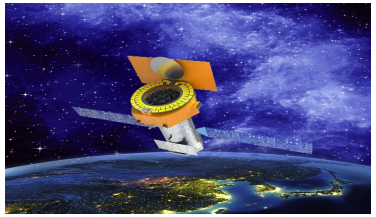


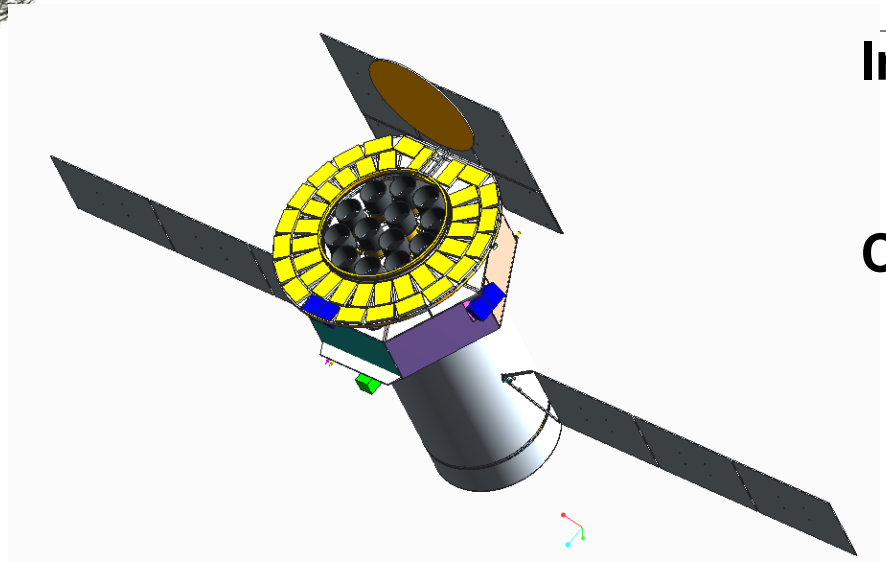
Development of X-ray Optics onboard the enhanced X-ray Timing and Polarimetry (eXTP) mission

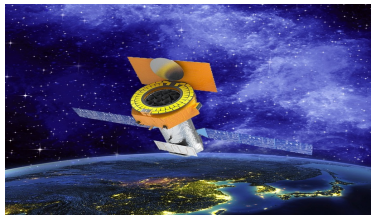
Yanji Yang
on behalf of eXTP Opitcs Team

5th. Dec. 2023

AXRO2023, Prague, 04-08, Dec, 2023

eXTP: enhanced X-ray Timing and Polarimetry





Important Sciences

- Extreme density, gravity, magnetism
- Neutron stars, black holes, etc

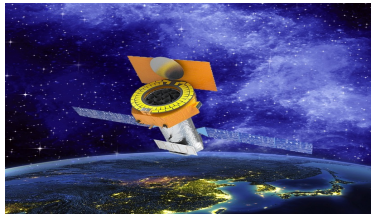
Cutting-edge technology

- Spectral, polarization, timing, imaging
- Large eff. Area (~3.4 m^2@6 keV)
- High spec. resol.(<180 eV@6 keV)
- High throughput: 15 Crab up to 8 hours

Payload	Configuration	Eff. area (m^2)	Timing res. (μs)
Spectroscopy Focusing Array (SFA)	9 telescopes	0.6 m^2@1-2 keV	10
Large Area Detector (LAD)	40 modules	3.0 m^2@8 keV	10
Polarimetry Focusing Array (PFA)	4 telescopes	300 cm^2@3 keV	10
Wide Field Monitor (WFM)	6 cameras	3.1 Sr (FOV)	10

Consolidated in Phase B

eXTP International Consortium (with hardware contribution)

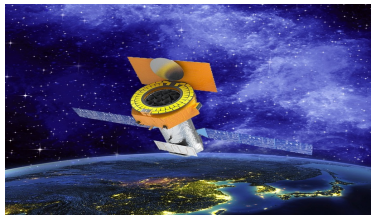


PI: Shuang-Nan Zhang (IHEP); Europe: Marco Feroci (INAF, Rome)

CAS	中国科学院 CHINESE ACADEMY OF SCIENCES
CNSA	CNSA
IHEP, CAS	Institute of High Energy Physics Chinese Academy of Sciences
Tsinghua University	清華大学 Tsinghua University
HIT	哈爾濱工業大學 HARBIN INSTITUTE OF TECHNOLOGY
XIOPM,CAS	中国科学院西安光学精密机械研究所 XI'AN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS
NNVT	北方夜视技术股份有限公司 NORTH NIGHT VISION TECHNOLOGY CO., LTD
SIMIT, CAS	SIMIT Shanghai Institute of Microsystem and Information Technology
CAST Beijing	中国航天 中国空间技术研究院 China Academy of Space Technology
IAMC Shanghai	microsat

Italy	INAF, INFN, FBK Fondazione Bruno Kessler, Politecnico Milano
Spain	CSIC, IEEC Institut d'Estudis Espacials de Catalunya
Germany	Eberhard Karls Universität Tübingen, MPE, FAU Friedrich-Alexander Universität Erlangen-Nürnberg
France	cea
Switzerland	Université de Genève
Czech Republic	asu Astronomical Institute of the Czech Academy of Sciences
Poland	CBK PAN, CAMK PAN
Denmark	DTU
The Netherlands	NOVA, SRON
Austria	universität wien
Turkey	Sabancı Üniversitesi, TÜBİTAK

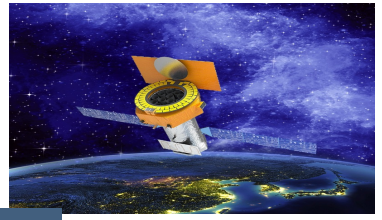
Phase B Progress



Supported through *eXTP Major Background Study project* by CAS, with contributions supported by ASI and other Eur. member states.

- 2019.02 The 2nd eXTP Consortium meeting
  & Phase B technical kick-off in Beijing.
- 2022.01 Satellite/Chinese payloads conceptual design review.
- 2022.06 Selection for the China Space Science Plan (SPP-3) .
  - Organized by CAS with support of a international review team.
  - eXTP is highly recommended with perspective adoption around the end of 2023.
- 2023.03 - eXTP Major Background Study project under evaluation
  - Technical part successfully completed.
  - Budget/programmatic part completed.
- 2023.04 LAD and WFM instruments completed Phase B1 study and I-SRR.

Phase B progress in Europe

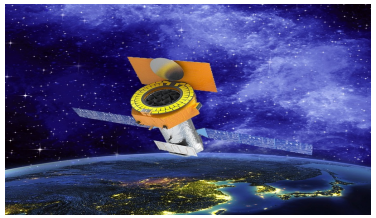


- The LAD and WFM instruments have recently completed their Phase B1 study. The Instrument System Requirements Review (I-SRR) was successfully closed in April 2023.

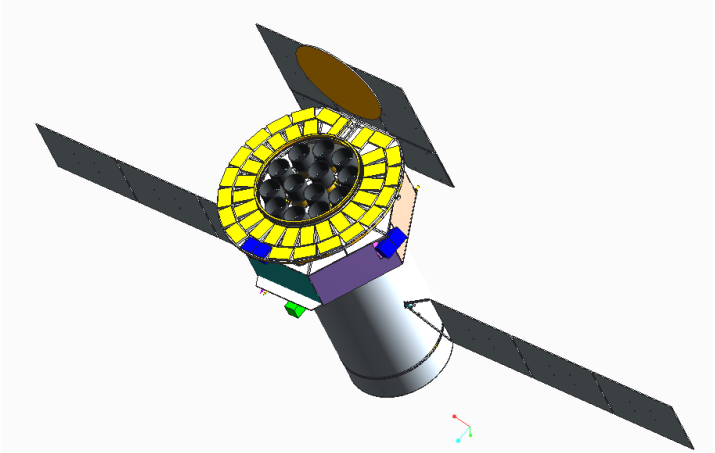
- The I-SRR Review Panel was composed by 4 international scientists and 3 ESA engineers. The review was organized and coordinated by the Italian Space Agency and a delegation of Spain.

