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SVOM-MXT Optic and Telescope Testing at PANTER

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ABSTRACT

The Microchannel X-ray Telescope (MXT) for the Space-based multi-band astronomical Variable Objects Monitor (SVOM), a Franco-Chinese mission (CNES/CNSA), is designed for the soft X-ray range (0.2-10 KeV) to observe gamma-ray bursts (GRBs) from the beginning to the afterglow emission. In the past years, the PANTER test facility has been testing the different MXT optics models. Each optic is made up of an array of 5 x 5 Micro Pore Optic (MPO) plates. We characterized the performance of the SVOM optic at different phases: Bread-Board (BB), Qualification Model (QM), Flight Model (FM), and Flight Spare (FS) for the optic followed by the Performance Model (PM) and Flight Model (FM) for the complete telescope fully integrated with the optic, detector, radiator and electronics. For the FM end-to-end test, in October 2021, the goal was to determine the half-energy width (HEW) on-axis and off-axis, and to characterize the flight telescope's energy-dependent efficiency (effective area) under different thermal loads, i.e. different detector and optics temperatures. The final numbers will be presented in a paper in preparation. This paper provides the overview of various activities: setup, metrology and measurement, carried out at the PANTER facility during the development of the SVOM-MXT towards the end-to-end test.

Keywords: X-ray optics, SVOM, X-ray Astronomy, X-ray optics testing, PANTER

1. INTRODUCTION

The China National Space Administration (CNSA), Chinese Academy of Sciences (CAS) and the French Space Agency (CNES) are developing the small X-ray telescope Space Variable Objects Monitor (SVOM) [1] satellite to be launched end of 2023. The mission has instruments onboard to detect gamma-ray bursts and localize them. The four main instruments are ECLAIRs: a wide field coded mask camera, GRM: a gamma-ray non-imaging spectrometer, MXT: a Microchannel X-ray Telescope, and a Visible Telescope.

The onboard Microchannel X-ray Telescope (MXT) [2] is a development led by CNES in collaboration with CEA-Saclay/Irfu, the University of Leicester, the Max Planck Institute for Extraterrestrial Physics (MPE) in Munich, and the IJ-CLab in Orsay. The SVOM-MXT, an X-ray telescope sensitive in the 0.2–10 keV energy range, is a compact (focal length ~ 1.15 m) and light (< 42 kg) instrument. The ultra-lightweight MXT OPtical assembly (MOP) is a structure holding an array of 5 x 5 Micro Pore Optics (MPOs) following a "lobster eye" optical design [3]. Each MPO is 40 mm a side and has a thickness of 1.2 mm and 2.4 mm for the outer and inner plates respectively. Each MPO is made up of about 1000 × 1000 iridium coated channels (size of a single channel 40 μm × 40 μm) that focus the X-rays onto a low-noise pnCDD X-ray detector [4, 5]. The field of view of the telescope is approximately 57 arcmin a side with a collecting area of about 35 cm^2 at Al-K (1.5 keV).

For the last 7 years, the PANTER X-ray test facility [6, 7] of the Max Planck Institute for Extraterrestrial Physics (MPE) located in the south west of Munich, Germany, has been involved in the development and testing of the MPO mirrors that are used in the SVOM-MXT telescope. The work on specific 1.15 m focal length MPOs for the SVOM Mission has been ongoing since 2016. With the X-ray source at a distance of >120 m from the test optic, the PANTER beamline allows the testing with a slightly divergent beam. For the SVOM-MXT optics tests the PANTER detectors were used whilst for the telescope tests the MXT detectors were used.

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2. SVOM-MXT OPTIC TESTING AT PANTER

The performance of the SVOM-MXT optics (MOP) was characterized at different development phases between Jul 2016 to May 2022: Bread-Board (BB), Qualification Model (QM), Flight Model (FM), and Flight Spare (FS). For details see Table 1. Photographs of the different optic models in the PANTER vacuum chamber are shown in Figure 1 and Figure 2.

At PANTER, it is possible to characterize optics in great detail. The multi-target X-ray source allows measurements be made at many different energies from B-K at 0.18 keV through Al-K at 1.5 keV all way up to Ge-Kβ at 11 keV. This covers the range at which the MXT telescope will work and the measurements were done at most of these available energies. A clean energy selection is possible as the TRoPIC pnCCD detector available at PANTER is operated in single photon counting allowing for a good determination of the photon energy.

