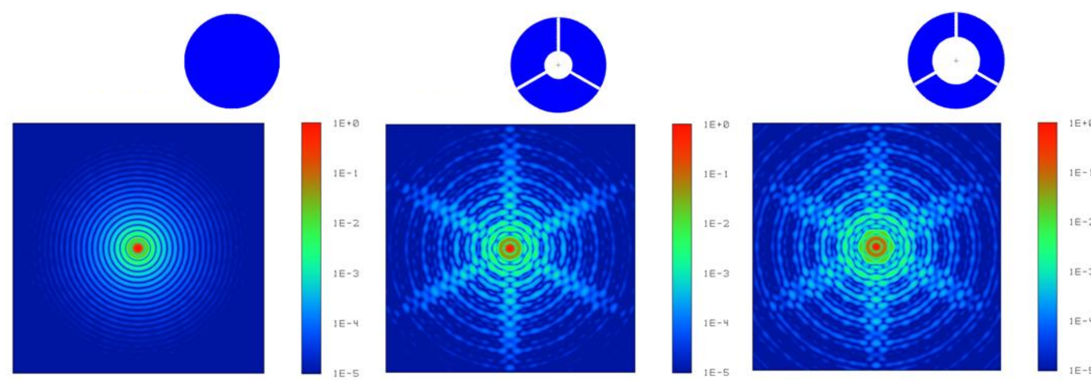




- No center obscuration, which makes a better spot diagram energy concentration
- No spider, which has lower scattering effect.

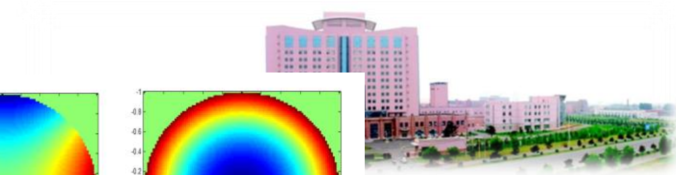


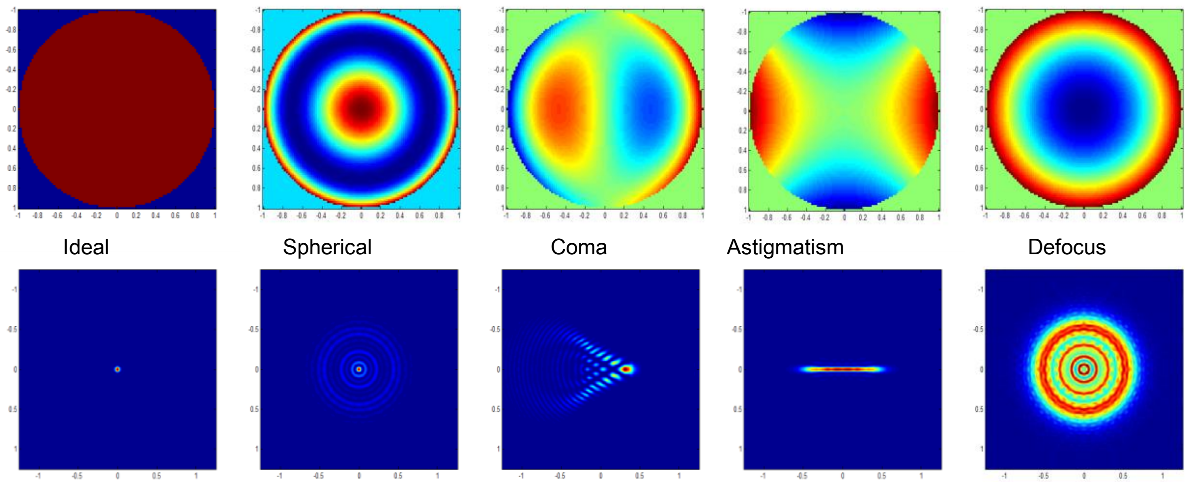
Energy concentration curve at CO of 0%, 30%,40%, 50%



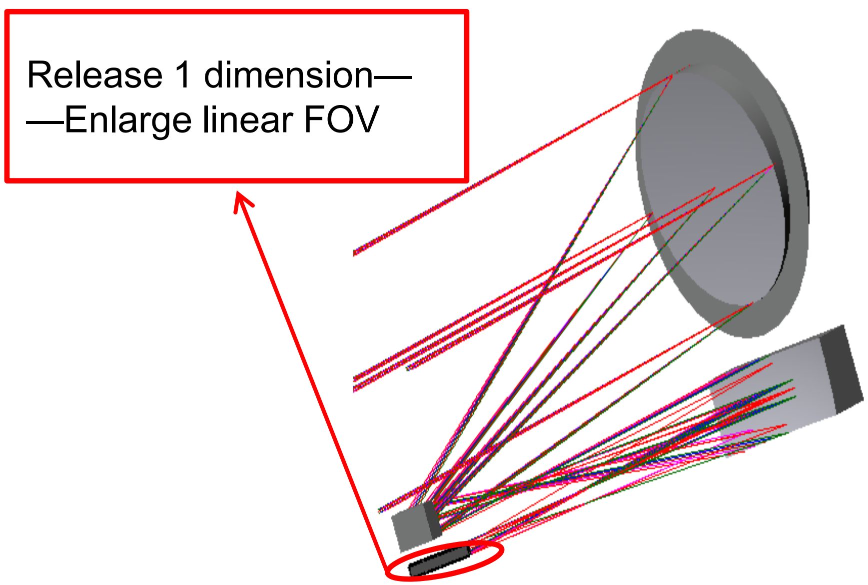
No CO	CO 30%	CO 50%
Ellipticity 0	Ellipticity 0.08	Ellipticity 0.08

Ellipticity - WFE factors

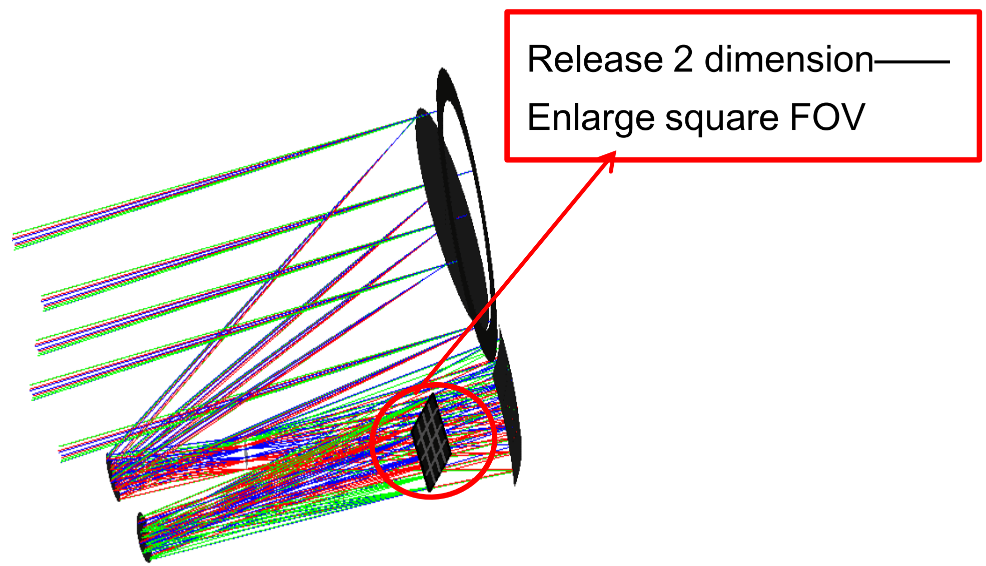




Low order astigmatism and coma are dominating factors of ellipticity and its uniformity