- The technical status of the LAD and WFM was assessed as excellent and in line with the current status of the program. A number of RIDs identified actions to the Team, aimed at a technically improvement the program and are considered as normal work.

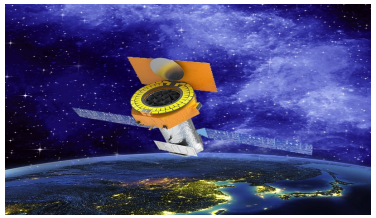
eXTP Mission Overview



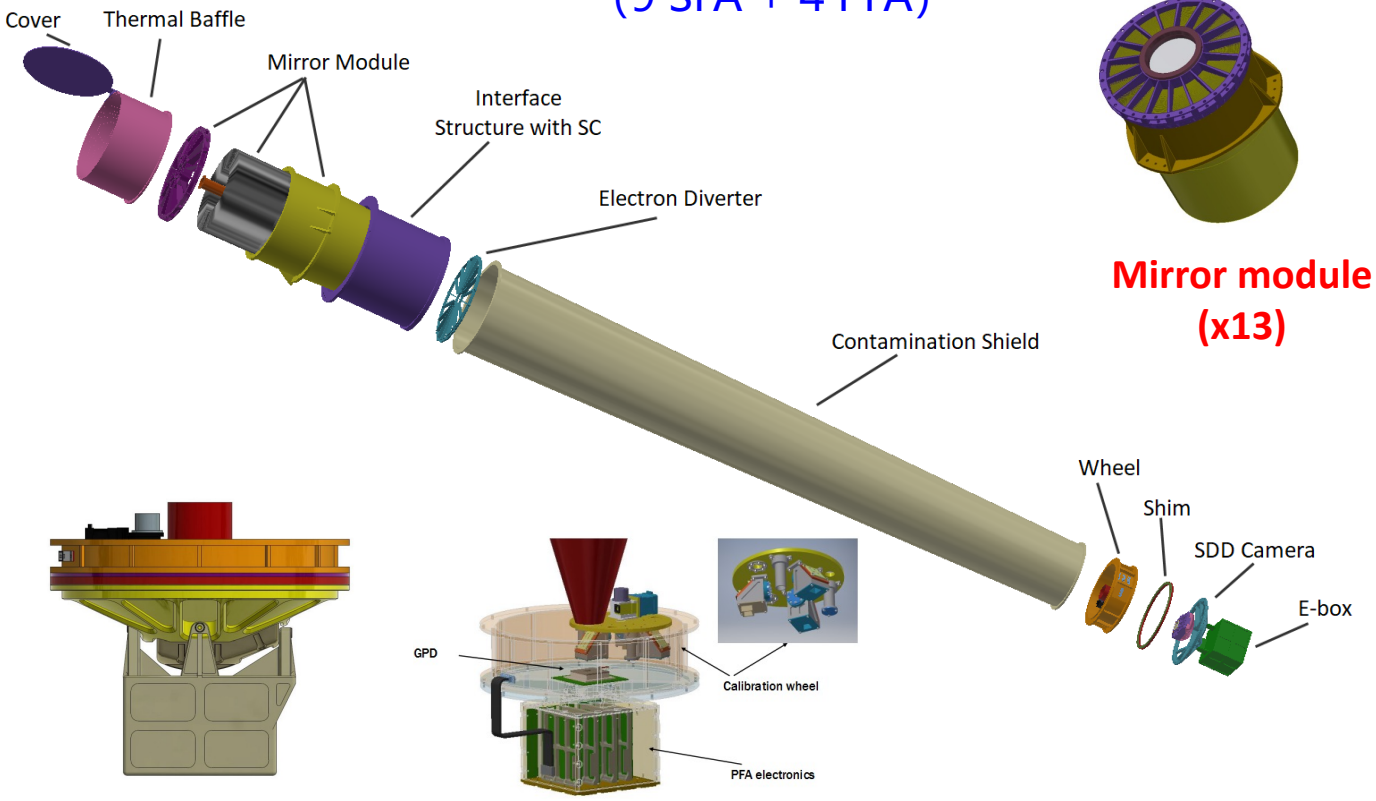
Parameter	Value
Orbit	550 km, inclination ~ 0°
Pointing	3-axis stabilized, < 0.01° (3σ)
Launch	LM-5, from Wenchang (19° N)
Launch mass	~5300 kg
Telemetry	1.6 Tb/day (X-band)
Burst alert & real-time control	BeiDou Short Message, 30s to SOC (Up/down link: 400/500 bps) ; VHF transmitter (SVOM, TBC);
Ground Stations	Colombo (China), Malindi (Italy)
Mission duration	5 years (goal 8 years)
Launch date	~ 2029



Preliminary Design of eXTP Optics



13 Telescope
(9 SFA + 4 PFA)

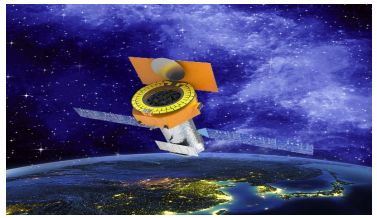


Mirror module (x13)

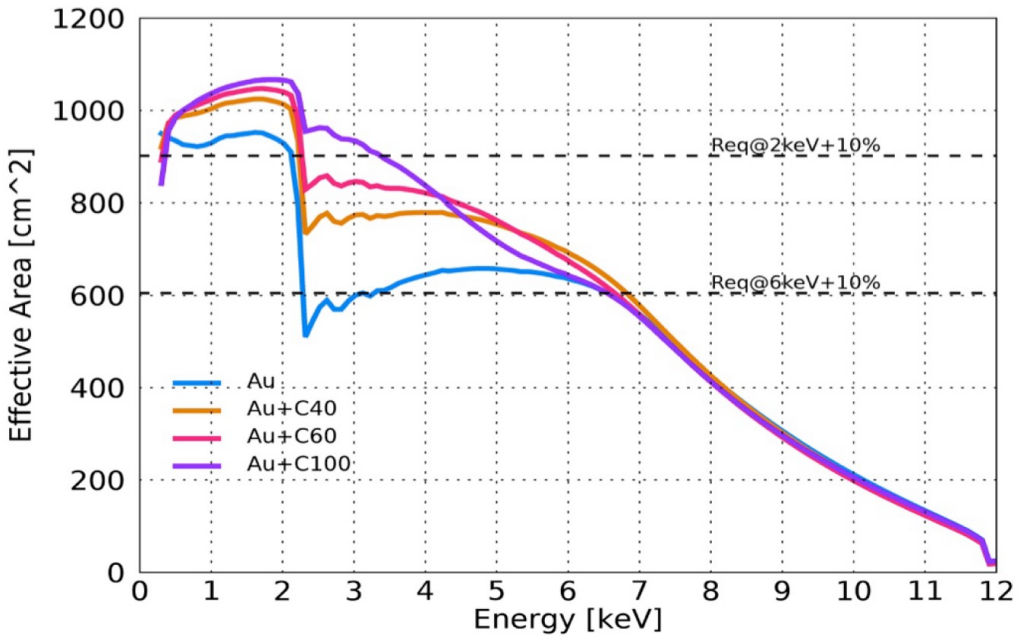
SFA camera (x9)

PFA camera (x4)

Requirement of eXTP Optics

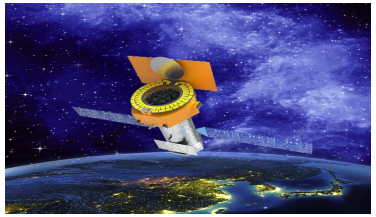


	SFA	PFA
Number of Mirror Modules	9	4
Focal length	5.25 m	
Envelope	≤600 mm（Diameter）	
Collecting area on axis	≥820 cm² @ 2 keV ≥800 cm² @ 3 keV ≥550 cm² @ 6 keV	
Energy range	0.5~10 keV	
Field of View	>12′	
Angular resolution（HPD）	<30″（15″）	
Mass budget	≤130 kg for 1 spider	
Working temperature	20±1 ℃	



Updated Dec. 2023

Milestones for eXTP Optics



2018

Start the Phase A+ study of eXTP

2019

- Our first focusing mirror has been tested by X-ray in March.
- Finished the STM1 of the Einstein Probe mission in October.