The optics test at PANTER consisted of:

- Optical laser pre-alignment before pump down
- X-ray pitch and yaw alignment
- Focus search scans
- Deep PSF measurements (see Figure 3 top, left and bottom)

  → to study the cross arms of the PSF in detail
- Focal plane scans covering a grid of pitch and yaw angles (see Figure 3 top, right)

  → to study the dependence of the PSF and effective area on the off-axis angle.

The focus scans were done at C-K, Al-K, and Ti-K. The deep PSF and Focal plane scans were executed in several different energies from C-K to Cu-K. In addition, continuum flux measurements were performed to consolidate the shape of the effective area curves between the single energy measurements.

Table 1 Overview of the SVOM-MXT optics tests performed at the PANTER X-ray test facility

Optic Tests	Date	Optic	Type of tests [reference]
Bread Board (BB)	Jul. 11 – Jul. 15, 2016	7 MPOs	Testing individual MPOs [8]
Qualification Model (QM)	Jul. 10 – Jul. 26, 2019	Fully populated	Calibration (test run) [9]
Flight Model (FM)	Jan. 11 – Feb. 04, 2021	Fully populated	Calibration (final) [10]
Flight Spare (FS)	May 02 – May14, 2022	Fully populated	Calibration (final) [in prep.]

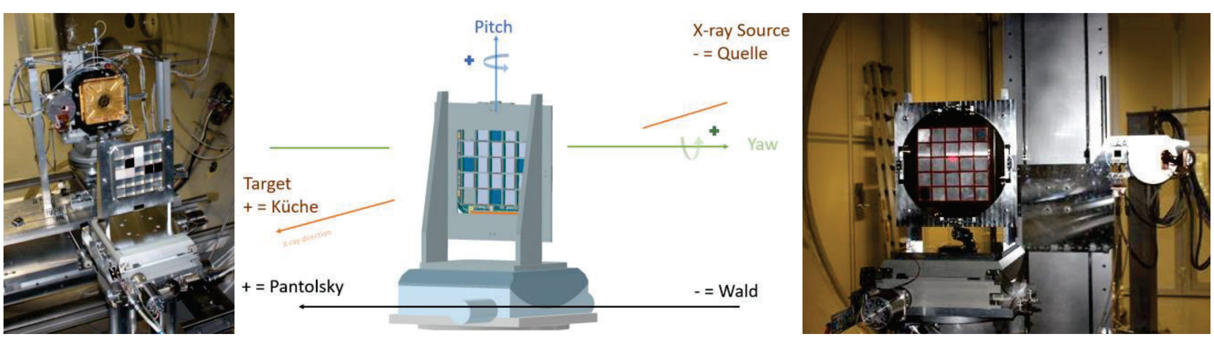

Figure 1 SVOM-MXT-MOP optics in the PANTER vacuum chamber, view from the source toward the detector: (left) the Bread-Board (BB) and (right) the Qualification Model (QM) models are shown. (center) shows the coordinate system used in PANTER during the optics measurement campaigns. During the BB measurements**,** the Position Sensitive Proportional Counter (PSPC), a ROSAT flight spare, was also used for measurements together with the TRoPIC pnCCD camera.

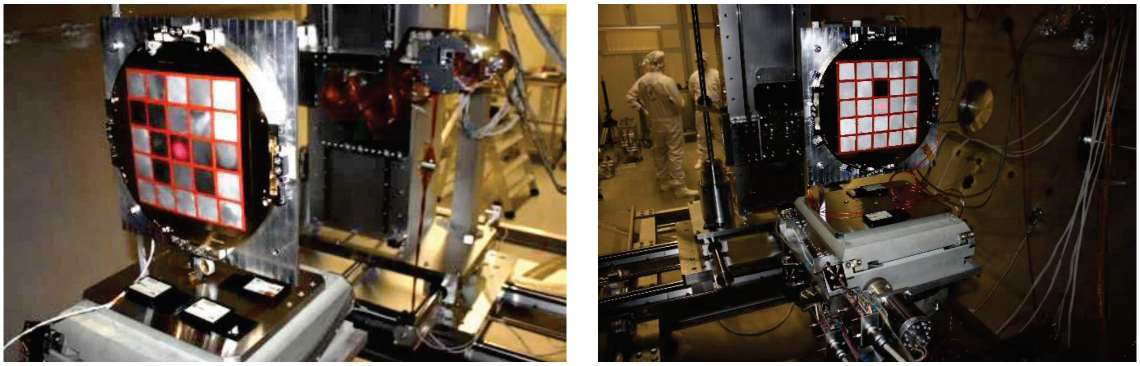

Figure 2 SVOM-MXT-MOP optics in the PANTER vacuum chamber, view from the source toward the detector: (left) the Flight Model (FM), and (right) the Flight Spare (FS) models are shown.

