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# IXPE DU-FM ions-UV filters characterization

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## ABSTRACT

IXPE (Imaging X-ray Polarimetry Explorer) is a NASA Small Explorer mission in a partnership with ASI. The focal plane Detector Units and the Detector Service Unit were developed by the Italian research Institutes INAF-IAPS and INFN and were manufactured by OHB-I. The mission will allow to investigate X-ray polarimetry in the 2-8 keV energy band. The payload comprises three identical telescopes, each composed of a mirror and a detector unit (DU) with an X-ray polarimeter based on the Gas Pixel Detector (GPD). A stray-light collimator (SLC) is mounted on the top of the DU to shield the GPD from background X-rays not coming from the optics. At the bottom of the SLC, an ions-UV filter is mounted to reduce the thermal load and to prevent ions and UV from entering in the DU. The ions-UV filter is mounted on the top of venting openings needed to keep a low differential pressure on the two faces of the filter during launch. The ions-UV filters consist of 1 $\mu$m LUXFilm® polyimide with a deposition of 50 nm Al on the top side (towards the external environment) and 5 nm of amorphous C on bottom side (towards the interior of the DU), mounted on a custom aluminum frame supplied by Luxel Corp. During ground calibration activities of the IXPE DUs, X-ray transmittance of DU-FM ions-UV filters was measured with monochromatic X-ray at 2.7 keV and 6.4 keV at INAF-IAPS. Results are reported in this proceeding.

**Keywords:** IXPE, X-Ray, X-Ray polarimetry, ions-UV filter, GPD.

## 1. INTRODUCTION

IXPE is a NASA Small Explorer mission in a partnership with the Italian Space Agency (ASI), scheduled to launch in 2021.[1,2] The focal plane Detector Units (DUs) and the Detector Service Unit (DSU) were developed by the Italian research Institutes INAF-IAPS and INFN and were manufactured by OHB-I. IXPE will measure the polarization of cosmic X-ray sources (neutron stars, black hole systems, active galactic nuclei, and supernova remnants) in the 2 keV to 8 keV energy band with high significance. IXPE will open a new window in X-ray Astronomy regarding astrophysical magnetic fields and scattering geometries, adding polarization degree and angle to the space of parameters derived from timing and spectroscopy studies. IXPE's scientific payload consists of three identical telescopes, each with X-ray optics and detector separated by a deployed boom to match the telescopes' 4-m focal length. The Italian team provides the focal plane instrumentation. It comprises three flight Detector Units (DUs) and a Detector Service Unit (DSU). The DU employs a Gas Pixel Detector (GPD), a device that exploits the photoelectric effect to measure X-ray polarization, invented and developed by the Italian

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team for 20 years.[3,4] A stray-light collimator (SLC) shields the GPD inside the DU from background X-rays not coming from the optics. The driving requirements are low mass, adequate shielding, optical aperture matching with the telescope field of view, and good stiffness. At the bottom of the SLC, an ions-UV filter is mounted to reduce the thermal load and prevent UV photons and ions from entering the DU. The GPD inside the DU is powered by means of 3 high voltage stages, including the outermost entrance window and the surrounding Ti frame, making the detector highly sensitive to charged particles. Ions and electrons extracted by UV light Ions and UV photoelectrons can be accelerated in the vicinity of the detector, creating a Bremsstrahlung X-ray background immediately in front of the detector.

In the late 1970s and for many years in the 1980s, the problem of stopping UV radiation in X-ray space science was solved by using polycarbonate film, sold commercially under the trade name Lexan ($C_{16}H_{14}O_{13}$).[5] It could also be aluminum coated for infrared, optical, and UV attenuation, or to reduce surface charging, like those used in EXOSAT, ROSAT, EUVE, and Yohkoh.[6] In the 1990s, Luxel Corporation introduced polyimide film as an alternative to polycarbonate. It offers greater mechanical strength to survive the severe acoustical and vibrational loads of a rocket launch, improved temperature stability, and better effectiveness in blocking unwanted ultraviolet radiation and visible light compared to polymeric films previously employed, but still possess high transmission to soft X-ray (0.1 to 10 keV) radiation.[7] Since then, most of the satellite and ISS X-Ray experiments have used polyimide films, including the Advanced X-ray Astrophysics Facility (AXAF/Chandra), the X-Ray Spectrometer (XRS) on Astro-E/Suzaku, the Advanced Composition Explorer (ACE), and the Geostationary Operational Environmental Satellite (GOES), NICER, ASTRO-H, etc.