2020

- Finish STM2 of the Einstein Probe mission in February.

2021

- Finish the QM of the Einstein Probe mission in July.

2022

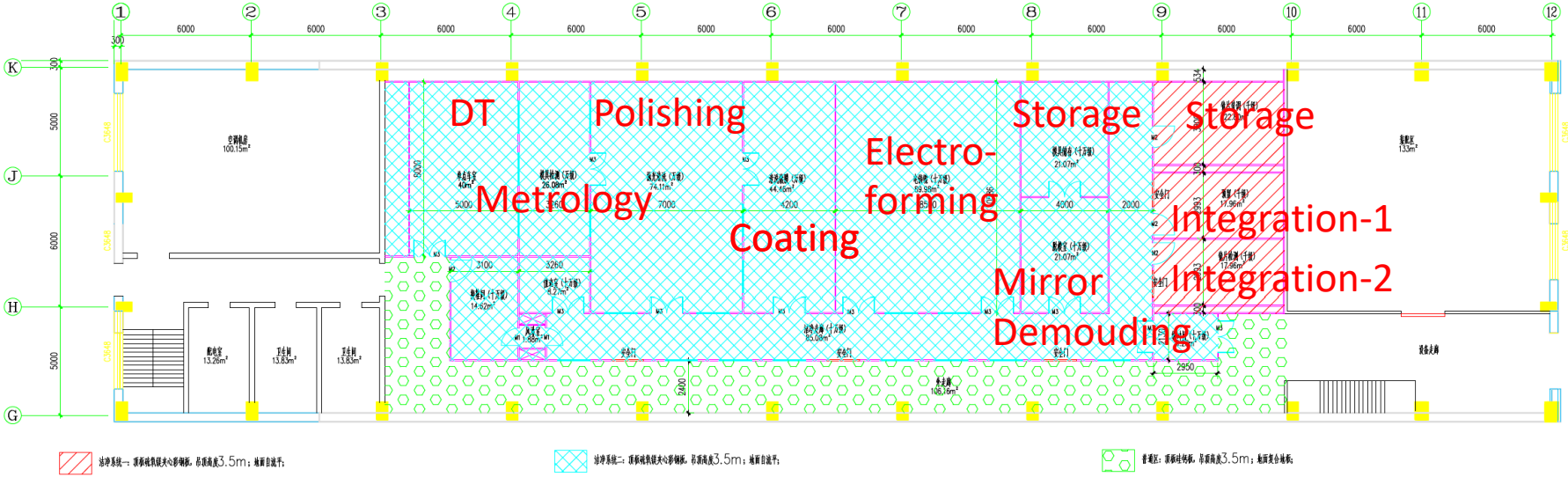
- The first eXTP mirror shell with 1 mm thickness has been test by X-ray, HPD = 20” in February.
- The eXTP mirror shell with 0.2 mm thickness has been test by X-ray, HPD = 33” in April.
- The DM1 has been finished, HPD = 64” in November.

2023

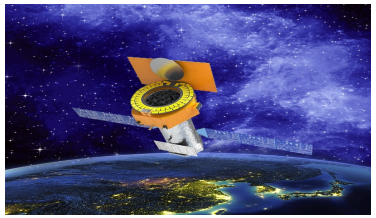
- The DM2 has been finished, which angular resolution is ab. 40” in June.
- The DM3 from MLS has been accepted in September, 24 ”.
- The DM4 with nickel coating only will be finished to test with the PFA camera in ?.

Overview

- 1000m^2 clean room located at south of Harbin City with:
- Diamond turning machine
- Dedicated metrology room & instruments
- Polishing (super polishing & figuring)
- Gold coating chamber
- Electro-forming bath
- Mirror separation stand & mandrel storage room
- Mirror inspection & integration



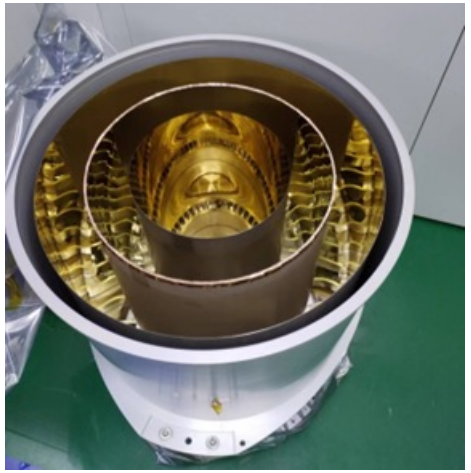
Layout of the mirror production facilities



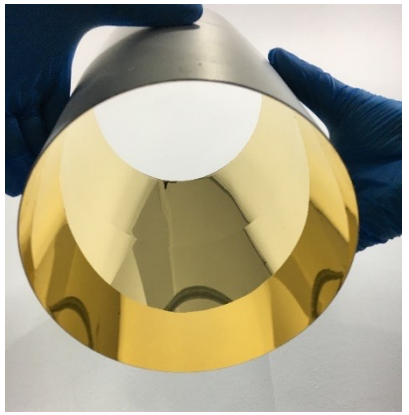
Overview

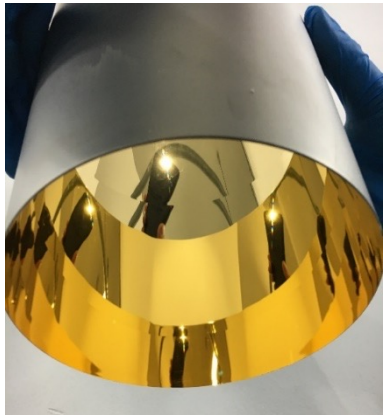
Electroformed Nickel Replication (ENR) fabrication process is adopted: nickel mirror shells are electroformed onto a figured and super-polished aluminum mandrel. Later mirror shells are released from the mandrel using differential thermal contraction.

芯轴精密车削 Mandrel Precision turning → 化学镀镍磷合金 Electroless plating Ni-P alloy → 芯轴超精密车削以及抛光 Mandrel UP turning& polishing → 芯轴真空镀膜 Mandrel coating (DLC&Au) → 电铸镍 Nickel electroplating → 脱模 Demolding

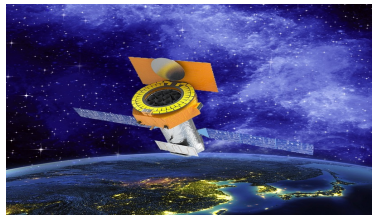


Manufacturing processes of eXTP mirrors

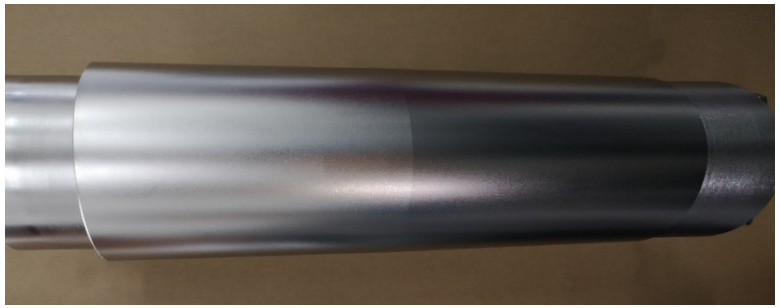




Overview



1. Aluminum blank turned into rough shape



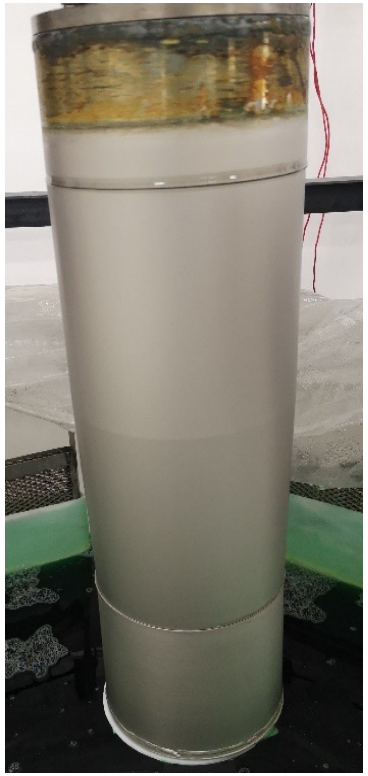
2. Electro-less NiP plating of 150um thick