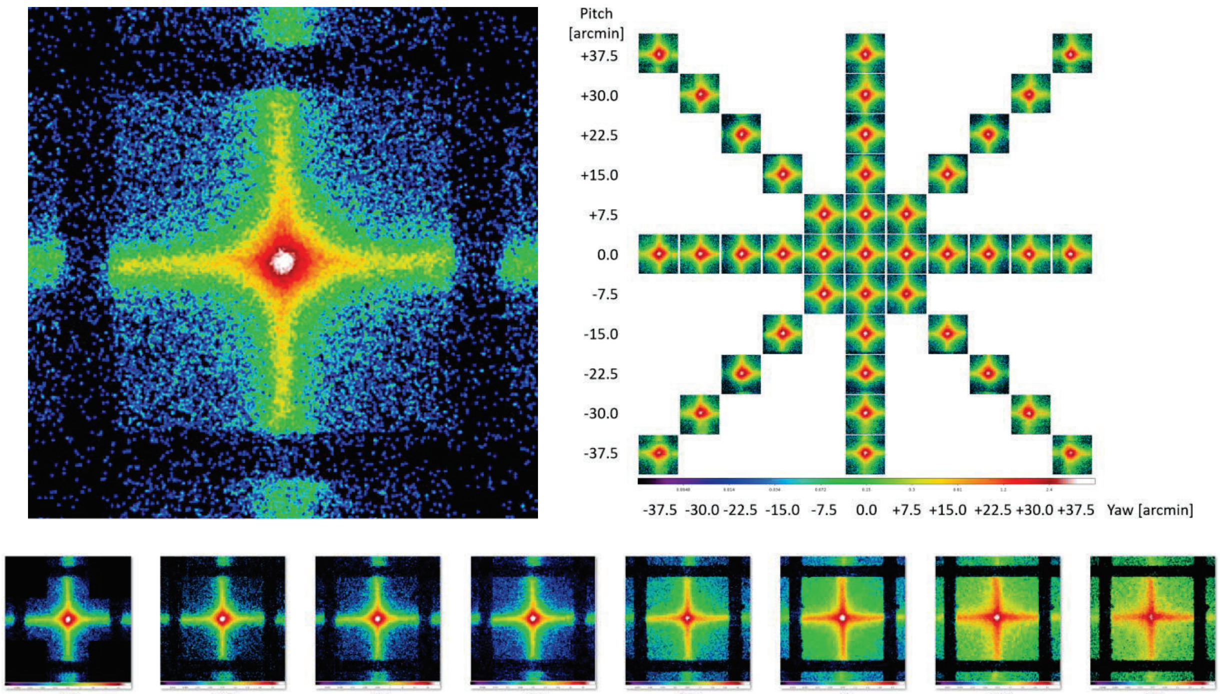

Figure 3 Measurements of the MXT-MOP-FM at Al-K (1.5 keV): (top left) a grid of 3 × 3 TRoPIC images combined to study the cross arms of the PSF in detail, (top right) a so-called focal plane map obtained to study variation of the PSF and efficiency of the optic on-axis as well as for a grid of off-axis angles. (bottom) the PSF as a function of energy is shown from left to right C-K, O-K, Cu-L, Al-K, Ag-L, Ti-K, Fe-K, Cu-K.

3. SVOM-MXT TELESCOPE PERFORMANCE TESTS AT PANTER

The goal of the SVOM-MXT tests at PANTER was to characterize the performance of the telescope by studying the on-axis and off-axis PSFs, measuring the energy-dependent efficiency (effective area) of the flight telescope under different thermal loads, with a different detector and optic temperatures, as well as testing the X-ray source localization algorithms. Furthermore, measurements with optical lasers, and laser trackers were combined with the X-ray measurements, allowing for an accurate determination of the line of sight (LOS) and characterization of optical loading on the detector [11]. In addition, a verification of the thermal properties of the telescope was possible as for these tests a liquid nitrogen cooled shroud mounted above the telescope radiator was available (see Figure 6).