The IXPE DU-FM ions-UV filters are purchased from Luxel Corporation. The design (see Figure 1) is based on the scientific requirements of the mission and it is in accordance to the Luxel Corp. expertise and long heritage. It comprises a 1 $\mu$m thick LUXFilm® polyimide with a deposition of 50 nm Al (top side towards the external enviroment) and 5 nm of amorphous C (bottom side towards the interior of the DU) mounted on a custom two-part aluminum frame (see Figure 2). The frame anodization is Trivalent Chromium Pretreatment - Hexavalent Free (TCP-HF) and the film is electrically grounded to it on both sides. The filter has a circular aperture with a diameter of 32.50 mm. The ions-UV filter is mounted on the top of venting openings (see Figure 3), which reduces the differential pressure across the filter during launch.

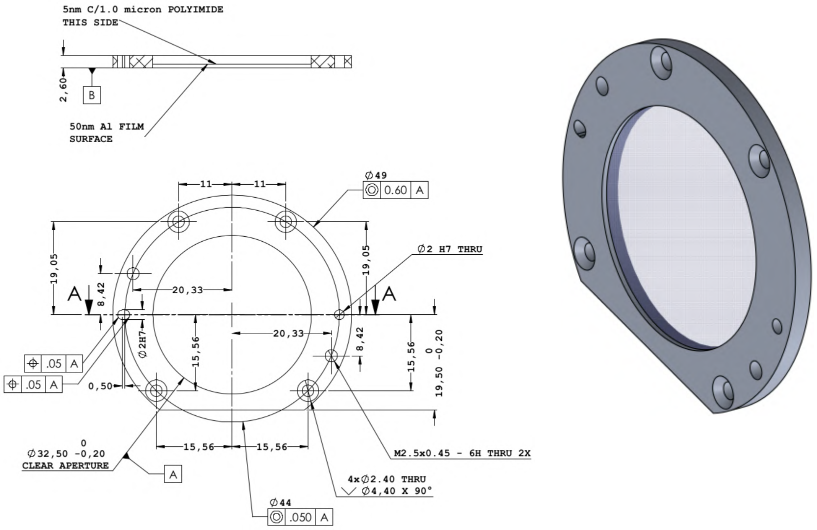


Figure 1: Drawing of the IXPE DU-FM ions-UV Filter. (All dimensions are in millimeters.)

## 2. IONS-UV FILTER QUALIFICATION

The IXPE DU ions-UV filters underwent acceptance and qualification at unit level in compliance with the Environmental Design and Test Specification (EDTS) for IXPE Spacecraft components. As required by the

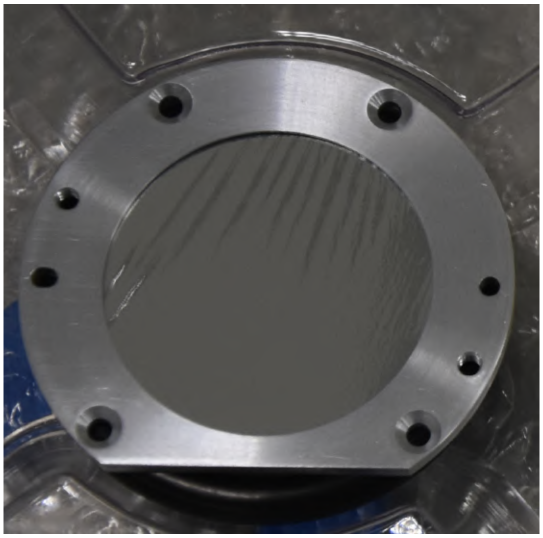


Figure 2: The DU flight model ions-UV Filter. The wrinkles on the filter film are due to air humidity.

EDTS, the acoustic qualification was done through the application of random vibrational loads. The proto-flight vibration test on the units was concluded successfully and the structural requirements were verified.[8] No damage has been detected by the visual inspection performed after each axis vibration.