Traditional off-axis design with general aspheres

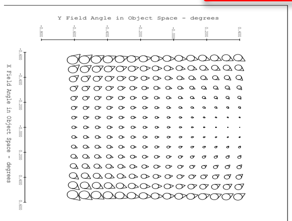


Tilted off-axis design with freeform surfaces

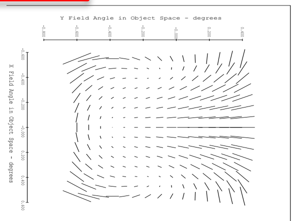
Tilted axis helps to enlarge FOV in 2D

Off-Axis TMA

Coma

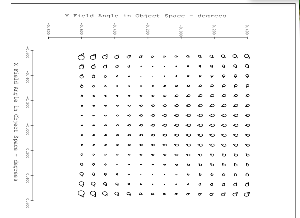


Ast.

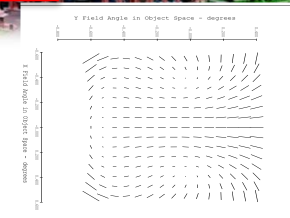


Tilted-Axis

Coma



Ast.



1.1deg^2 average 0.046λ (λ=632.8nm)

1.1deg^2 average 0.068λ (λ=632.8nm)

1.1deg^2 average 0.022λ (λ=632.8nm)

1.1deg^2 average 0.045λ (λ=632.8nm)

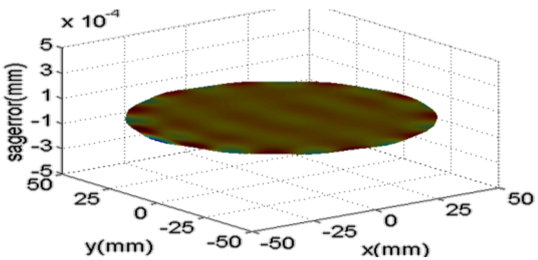
Introducing freeform as defined below, helps to improved residual WFE

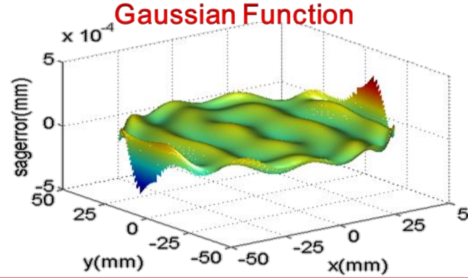
$$FH(\rho,\theta)=\frac{c\rho^2}{1+\sqrt{1-c^2\rho^2}}+\sum_{n=0}^{N}\sum_{m=0}^{M}\{[a_n^m\cos(m\theta)+b_n^m\sin(m\theta)]R_{n+m}^m(\rho)\}e^{-w_x^2(\rho\cos\theta)^2-w_y^2(\rho\sin\theta)^2}$$

Polynomials

Gaussian Function

64Trems function fitting residual



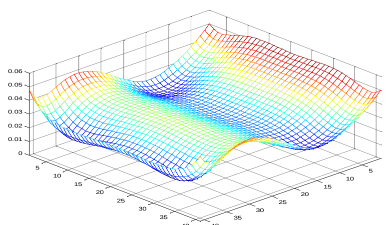


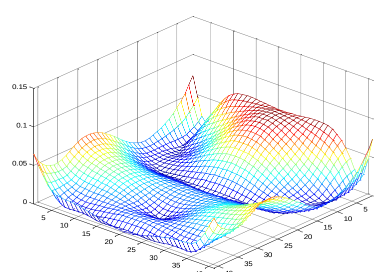
66Trems Zernikes fitting residual

Final Results for 1.1deg^2 FOV (Area of FOV 350 times larger than HST)

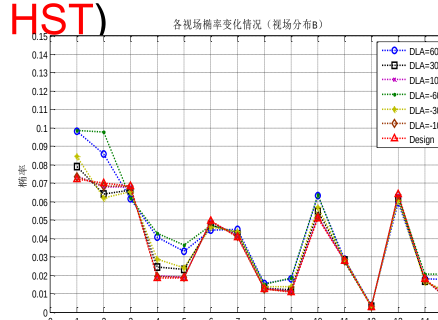
Average RMS WFE 20nm (~λ/32)

Minimum value :	0.017707
Maximum value :	0.052911
Average value :	0.032070
Std deviation :	0.007678
No. of points :	1681





PV of Ellipticity 0.07
Average better than 0.035

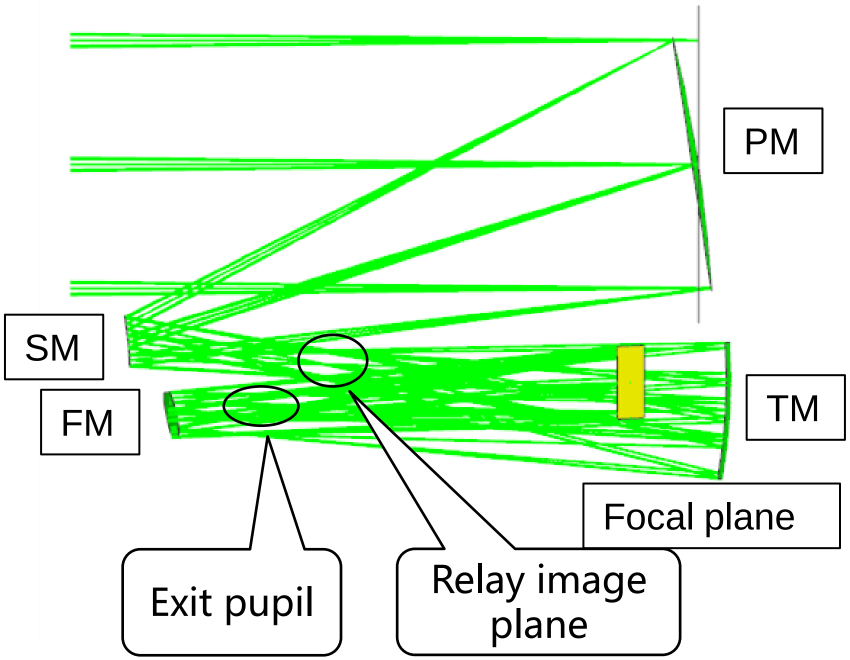


Sensitivity of the tolerance of ellipticity

Optical System

The off-axis TMA system based on optical freeform surface.