At PANTER, performance tests of two different models of fully integrated SVOM-MXT telescopes were done that included the optic, the detector, the radiator, and the camera plus telescope control electronics. The first so-called "Performance-Model (PM)" test was a combination of the QM optic and an engineering model (EM) detector (see Figure 5 and Figure 6), in this model the telescope tube was made of aluminum. This PM performance test took place during the first quarter of 2020 and was completed just prior to the onset of the covid-19 pandemic. The performance test of the Flight Model (FM) (see Figure 7) took place during the last quarter of 2021 when it became possible to travel again (but still under strict covid-19 regulations). For this test, all flight Model (FM) components (optic, detector, carbon fiber telescope tube, radiator and control electronics) were used.

Table 2 Overview of the SVOM-MXT telescope tests performed at the PANTER X-ray test facility.

Telescope Performance Tests	Date	Optic	Detector	Measurements
Laser alignment Test	July 2019	---	---	Feasibility test
Performance Model (PM)	Jan. 20 – Feb 28, 2020	QM	EM	Calibration (test run)
Flight Model (FM)	Oct. 05 -Nov. 19, 2021	FM	FM	Calibration (final)

The telescope in both tests was mounted on a tip-tilt (pitch) and rotary (yaw) stage which is visible under the telescope in Figure 5 left. This pair of stages was mounted on a translation stage that allowed for a side movement to be able to access the alignment laser with the optical cubes. The coordinate system used for the telescope test is described in Figure 5 right. The layout with distances in mm is shown in Figure 4. Due to the finite distance of the X-ray source, the image in the setup forms at 1 mm intra-focal (wrt to the nominal focus for a parallel beam). To be able to determine the effective area of the telescope, a Silicon Drift Detector (SDD) was installed 35 m from X-ray source to monitor and measure the X-ray flux its location is marked in Figure 4. In Figure 8 the positions used for measuring and characterizing the PSF is documented.
The resulting effective area measured during SVOM-MXT-FM performance test is shown in Figure 9. Further results and final numbers will be presented in a paper by Diego Götz that is currently in preparation.

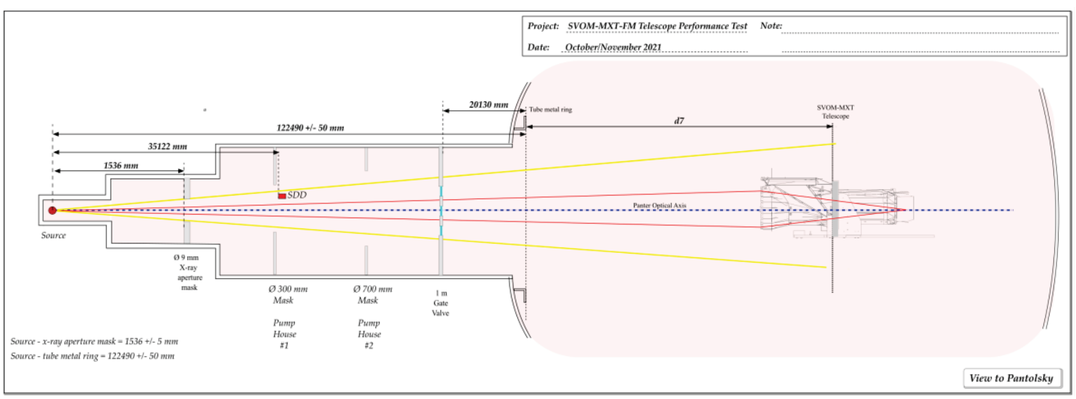

Figure 4 Diagram showing the position of the Telescope, and the measurement position d7 = 10282 ± 2 mm in the chamber.