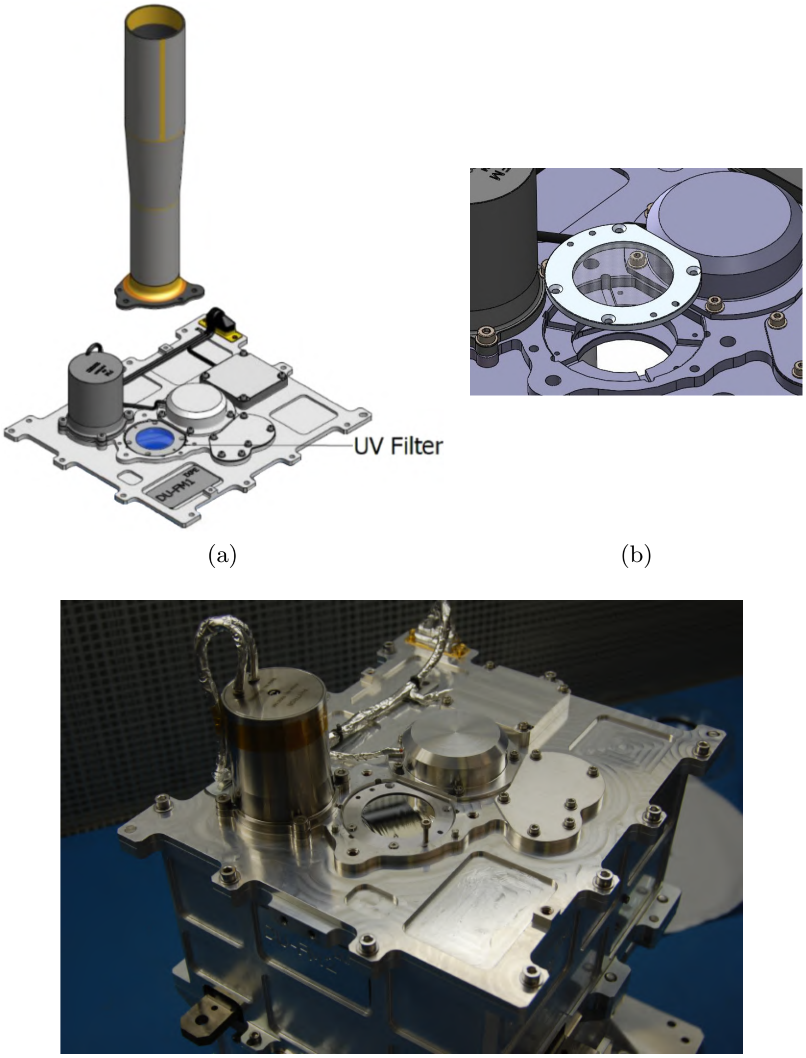
The X-rays transmittance was measured at INAF-IAPS for all the filters listed in Table 1, where the material composition and thickness are also reported for each filter. Luxel Corp. measured the transmission of visible light of ions-UV filters (see Table 3) with its Transmission Imaging Photometer (TIP). The TIP directly compares the intensity of a diffuse broadband visible (400 nm to 700 nm) light source both unattenuated and attenuated by each ions-UV filter for a high-sensitivity, spatially-resolved transmittance measurement. Figure 4 shows the transmission images, acquired by Luxel Crop., at the visible light of the 3 ions-UV filters mounted on the DUs-FM. No relevant defects are highlighted.

Table 1: ions-UV filters identification codes and material thicknesses with tolerances.

| Ions-UV Filter Serial Number | IXPE DU-FM | Aluminum Thickness ± Tolerance (nm) | LUXFilm® Thickness ± Tolerance (nm) | Carbon Thickness ± Tolerance (nm) |
|---|---|---|---|---|
| 38560-1A | | 49.8 ± 5.0 | 1045.5 ± 5.0 | 5.3 ± 2.5 |
| 38560-1B | | | | |
| 38560-2A | DU-FM3 | | 1049.0 ± 5.0 | |
| 38560-2C | DU-FM4 | | | |
| 38560-2D | DU-FM2 | | | |

## 3. EXPERIMENTAL SET-UP FOR MEASURING THE X-RAY TRANSMISSION

Ions-UV filter transmittance measurements were performed at INAF-IAPS with the Instrument Calibration Equipment (ICE).[9,10] This is a customized facility developed at INAF-IAPS to perform the on-ground calibration of the IXPE DUs, and it is installed in an ISO 7 (10,000 class) cleanroom. ICE provides X-ray beams of know energy, polarization degree and angle. The X-ray beam and the DU are aligned by means of micrometric movement stages. The ICE comprises off-the-shelf auxiliary detectors: a Silicon Drift Detector (SDD) spectrometer and a Charge Coupled Device (CCD) to fully characterize the energy and the shape of the beam.



(a) (b)

(c)

Figure 3: (a) Drawing of the top lid of the DU with SLC. (b) Drawing of DU-FM venting aperture on which the ions-UV filter is mounted. (c) DU-FM ions-UV filter mounted on DU-FM 2.