3. Ultra-precision diamond turning to get exact mandrel shape with error corrections

Overview

4. Super-polished to surface toughness ~0.5nm

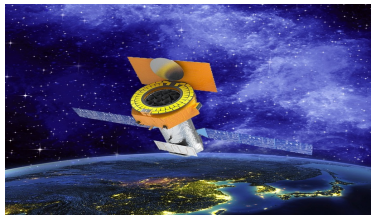
5. 150nm thick gold coating



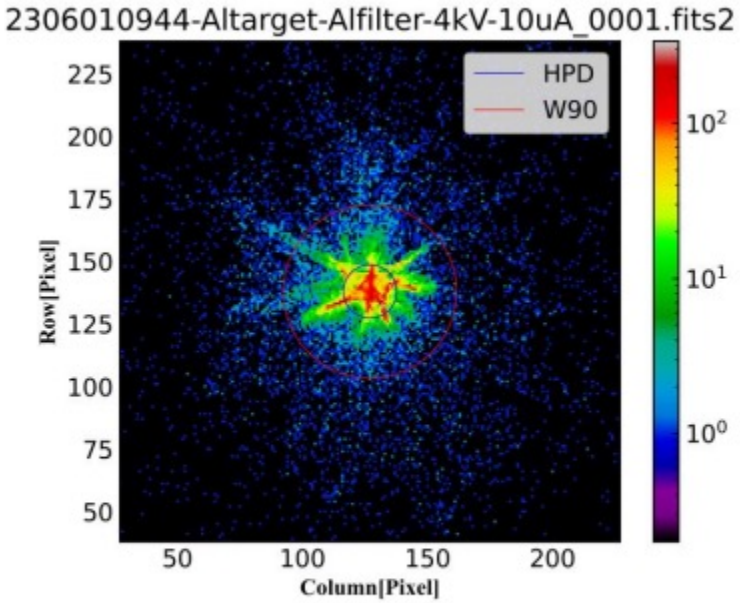
6. Nickel electro-forming (0.2~0.5mm)

7. Mirror shell separated from the mandrel

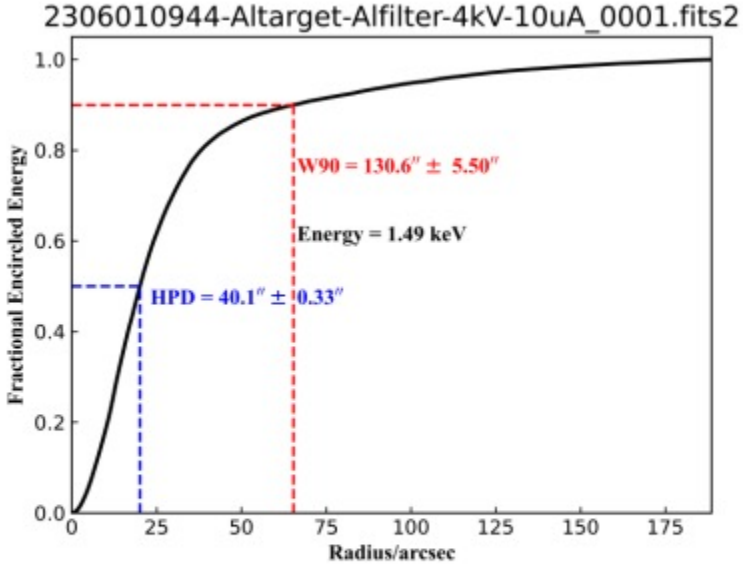
eXTP Demonstrator #2



- eXTP Demonstrator 2 consist of 4 X-ray Wolter I mirror shells, 1#, 20# and 21#, and 41 dummy shells, which angular resolution meets the requirement of SFA.

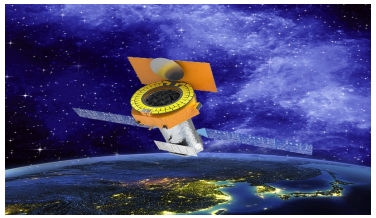


PSF: 200*200

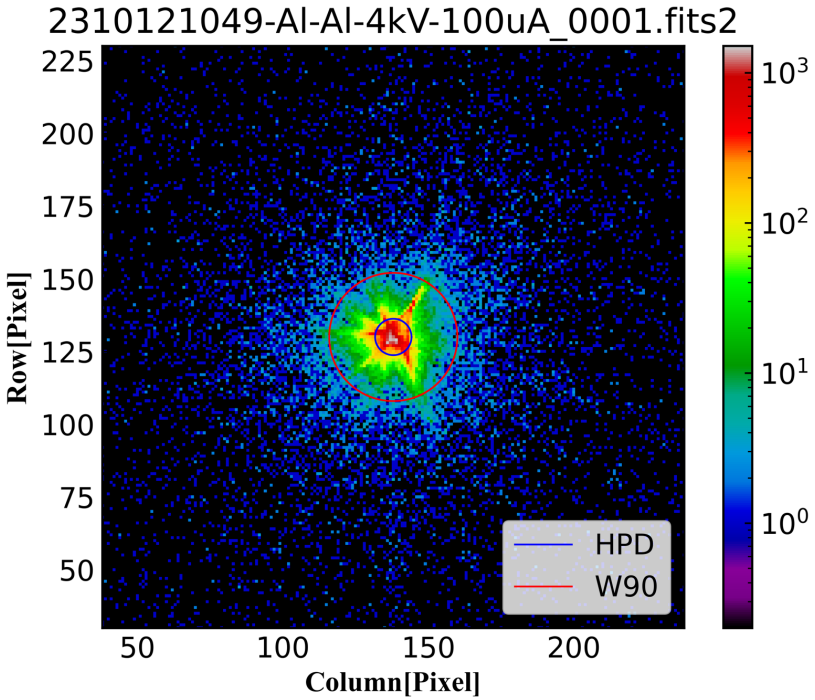


EEF

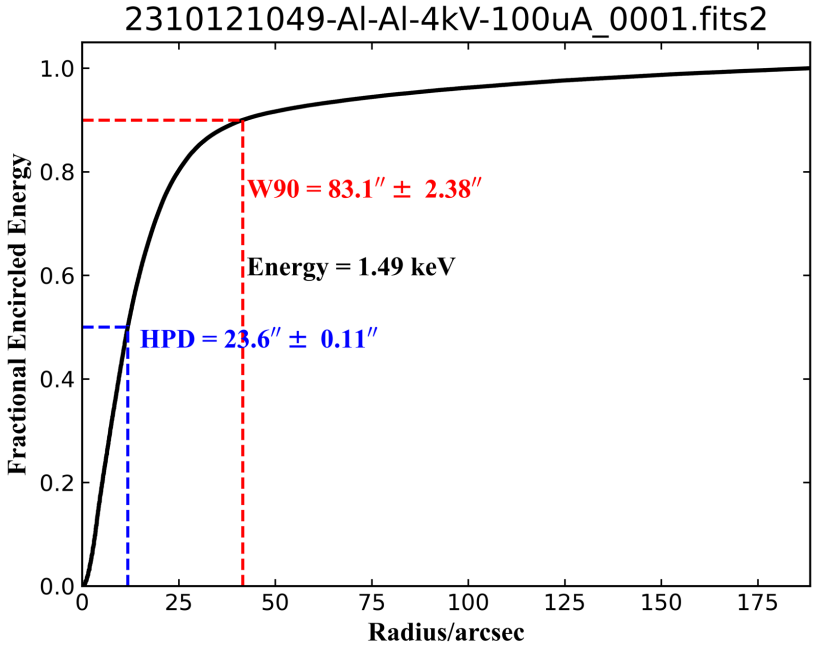
eXTP Demonstrator #3



- eXTP Demonstrator 3 is manufactured by Media Lario, which consist of 3 X-ray mirror shells, 1#, 21# and 22#.