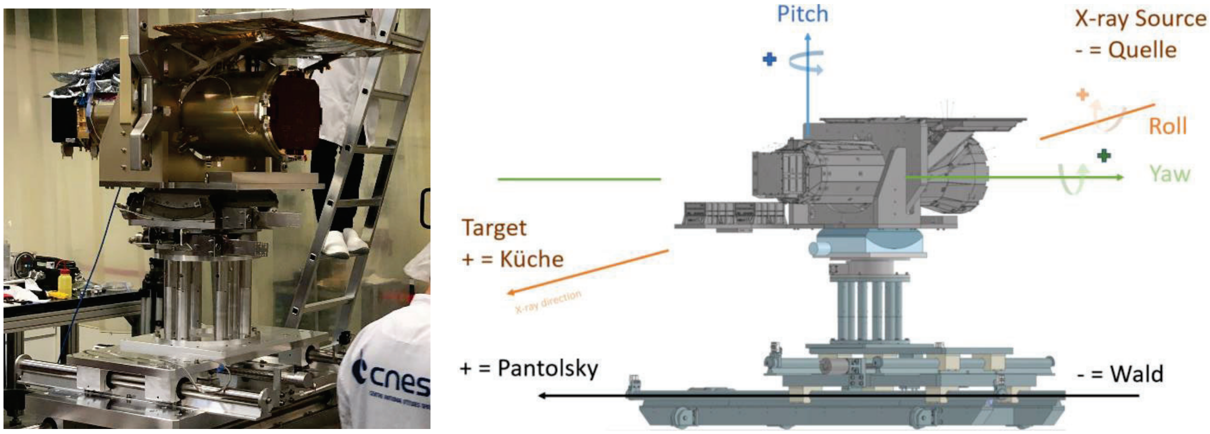

Figure 5 (left) Photograph showing the SVOM-MXT-PM model telescope being mounted onto the PANTER manipulators in the grey area. (right) shows the coordinate system used during the telescope tests.

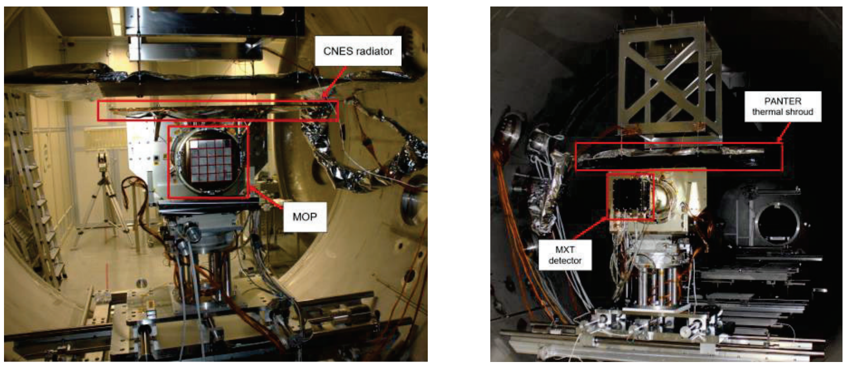

Figure 6 (left) The MXT-PM model in the chamber, with the MOP cover removed, prior to closing the chamber door and pumping down. The CNES radiator is highlighted. The laser tracker used for position measurements of the MXT-PM is visible in the background (photo taken looking from the direction of the X-ray source). (right) The detector end of the MXT-PM inside the chamber, shortly before closing the chamber and pumping down. The PANTER thermal shroud and its MLI covering are visible above the MXT-PM. The photo is taken facing the X-ray source.

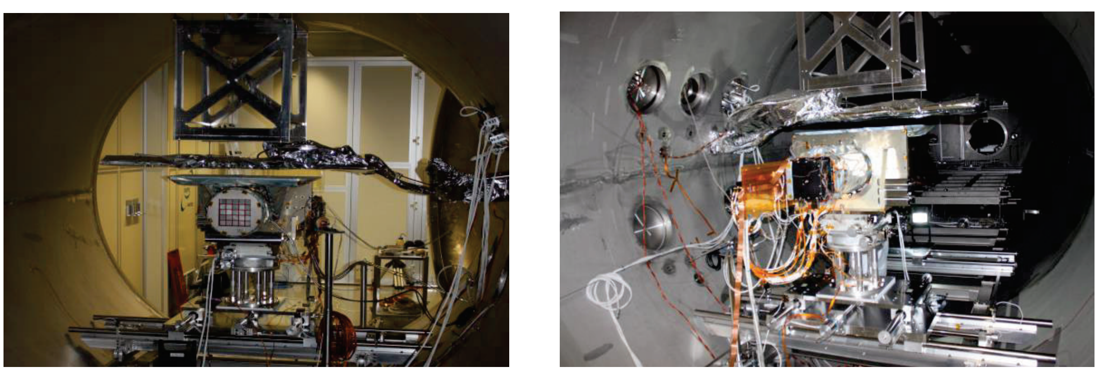

Figure 7 The PANTER thermal shroud and its MLI covering are visible above the MXT-FM. The MXT-FM model in the chamber, (left) with the MOP cover removed, prior to closing the chamber door and pumping down. Photo is taken looking from the direction of the X-ray source. (right) The detector end of the MXT inside the chamber, shortly before closing the chamber and pumping down. The PANTER thermal shroud and its MLI covering are visible above the MXT-FM. Photo is taken facing the X-ray source.