The X-ray transmittance of the ions-UV filters was measured with monochromatic X-rays at 2.7 keV and 6.4 keV. It is computed as the ratio of the integrated count rates recorded by an Amptek XR100-SDD detector illuminated by the X-ray source with and without the ions-UV filters interposed in between. The monochromatic X-rays are obtained through Bragg diffraction on crystals at nearly 45 degrees.[11] The energy E of diffracted photons must satisfy the Bragg condition:

$$E = \frac{nhc}{2d\,sin\theta}, \tag{1}$$

where $h$ and $c$ are respectively Planck's constant and the speed of light, $d$ the crystal lattice spacing and $n$ the diffraction order. If $\theta \approx 45°$, the spectrum is composed of equally spaced, nearly monochromatic and polarized lines corresponding to the various orders of diffraction $n$. Lines at different energies can be obtained by choosing different lattice spacing. X-rays are generated with commercial X-ray tubes (Oxford Series 5000) and the diffraction angle is chosen to diffract a fluorescence line produced by the X-ray tube (see Figure 5). In this case, the polarization angle is well-defined, and the polarization degree can be calculated from reflectivity values in the literature.[12] Collimators are mounted to constrain the incident and the diffracted direction of X-rays.

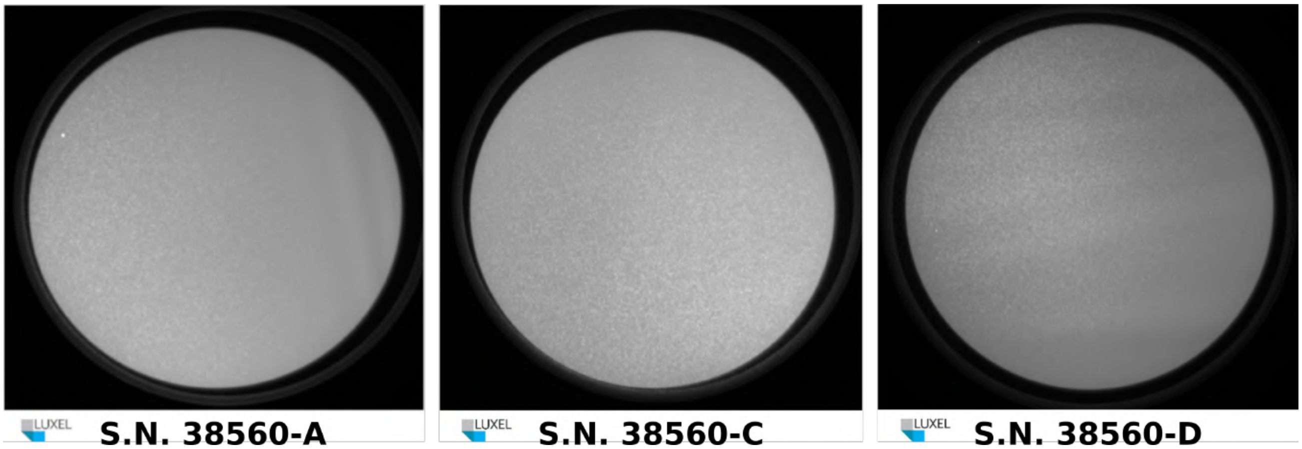
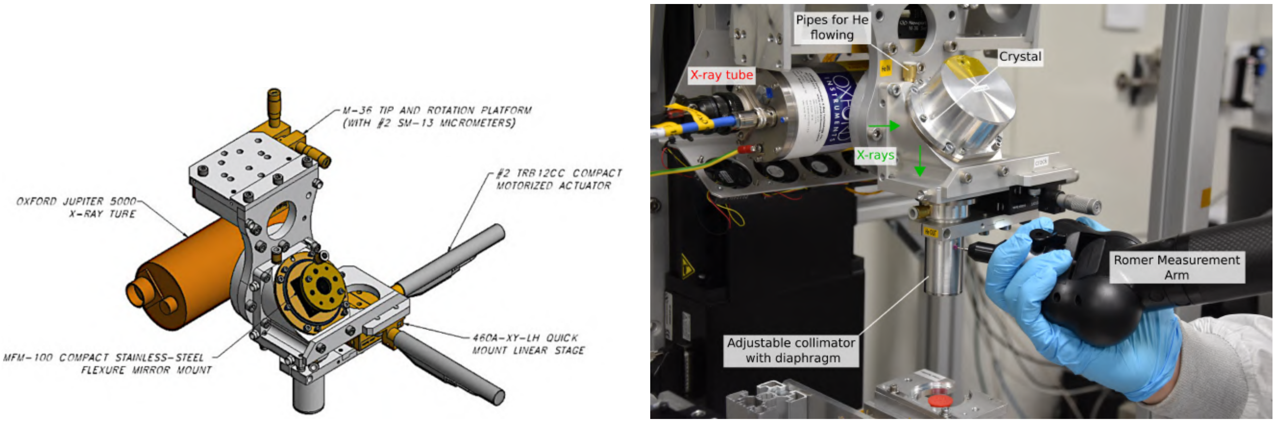