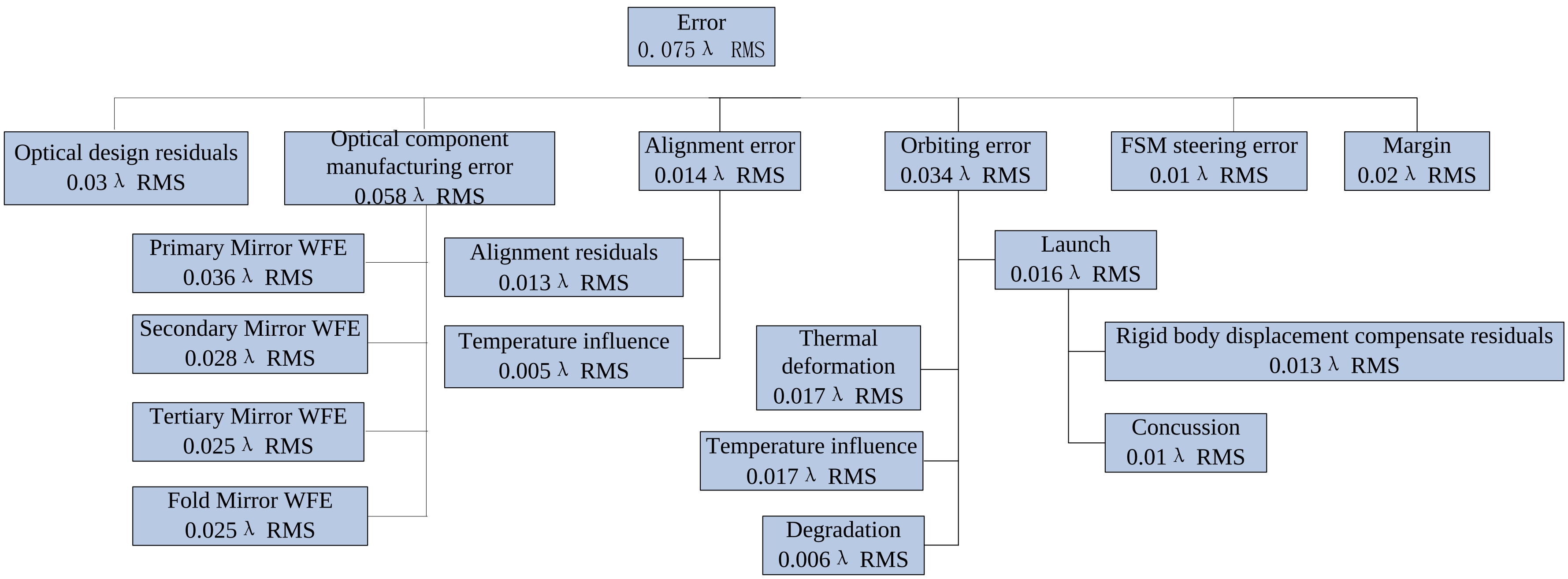
- aperture：Φ2m
- Field of view：$1.1deg^2$
- Large FOV、High-resolution、 no obscuration
- The central field is used to high-quality survey; the edge field is used for spectrograph, wavefront sensor, FGS.



- Rectangle field, beneficial to detector layout, high FOV availability ratio
- Real exit pupil——set fold mirror for focusing \image stabilization.
- With relay image plane, beneficial to stray light depression

WFE Tolerancing

- 2m telescope Diffraction limit angular resolution 0.078″, Wavefront Error less than 0.075λ , the Static angular resolution less than 0.13″。
- Error : Optical design residuals、 Optical component manufacturing error、Alignment error、 orbiting error 、FSM steering error.

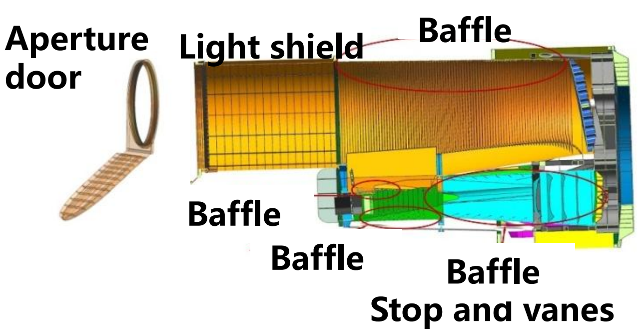


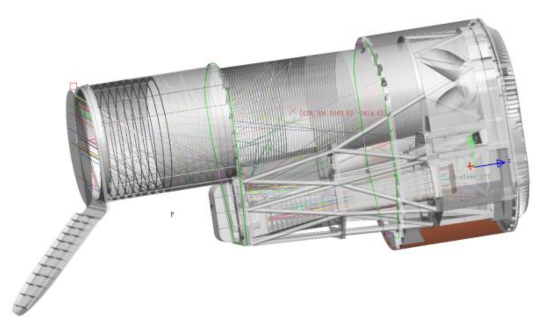
*RSS

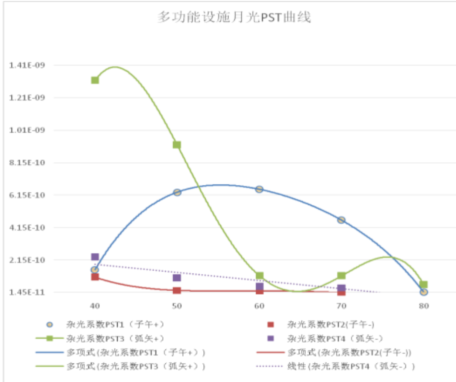
Stray light suppression design

- **Goals：the stray which were caused by sunlight, moonlight and the atmosphere radiation less than a third of the average level of zodiacal light background**

Stray light source	Suppression method	result
Sunlight	Aperture door :stop the sunlight from 65°	Total occlusion
moonlight	Light shield: eliminating the first scattering-attenuation and absorption	PST:1.32e-9 （40° ）
Earth and Atmosphere radiation	The vane inside the aperture door eliminated the first scattering- light shield stop the second scattering-attenuation and absorption inside the hood	less than 1/36 of zodiacal light background





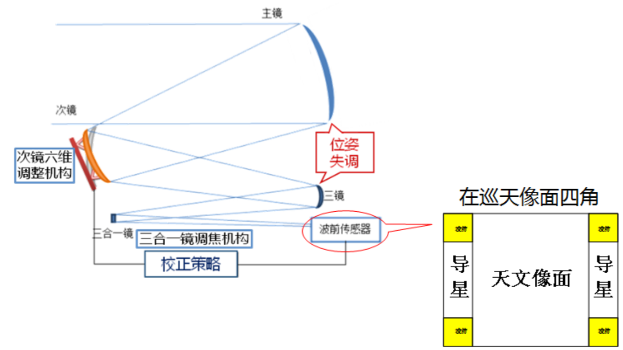


Simulation of miscellaneous light suppress

Active Adjustment

Principle

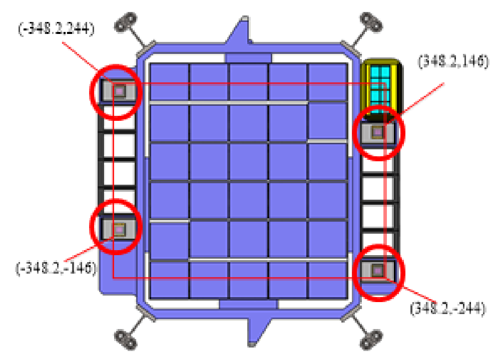
- SM /fold mirror alignment ,
- correct the misalignment caused by gravity release and on orbit environmental changes
- Satisfy the wavefront error and ellipticity requirements