PSF：200*200



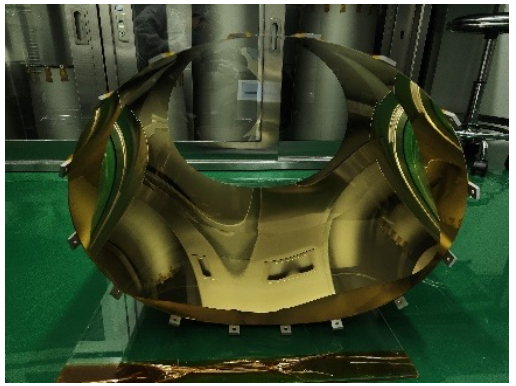
EEF

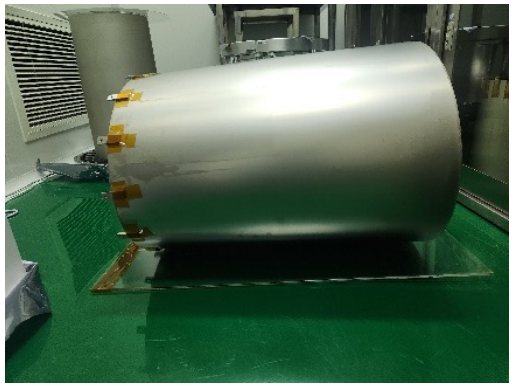
Energy /keV	HPD/″	W90/″
C-K:0.28	21.4±0.2	60.4±1.7
Al-K:1.49	23.6±0.1	83.1±2.3
Ti-K:4.51	28.3±0.3	130.6±7.2
Cr-K:5.4	30.6±0.4	137.4±6.4
Fe-K:6.4	30.8±0.4	140.8±7.1
Cu-K:8.04	29.9±0.4	139.1±5.7

Preliminary testing results

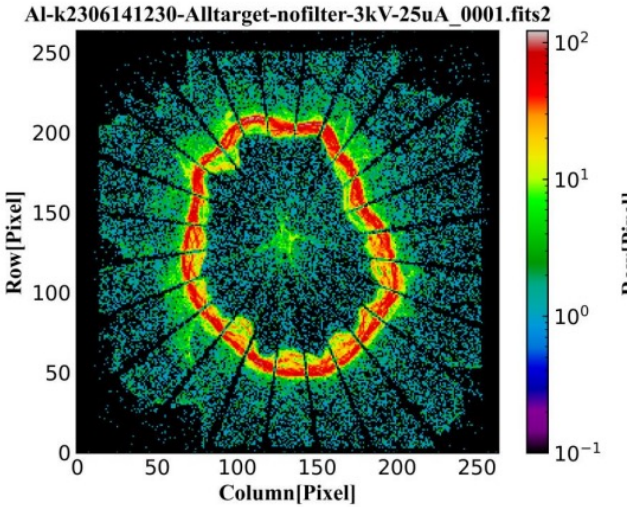
Test Result of eXTP 1st Mirror Shell

- eXTP mirror shells have the smallest t/R ratio, which is 1.75×10^{-3}.
- eXTP 1# shell is the biggest one, which entrance diameter is 480mm, and the thickness is only 0.41mm. It is easy to deform.

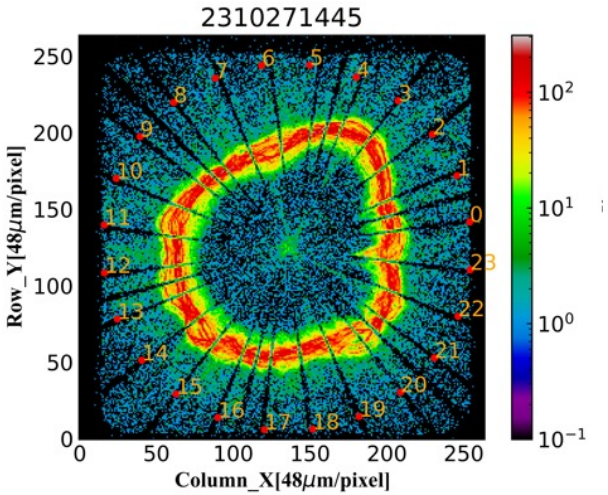




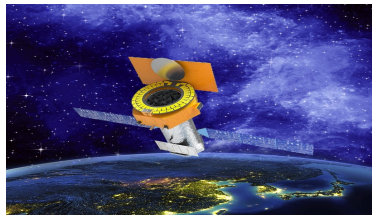
IHEP



MLS



Test Result of eXTP 1st Mirror Shell



- eXTP Focusing mirror has the smallest t/R ratio, which is 1.75×10^{-3}.
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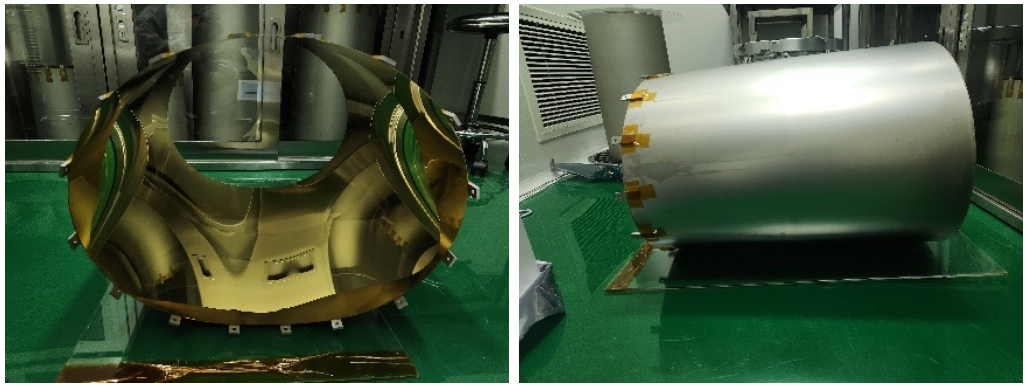

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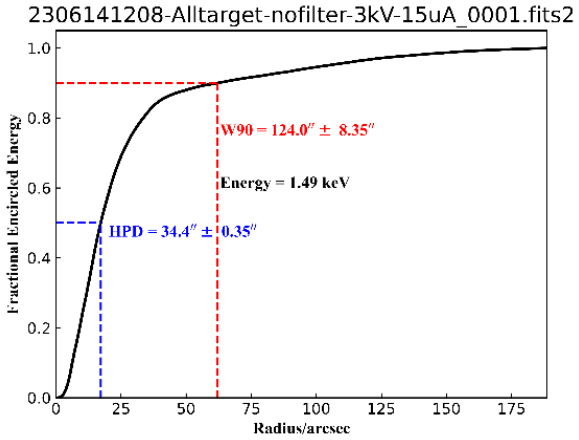