Figure 4: Transmission images at the visible light (400 nm to 700 nm) of the ions-UV filters. The filter S.N. 38560-2A is mounted on DU-FM3, the filter S.N. 38560-2C is mounted on DU-FM4 and the filter S.N. 38560-2D on DU-FM2.



(a) (b)

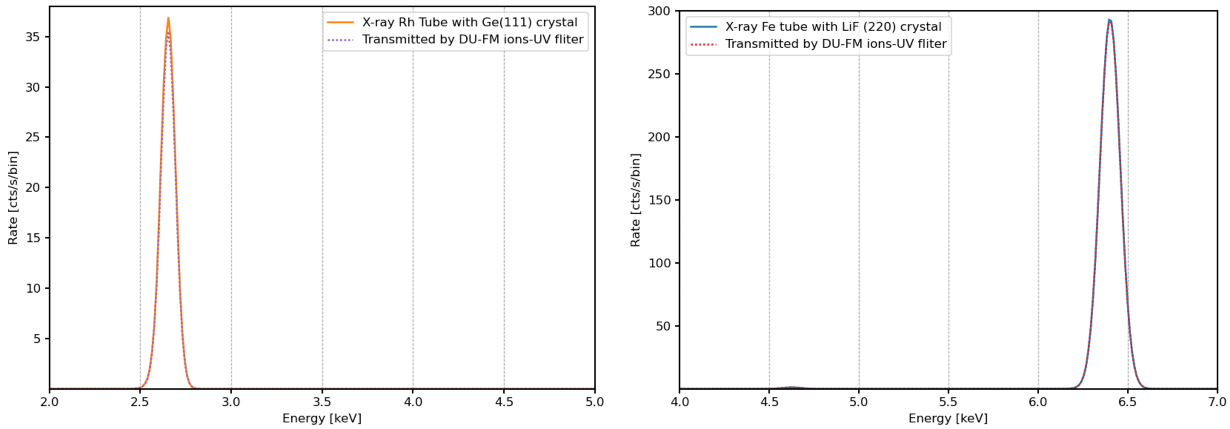
Figure 5: (a) Sketch of the source used to produce polarized X-rays. (b) The polarizer X-ray source used to measure the transmittance of ions-UV filters. In the picture is also possible to see the tip of the Romer measurement arm used to perform the alignment.

The crystal is mounted on a tip-tilt stage, which allows for its alignment to input and output collimator. A set of diaphragms with different diameters are mounted in front of the X-ray tube spot to limit X-rays scattering inside the source or on the diffracted beam to reduce its size. When the X-ray tube's fluorescence line energy is tuned with the crystal, only the diffracted line is present in the energy spectrum. A collimator is used to select a portion of the diffracted beam. For the sources used to measure the transmittance, a diaphragm of 400 $\mu$m is placed at the output of the polarizer, while a lead glass capillary plate (1/40 as collimation ratio) is added at the output before the diaphragm to reduce background due to scattering in the polarizer. To obtain monochromatic X-rays at 2.7 keV and 6.4 keV, the crystals employed are Ge (111) and LiF (220), respectively. Table 2 reports the energy of the diffracted line, the lattice constant, and the Bragg angle of diffraction for the two used crystals.

The spectra of the sources are shown in Figure 6. The measurements were performed with helium flowing in a transparent plastic box to have a dry environment around the ions-UV filter and remove the wrinkles of the filter film due to humidity (see Figure 7). When the helium saturates the volume around the ions-UV filter, the wrinkles flatten. Since the transmittance is measured by dividing the count rate with and without the filter, the

Table 2: List of the crystals used to test transmittance.

| Crystal | X-ray tube | Energy [keV] | 2d [Å] | Diffraction Angle [deg] |
|---|---|---|---|---|
| Ge (111) | Rh $L_\alpha$ | 2.7 | 6.532 | 44.877 |
| LiF (220) | Fe $K_\alpha$ | 6.4 | 2.848 | 42.859 |



(a)

(b)