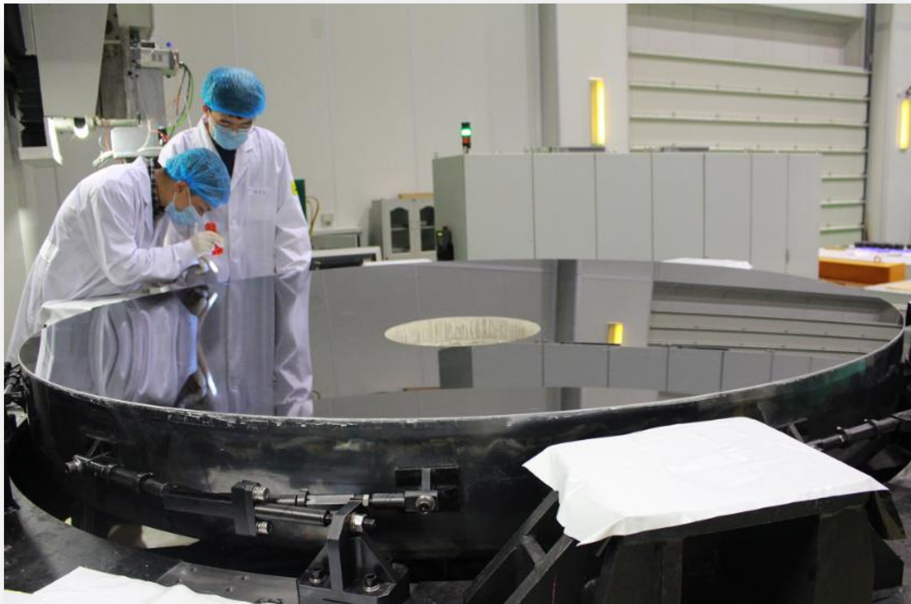
Design

- Wavefront sensor ---CMOS
- WFE determination ---the linear expansion PD algorithm
- Calculate alignment value of SM/ fold mirror ---sensitivity matrix and the vector aberration theory
- SM and the fold mirror are aligned by steward platform.

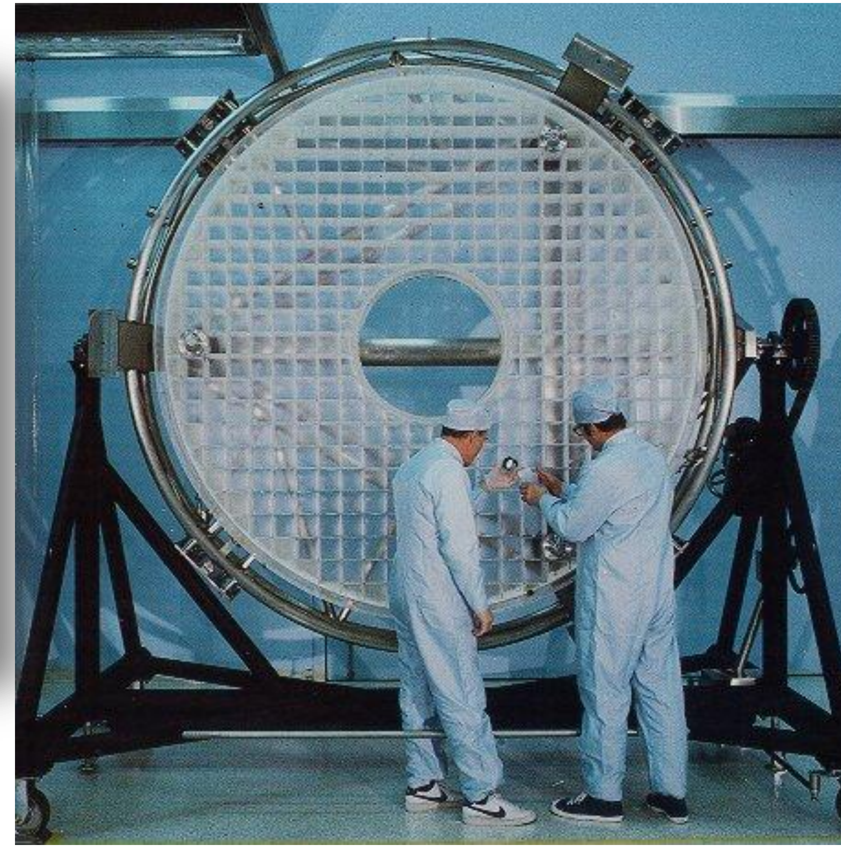
Wavefront sensor



SiC vs. ULE



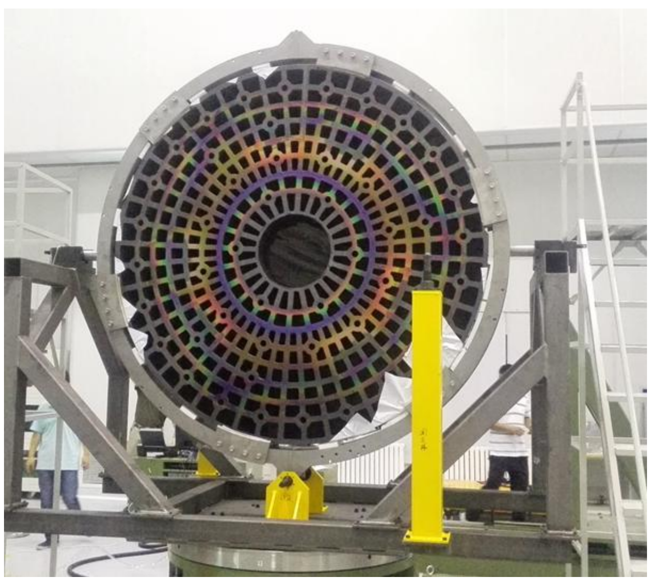
CIOMP's 2.2m SiC PM, 340kg
(Areal Density:89kg/m^2)