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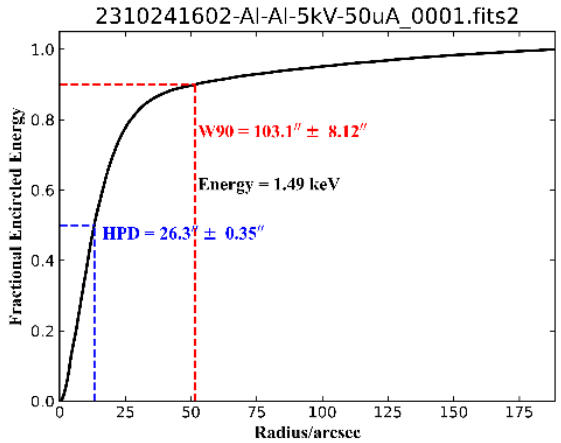
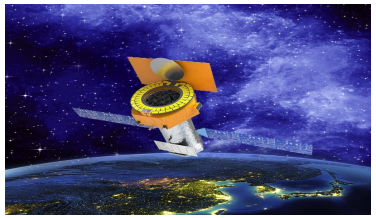
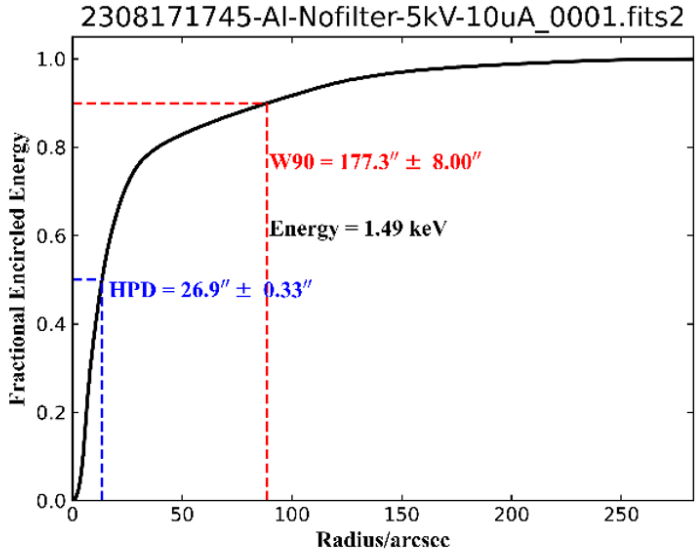
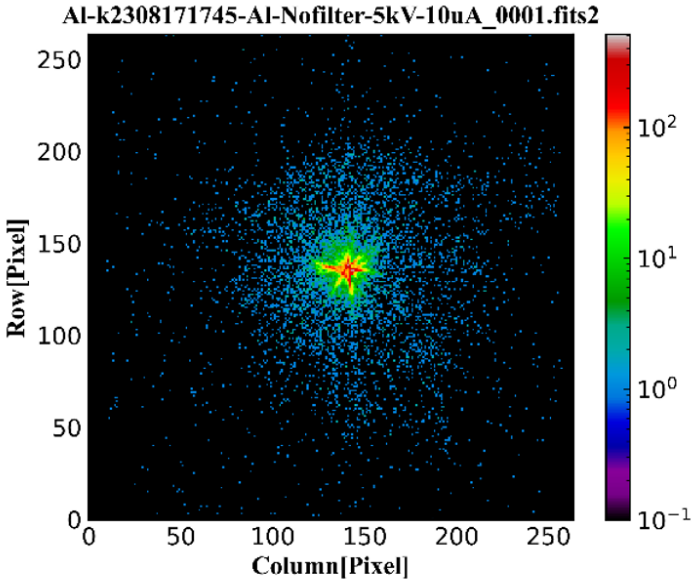


eXTP Mirror Shell 21st with the gold free

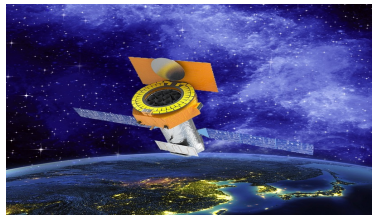


- eXTP mirror shell 21st has been manufactured with gold free, which angular resolution meets the requirement of PFA.

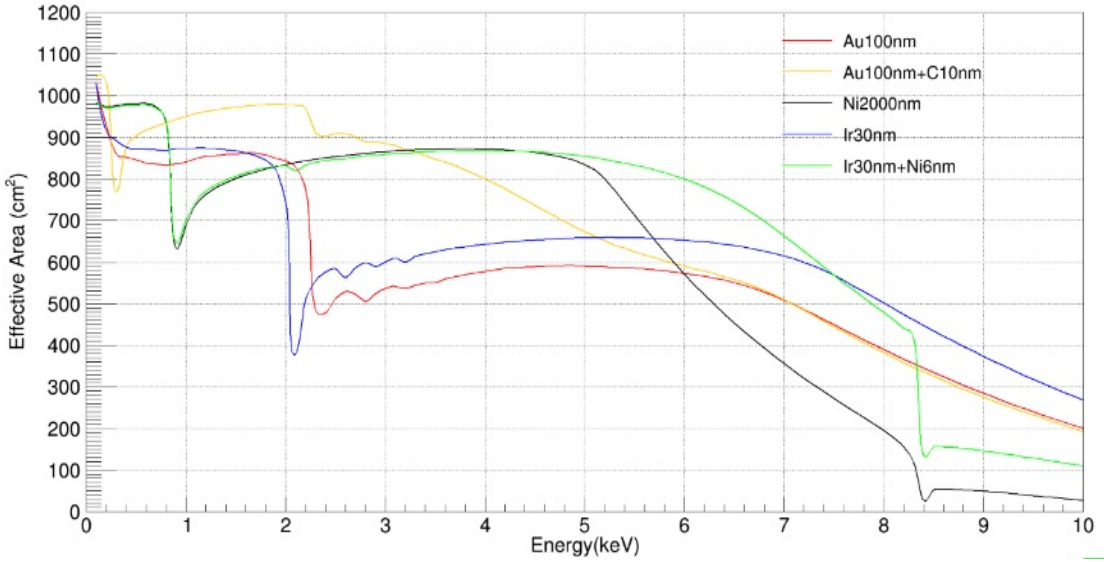


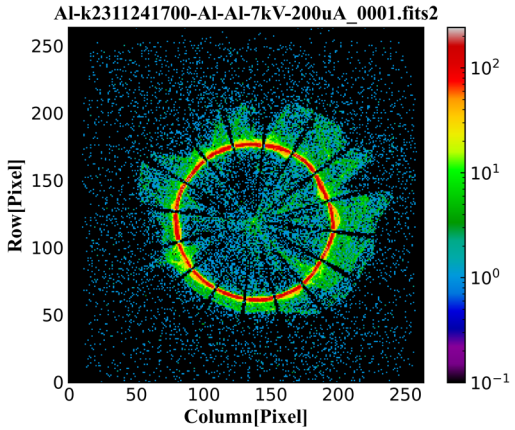


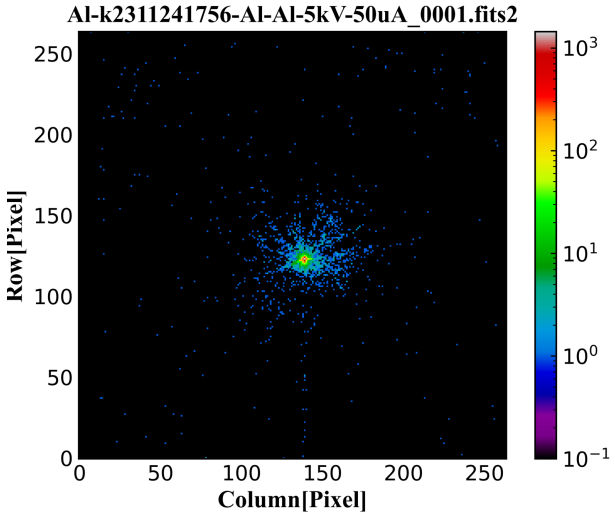
Mirror Shell with dual coating layers

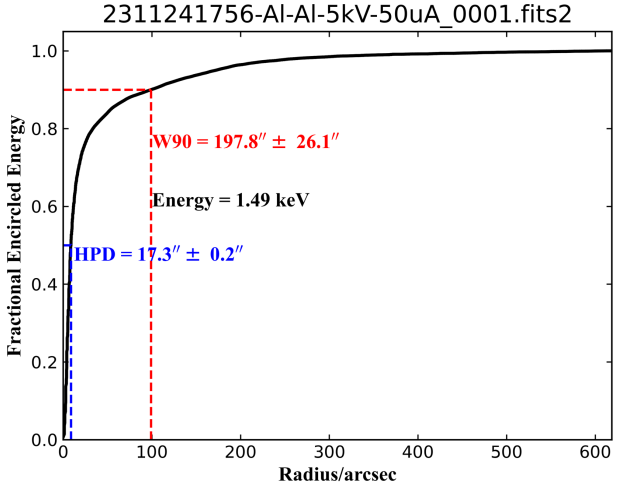


- The mirror shell adopts 6nm Ni and Au 100nm, which increase the effective area from 3keV to 6keV (PFA).
- The angular resolution is 17.3 arcsecs.