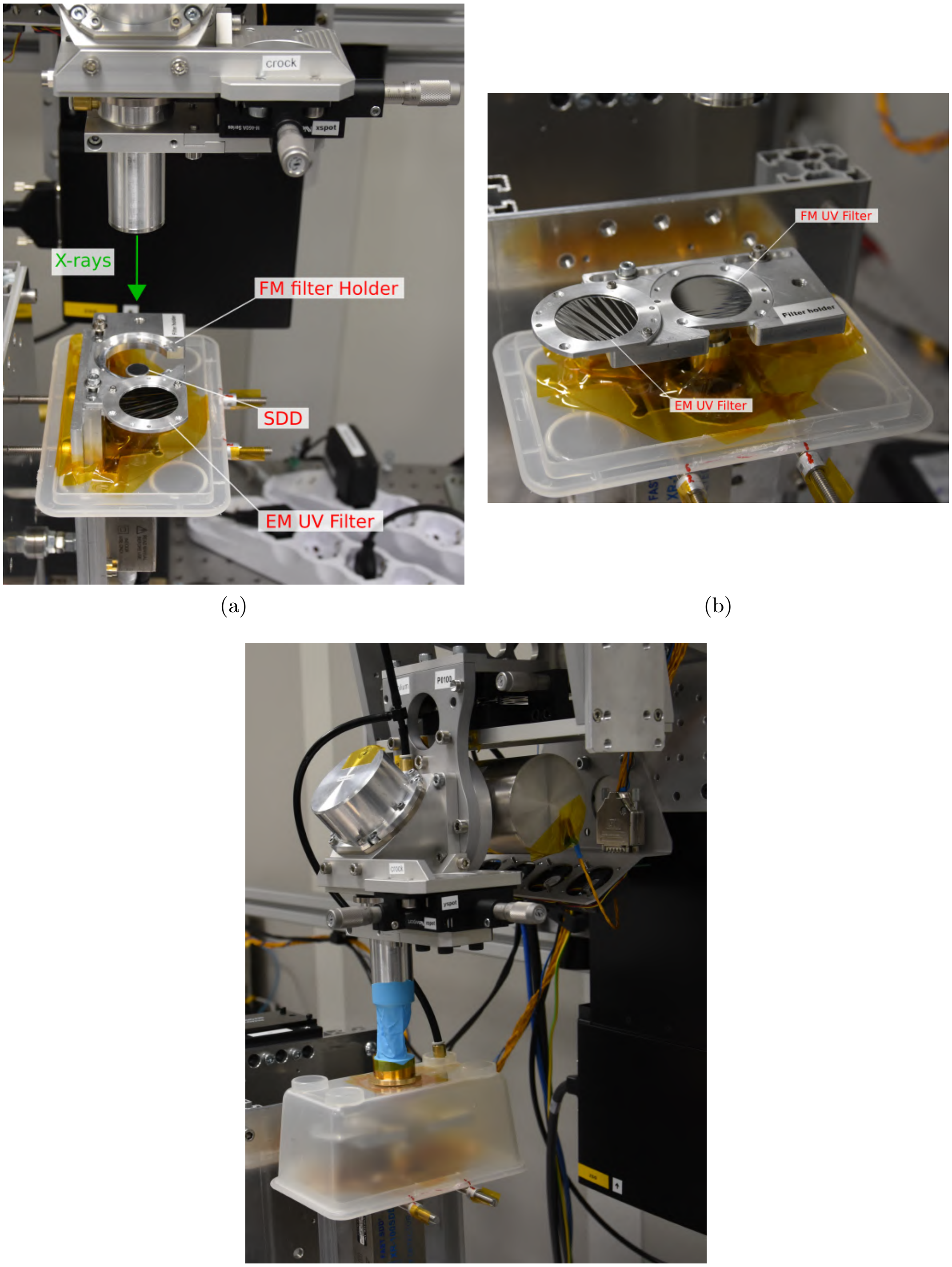
Figure 6: (a) The spectrum of the source at 2.7 keV (X-ray tube with Fe anode diffracted by LiF(220) crystal) and the relative spectrum transmitted by one of the tested ions-UV filters. (b) The spectrum of the source at 6.4 keV (X-ray tube with Rh anode diffracted by Ge(111) crystal) and the relative spectrum transmitted by one of the tested ions-UV filters.

same helium concentration has to be ensured. Therefore, a reference engineering Model (EM) ions-UV filter was placed in the flowing box beside the FM filter holder (see Figures 7a and 7b). When there is no FM filter and the wrinkles flatten on the EM filter, it is assumed that the same concentration of He is reached. However, what is relevant is not the absolute helium concentration in the flowing box, but the repeatability of the conditions. Indeed, an extra time of 1 minute was waited since the SDD Be window is about 10 mm below the filter film. The helium also flows in the polarizer, and the output collimator is joined to the entrance hole of the plastic flowing box (see Figure 7c).