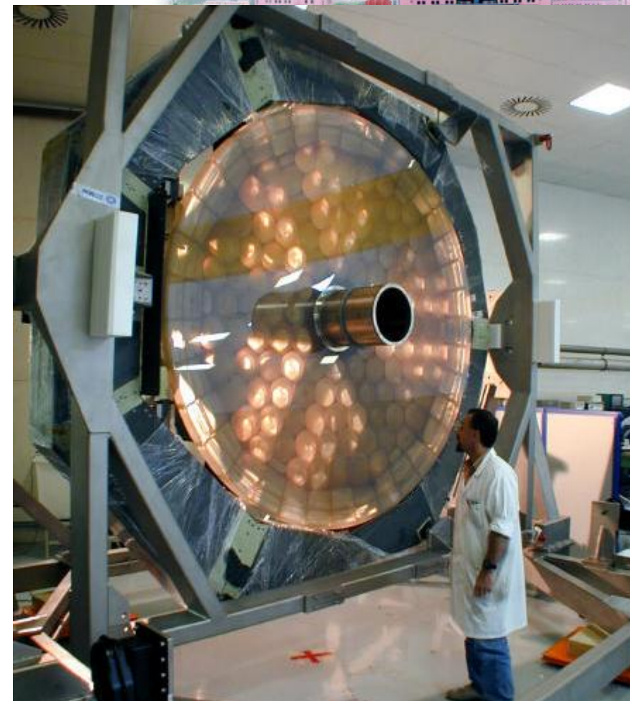


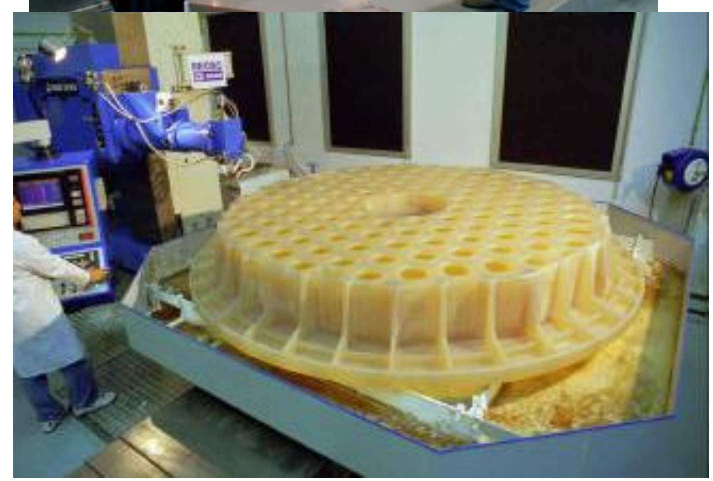
Hubble's 2.4m ULE PM, 817kg
(Areal Density:180kg/m^2)

Weight reduced by a factor of 2!

SiC vs. Zerodur



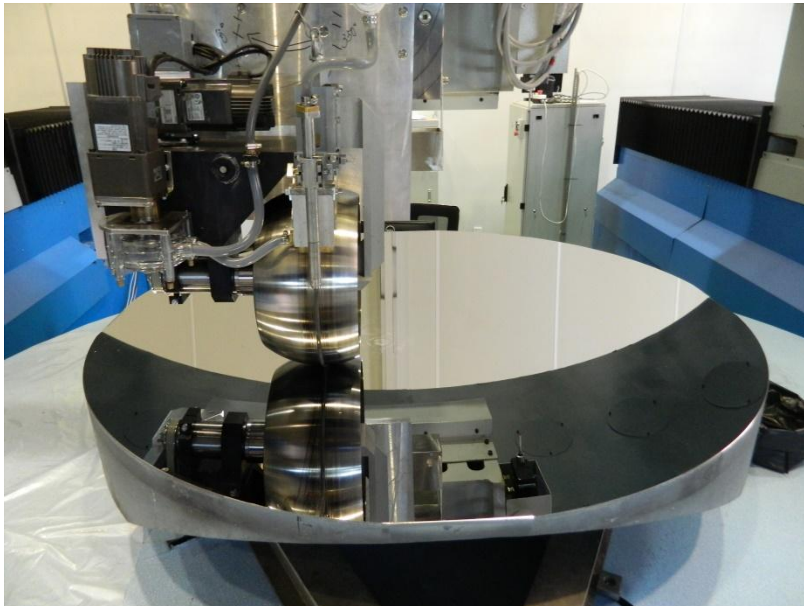


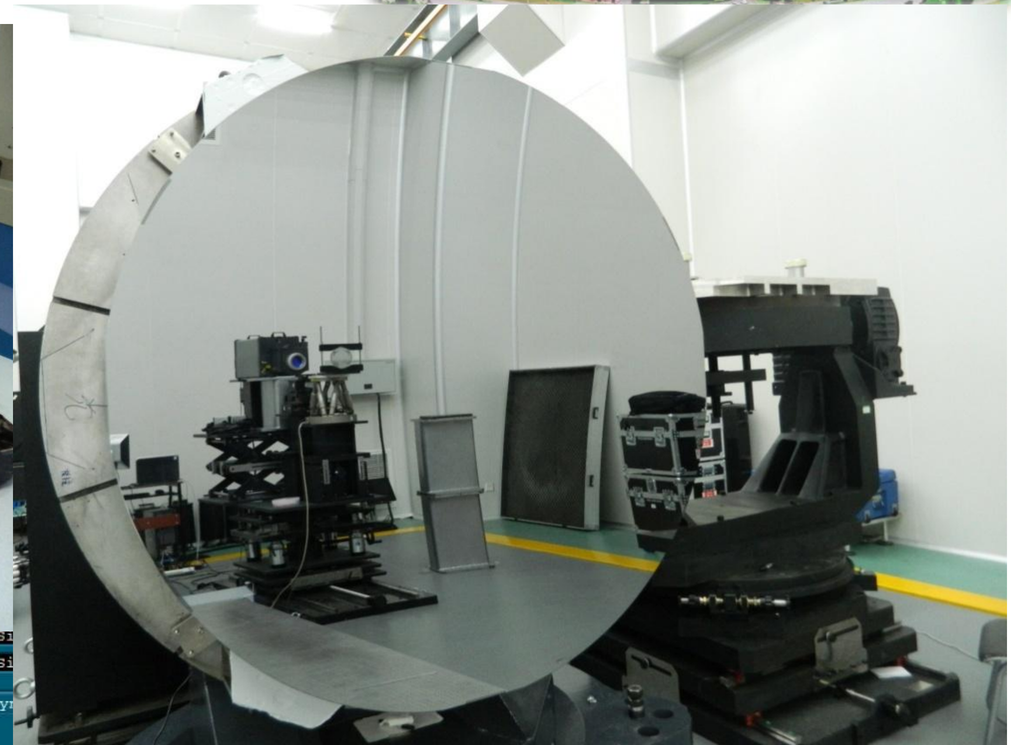


- **Cast into near net-shape, without complex lightweight milling process.**
- **Low risk and cost effective!**

SOFIA's 2.7m Zerodur PM, 850kg
(Areal Density:148kg/m^2)