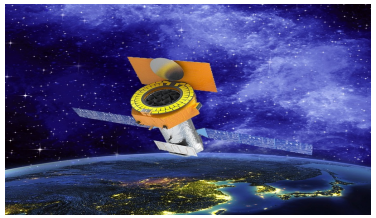








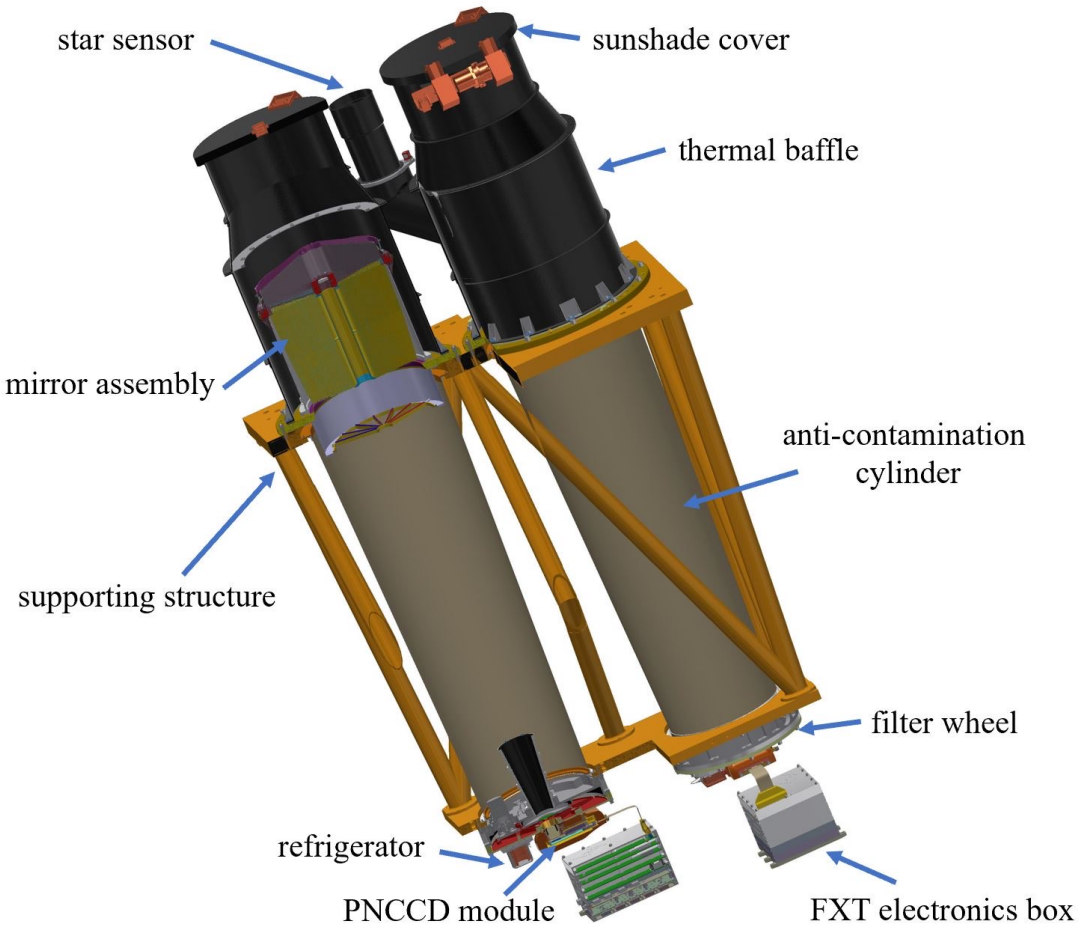
Introduction of FXT



- A small mission for all-sky monitoring to discover and study high-energy transients and variability in the soft X-ray band.
- Proposed in 2012, and managed in the Space Science Programme of the CAS.
- FXT is one of the payloads onboard the EP mission.

Designed characteristics of FXT

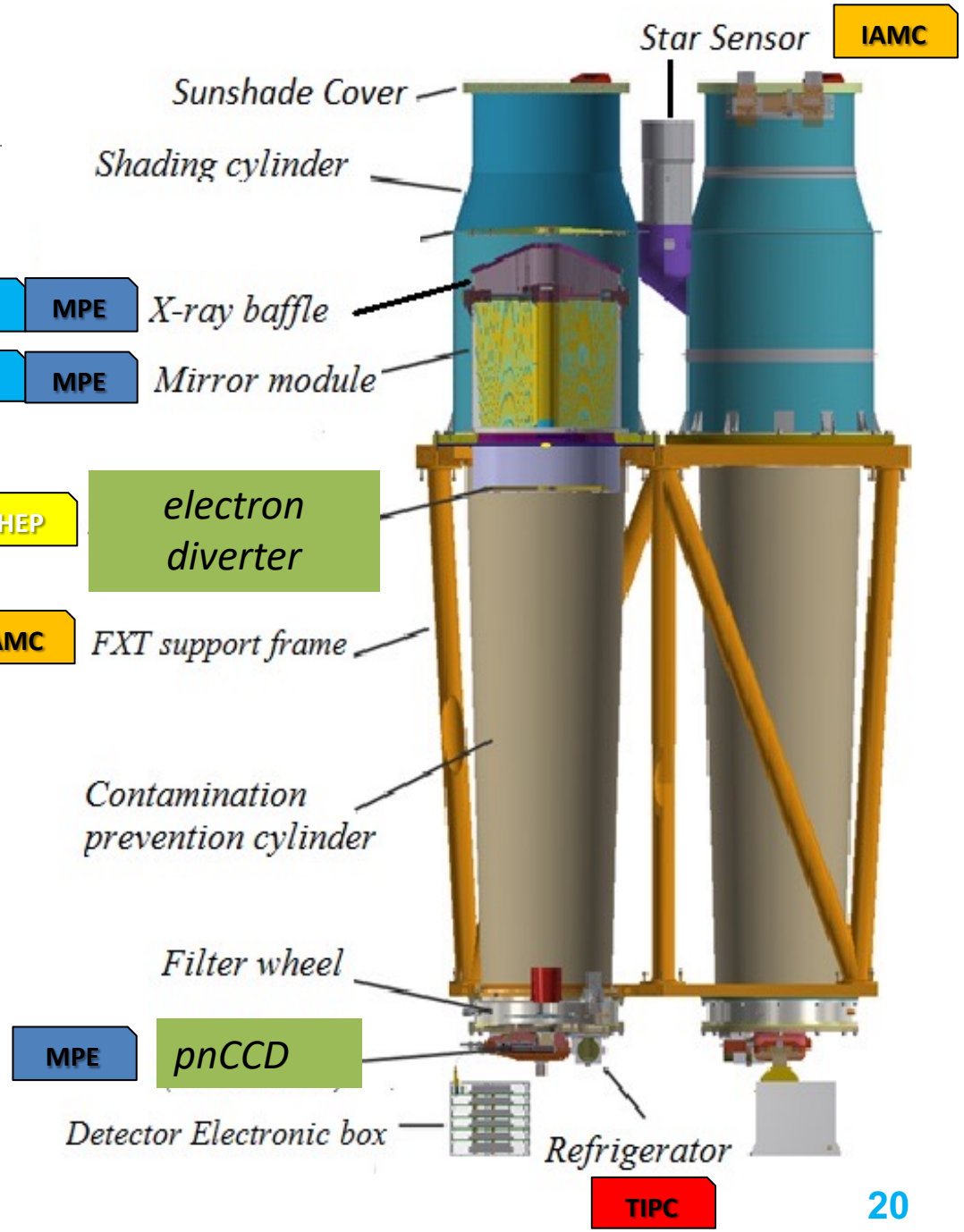
	goal
FOV	1°×1°
EA	≥600cm^2 @1.25 keV，on axis
angular resolution	≤30″ ; HPD
Energy resolution	FWHM ≤120 eV@1.25 keV (Mg-K)
Energy range	0.3-10.0 keV
Source location error	<4" (1 σ; detector coordinate)



FXT configuration

MA A	MA B
ESA FM	MPE eROSITA FS

Electron diverter A	Electron diverter B
ESA ED FM2	Domestic ED FM



ESA : European Space Agency

MPE : Max Planck Institute for Extraterrestrial Physics

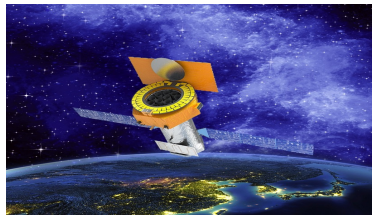
IAMC : Innovative Academy for Microsatellites, CAS