## 4. STABILITY OF COUNT RATE AND TRANSMITTANCE MEASUREMENTS

A variation of the count rate of the source could affect the measurement of transmittance. During the test, the X-ray source was turned on and off. Thus, we estimated its stability.

For the source at 2.7 keV, we first checked the temporal trend of the count rate of the source without turning it off for ∼12h, integrating each single measurement for 15 minutes and collecting the same number of counts of the acquisition with the ions-UV filters ($2 \cdot 10^5$ counts). The time trend of the count rate is shown in Figure 8, and it can be fitted with a constant. It means that, for this source, there is no substantial variation of the flux with time. A second set of measurements ($2 \cdot 10^5$ counts for each one of them) is obtained turning on and off the X-ray tube (see Figure 9). Also in this case the count rate remains constant between the various measurements, confirming that the system is stable to power cycling and warm-up times. Since transmittance is defined as the ratio of the count rate measured when the ions-UV filter is in between the source and the detector and the count rate of the source alone, the second set of measurements was also used to estimate the reference count rate of the X-ray source, with its uncertainty estimated as the standard deviation of the measured values. This accounts for



(a)

(b)

(c)

Figure 7: (a) EM ions-UV filter placed beside the position where the FM ions-UV filters are placed between the SDD detector and the output collimator of the X-ray source. (b) One of the tested FM ions-UV filter mounted on the holder aside the EM ions-UV filter. (c) The complete set-up for the measurement of the ions-UV filter transmittance with the helium flowing box closed.

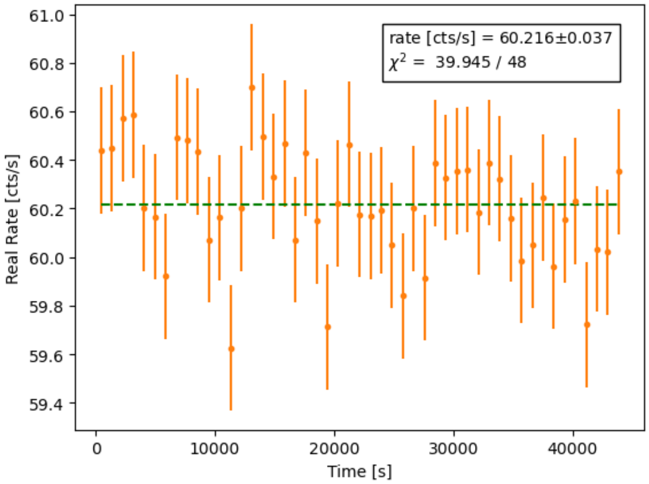


Figure 8: Series of measurements by integrating for 15 minutes without the turn off of the source at 2.7 keV and collecting about the same number of counts (2x$10^5$ counts) of the acquisition when the ions-UV filters are placed between the source and the detector. The time trend of the count rate shows no change with time.

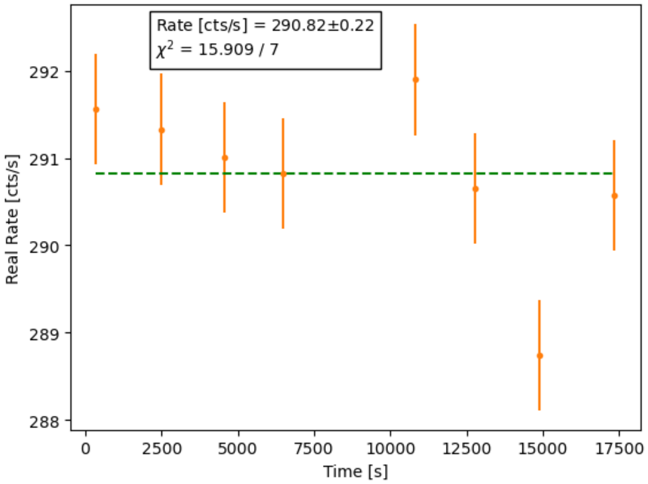


Figure 9: Set of measurements of 2.7 keV count rate in between the acquisition with ions-UV filters, collecting approximately the same number of counts (2x$10^5$ counts). Therefore, the time intervals during which the source is turned off are similar to those ones of the measurements with the ions-UV filters placed between source and detector.