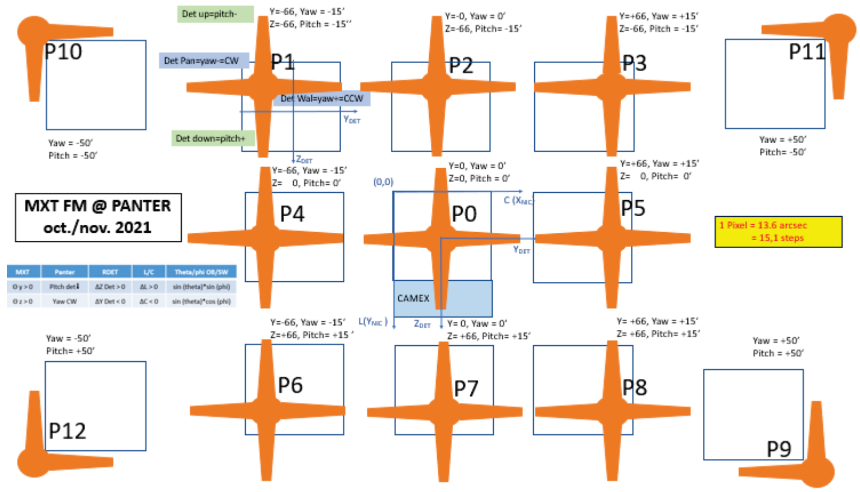

Figure 8 Measurement strategy showing the positions chosen for the location of the PSF on the detector with the corresponding pitch and yaw angles to which the telescope has to be oriented to.

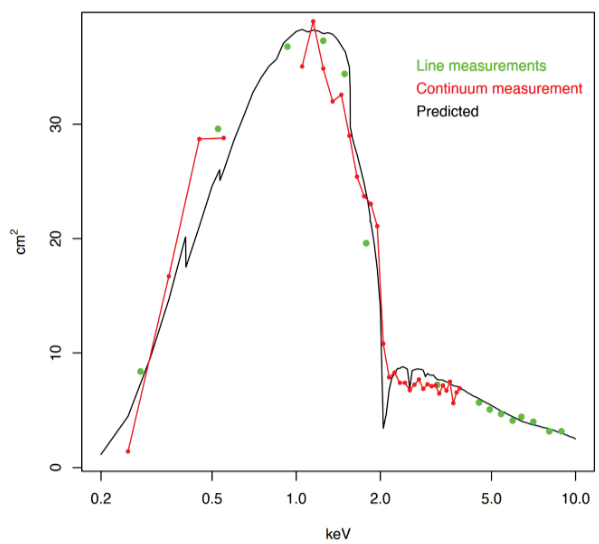

Figure 9 This plot shows the effective area of the SVOM-MXT-FM telescope as measured in PANTER during the performance tests: in green the effective area measurements at the characteristic lines of the X-ray source target elements available at PANTER, in red the continuum flux measurements and in black the effective area model prediction (image taken from [10]).

4. SUMMARY

During the last seven years multiple measurement campaigns took place at the PANTER X-ray test facility of the Max Planck Institute for Extraterrestrial Physics to follow the development and calibrate the flight and flight spare optics of the SVOM-MXT. Furthermore, two highly elaborate performance test campaigns were successfully completed at PANTER to study the on-axis and off-axis PSFs, to measure the energy-dependent efficiency (effective area) of the flight telescope under different thermal loads, test the X-ray source localization algorithms for sources on the sky, as part of proving the flight control electronics, as well as to determine the line of sight of the telescope and quantify the optical loading. Since the end of 2021 all is set to deliver the SVOM-MXT-FM telescope to China for integration into the spacecraft for a launch in 2023.

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