IHEP : Institute of High Energy Physics, CAS

TIPC : Technical Institute of Physics and Chemistry, CAS

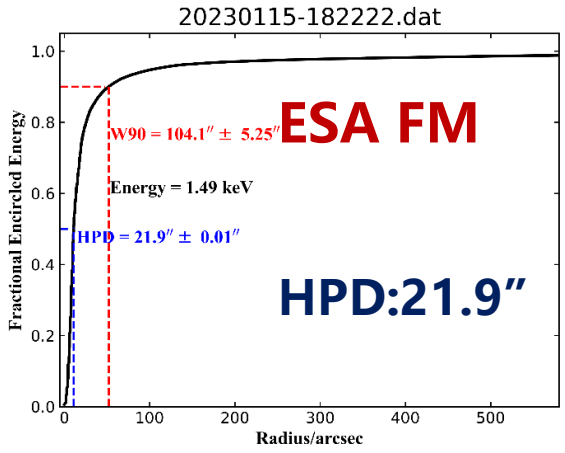
*All other unmarked contributions of FXT are provided by IHEP

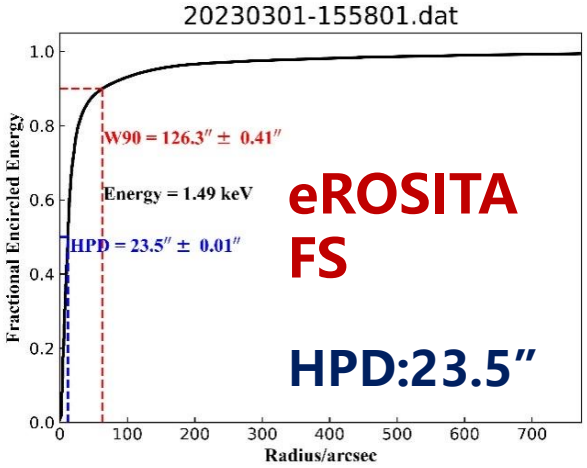
Complete the calibration of MA in 2022

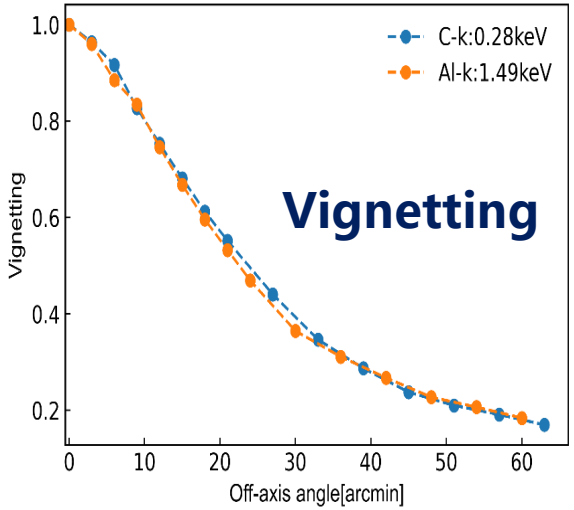


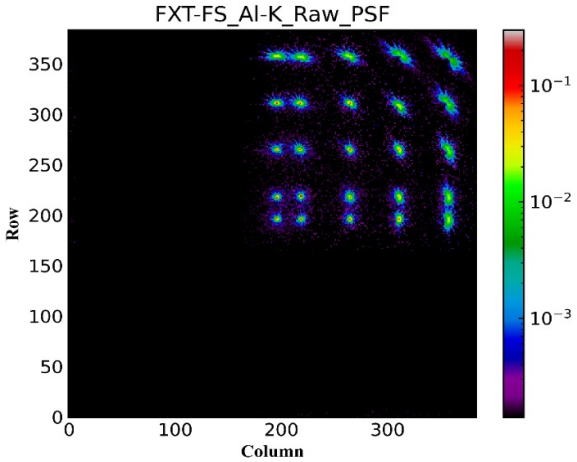
➢ ESA FM and eROSITA FS MA calibration

Angular resolution and effective area are basically consistent with those measured in MPE









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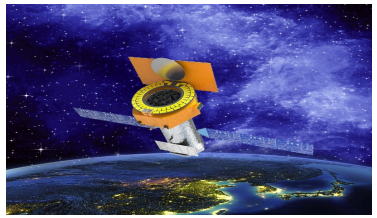
Effective Area

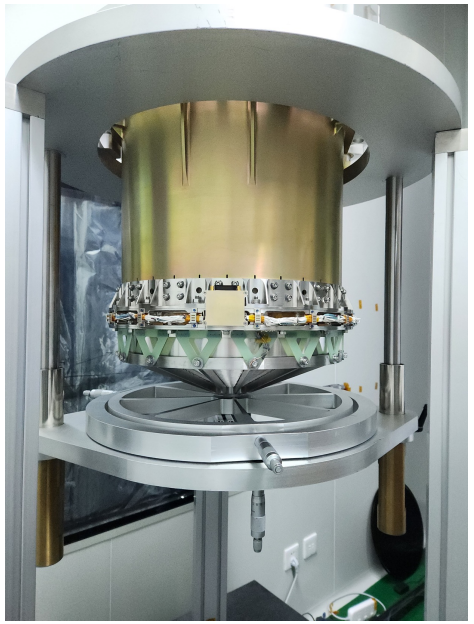
Energy keV	Effective Area cm^2
C-K:0.28	391.3±7.6
Cu-L:0.93	356.8±5.6
Al-K:1.49	363.3±1.9
Ti-K:4.51	67.6±0.4
Cr-K:5.4	52.3±0.4
Cu-K:8.04	20.4±0.2

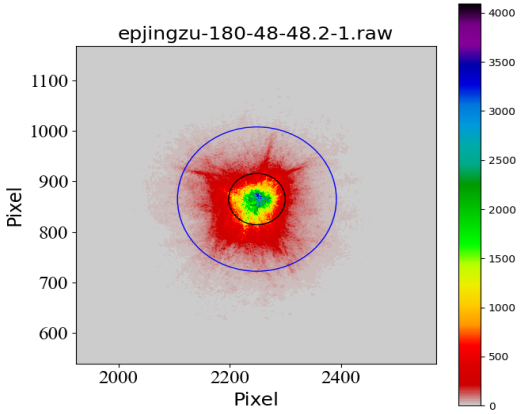
Energy keV	Effective Area cm^2
C-K:0.28	406.4±4.5
Cu-L:0.93	375.0±3.6
Al-K:1.49	373.0±4.7
Ti-K:4.51	77.6±1.4
Cu-K:8.04	22.6±1.1

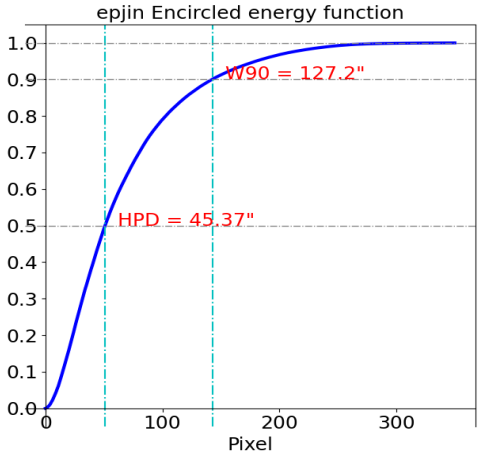
Development of EP-FXT Mirror Assembly Flight Spare

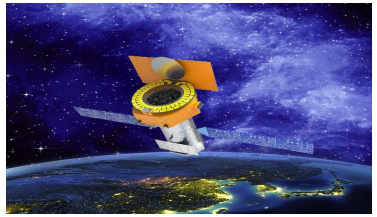


- Finish the development of the flight spare of the EP-FXT mirror assembly, which angular resolution is 45 arcsecs by 470nm parallel lights, and remains unchanged after the assembly with the X-ray baffle.









Thanks for your attention