CIOMP's heritage of SiC mirrors

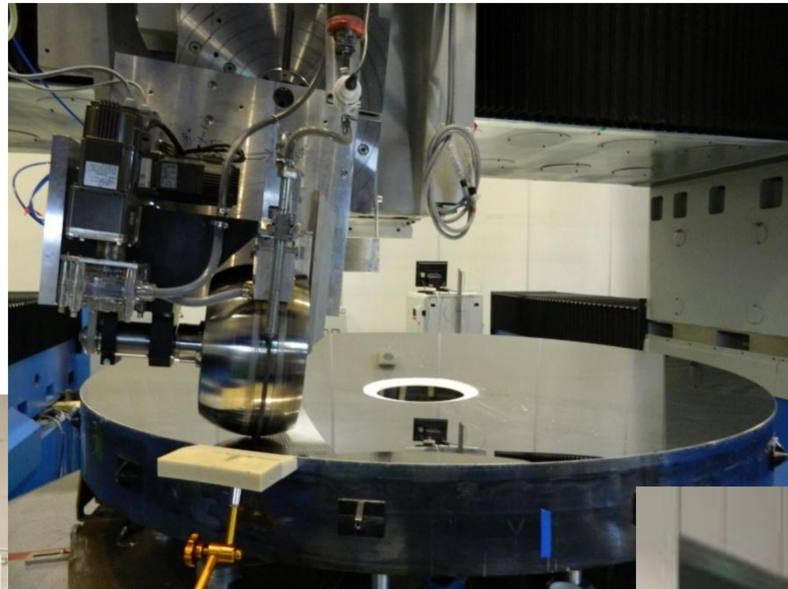


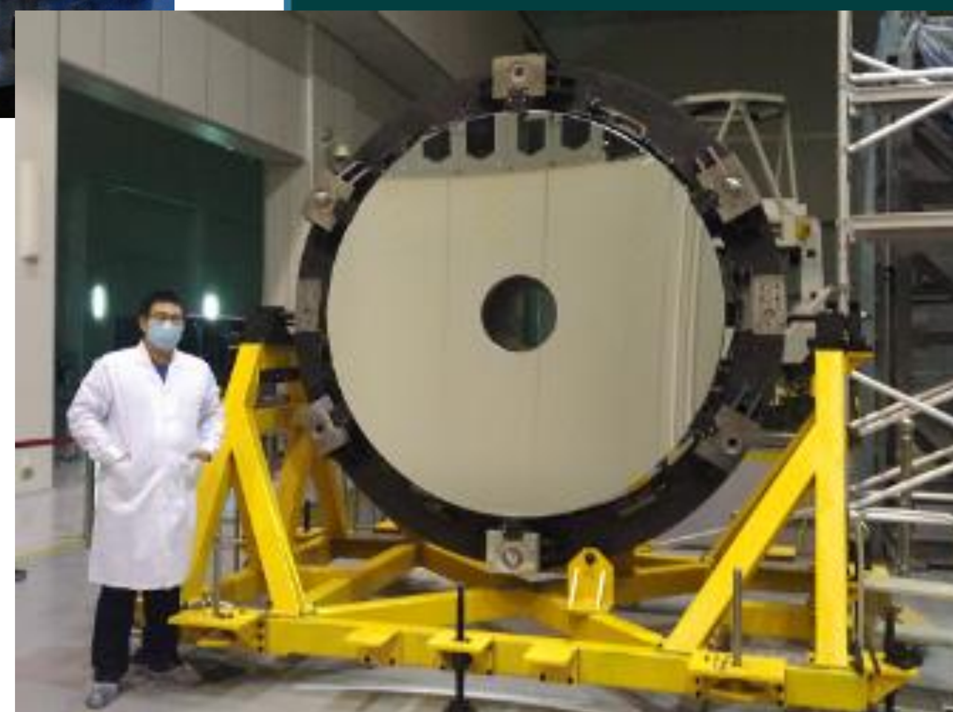


1.5m SiC aspheric mirror final result:

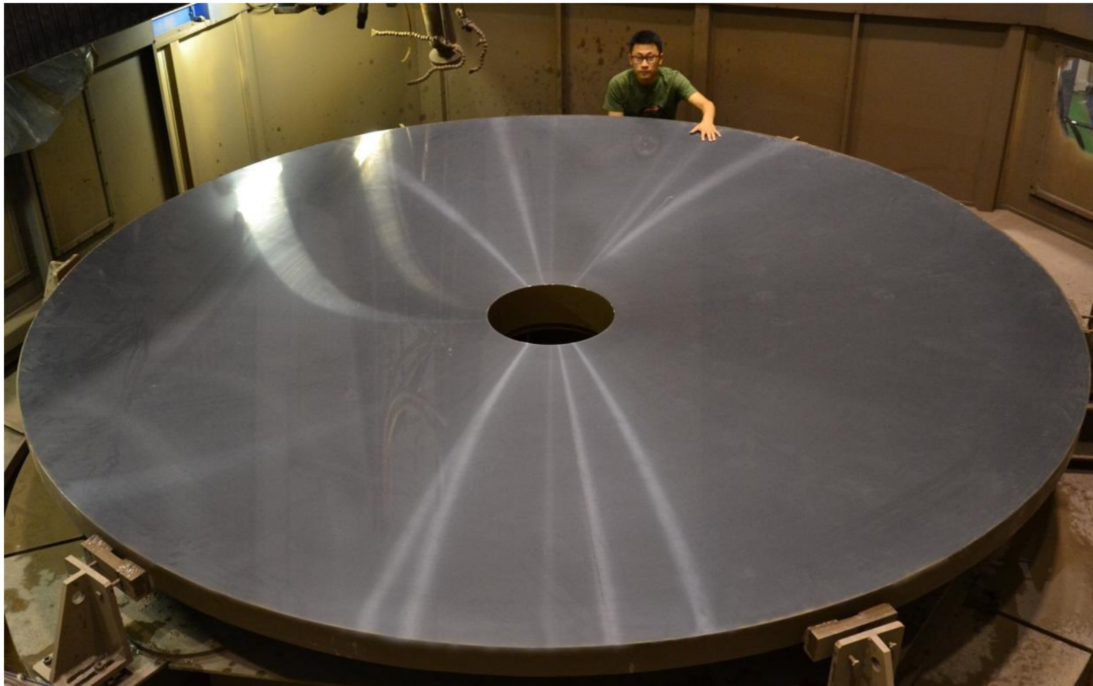
10nm rms， 1.2 μRad Slope rms

2m SiC aspherical mirror:12nm rms,
slopeRMS:1.5μRad



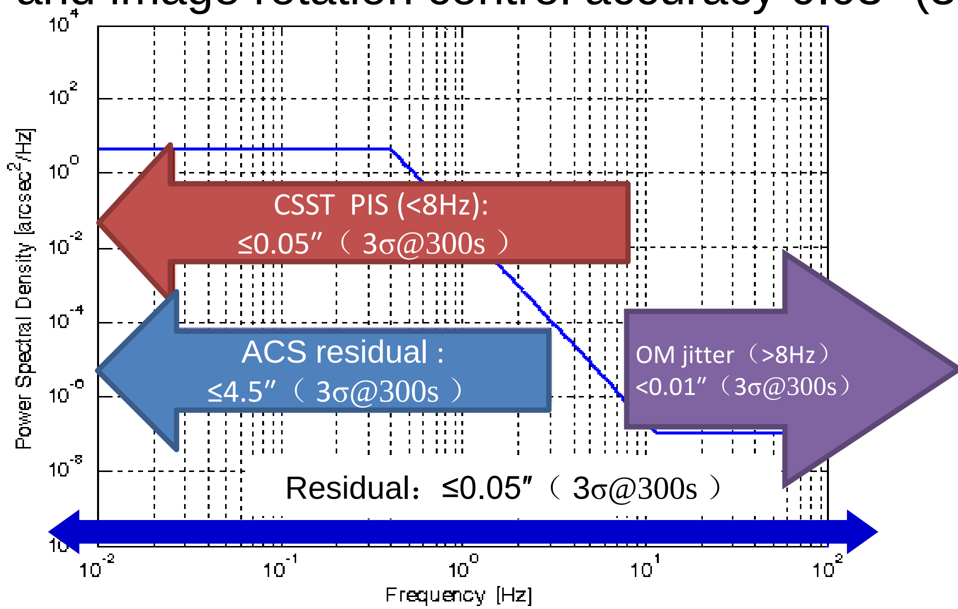


The ϕ4.03m CIOMP-SiC mirror blank（World largest! 2016）



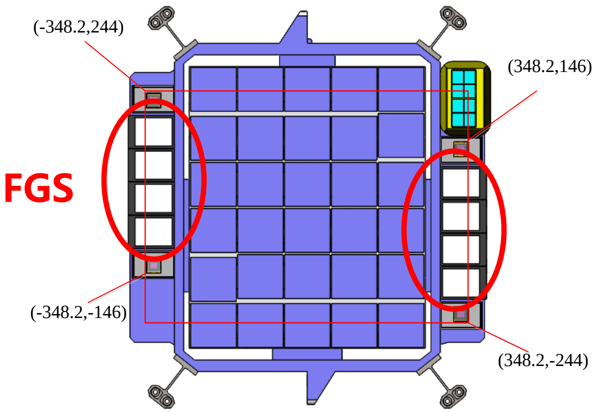
Precision Image Stabilization(PIS)

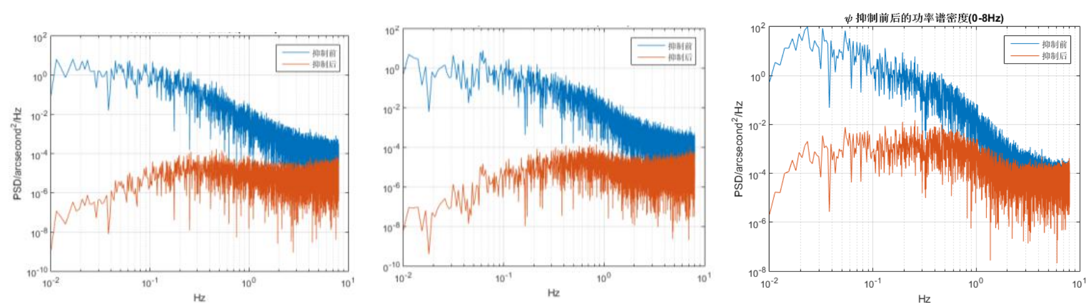
- ACS residual (4.5“(3σ)@300s) ;
- Precision image stabilization system suppress the disturbance below 8Hz , which is result from ACS and low frequency Jitter. After the suppression the vibration of the optical axis is within 0.05″(3σ);
- Jitter attenuation system suppress the disturbance above 8Hz. After the suppression the vibration of the optical axis is within 0.01″(3σ);
- The image stabilization accuracy 0.05 ″(3σ) is divided into translational axis control accuracy 0.04 ″(3σ) and image rotation control accuracy 0.03 ″(3σ) .



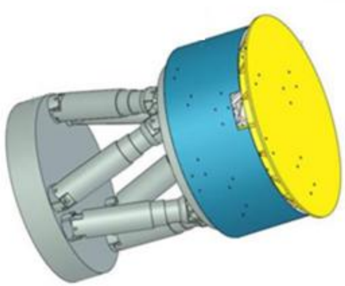
Precision Image Stabilization

- **system scheme：** Large aperture fast steering mirror mechanism + image rotating mechanism +precision image stabilization control+ FGS





Three axis residual PSD



Large aperture fast steering mirror mechanism

Translational direction accuracy is 0.036" , image rotation accuracy is 0.028 " , synthesis accuracy is 0.046" , less than 0.05" (3σ) requirement.

Precision Image Stabilization

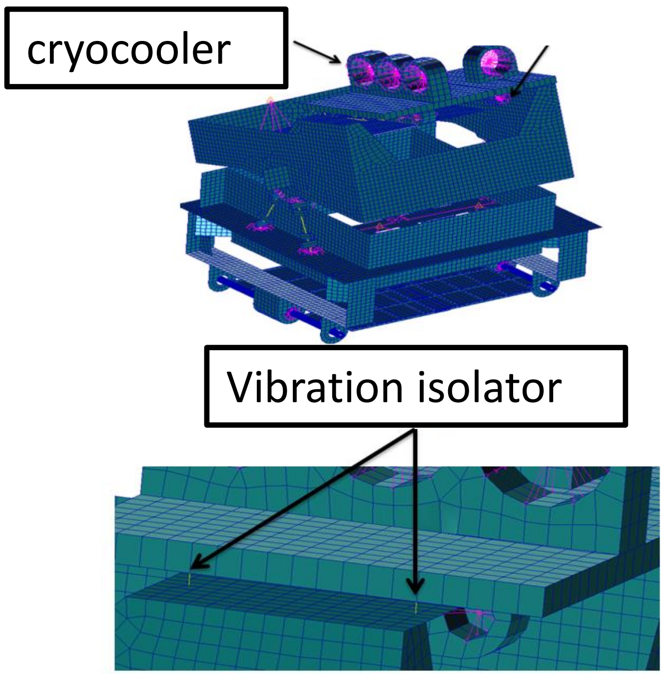
Astronomical observation requires high image stabilization accuracy(0.05″，3σ，300 second)

Requirements		Technical approach
High-precision attitude measurement of FGS	better than 0.01″	High speed large area array detector
		centroid subdivision algorithm
Large aperture fast steering mirror disturbance suppression frequency	Dynamic range : more than 20Hz (400mm×370mm)	Piezoelectric actuator
		PID feed forward control
Ground verification technique	performance verification of FGS	high-precision experiment and simulation verification platform
	fast steering mirror control verification	
	system level experiment	

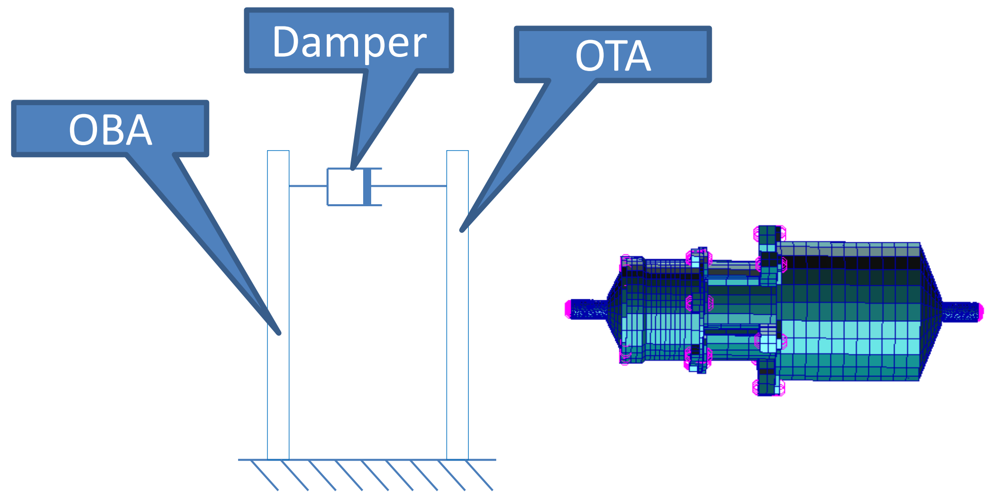
Jitter (Micro-vibration) Attenuation

- **Vibration isolation of disturbance source :** suppression of cryocooler maximum disturbance is above 90% ,suppression of CMG maximum disturbance is 86.5%.

- **Vibration Attenuation with Damping :**Improve the damping of structure.



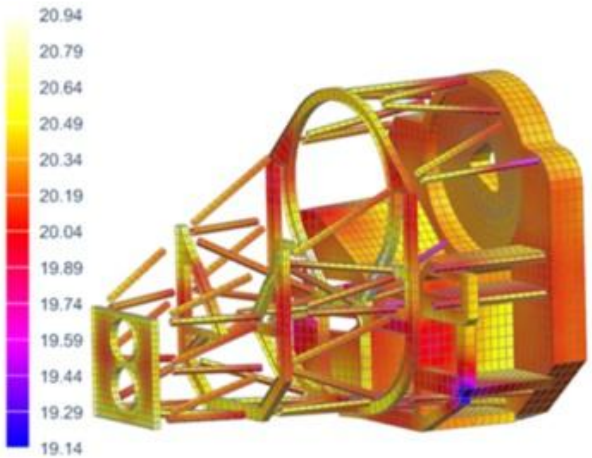
Vibration isolator of cryocooler



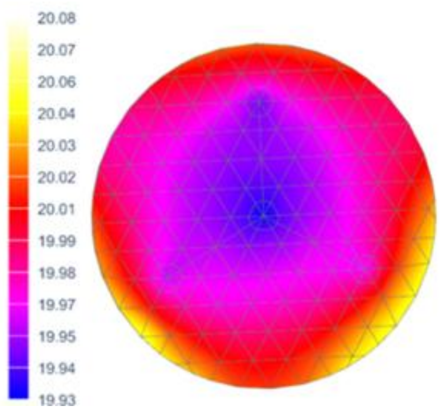
The position of damper

Thermal Control Design

- MLI ---- reduce the direct impact of external heat flow, improve the temperature stability
- Accurate insulation and precision active thermal
- Heat scattered out by 20 m² radiators.
- flat loop heat pipe(FLHP) for SI cooling



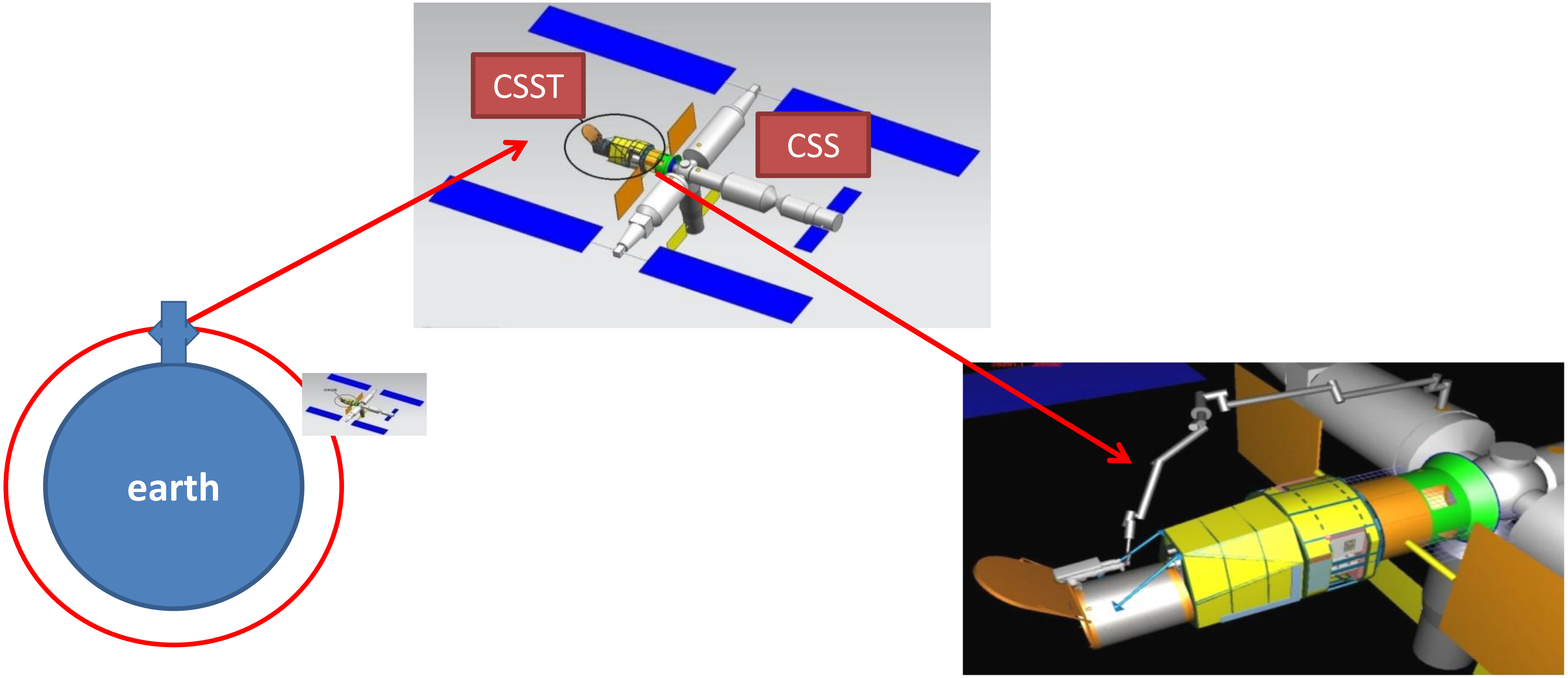
Truss：20 ±1 ℃



PM：20 ±0.1 ℃

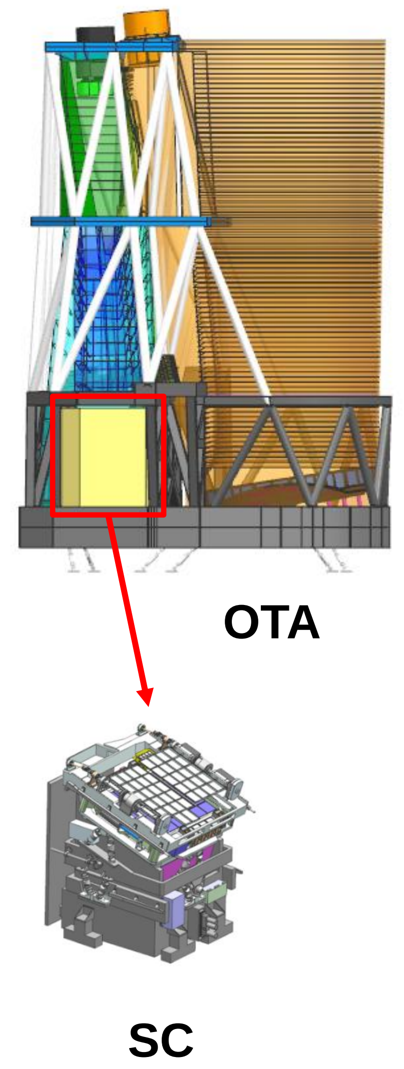
Orbital Maintenance

- CSST is expected to serve for more than 10 years. Orbital maintenance can be carried out for instruments update or malfunction while CSST dock to space station.
- Orbital replaceable units(ORU): scientific instruments, electronic units, thermal coat, movement mechanism.



Survey Camera

- Focal plane composed by 30 9k*9k sensors
- High integration low noise and power by ASIC
- Grating fixed before the focal plane for slitless spectrometric
- Cryocooler--the detector working under low temperature
- Fine rotation compensator--Piezoelectric ceramic driving flexible structure
- Main structure and the shutter are separately designed and orbit maintain



Survey Camera

- To achieve the goal of imaging depth, the reading noise of the focal plane should be below 5e-/pix@150kHz,and hence the noise of sensors and reading electronics should be restricted.
- The reading noise of CCD sensors is approximately less than 3e-/pix(proved by the manufacturer),so the noise of the reading electronics should be below 4e-/pix,or below 24μV。
- High circuit density, electromagnetic environment complex, circuites need low noise design and control.

中科院长春光机所
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Thank You For Your Attention !