systematic errors of the measurement set-up. An example of transmission energy spectrum by one of the tested ions-UV filters at 2.7 keV is shown in Figure 6a. The plot of the expected transmittance of an IXPE DU-FM ions-UV filter is shown in Figure 10. In the IXPE's energy band (2 keV to 8 keV) the transmittance ranges from 91.5% to 99.8%. The transmittance expected values are calculated by the tabulated values for the cross section of the interactions in the materials of the ions-UV filters, considering their thicknesses.[12] The measured value of the transmittance is reported in Table 3 and it is compared with the calculated expected value, considering the different thicknesses of the materials with their respective tolerances.[12] The table also shows the value of transmittance at visible light, measured by Luxel Corp.

The stability of the X-ray source at 6.4 keV was assessed with a first set of measurements by collecting the same number of counts as for the acquisition with the ions-UV filters ($3 \cdot 10^6$ counts) performed by turning off the X-ray tube for 2 minutes. Therefore, the time intervals during which the source is turned off are similar to

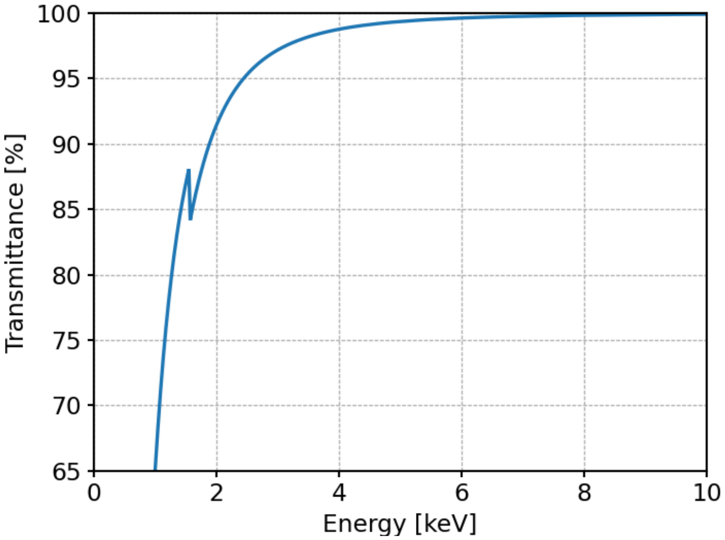


Figure 10: The expected transmittance of an IXPE DU-FM ions-UV filter.[12]

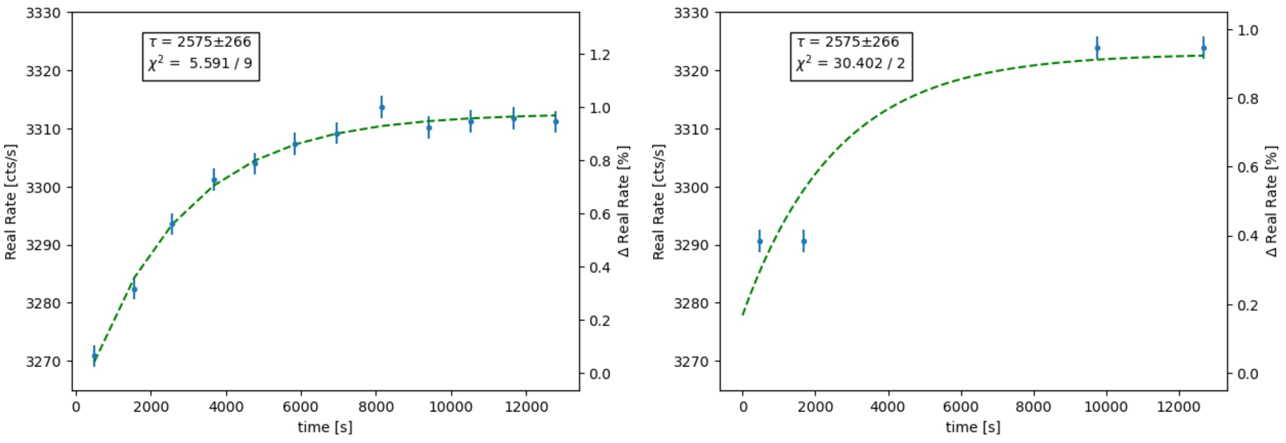
Table 3: Summary of measured X-ray transparencies compared with theoretical values. Also transmittance at visible light measured by Luxel Corp. is reported.

| Ions-UV Filter Serial Number | Transmittance [%] | | | | |
|---|---|---|---|---|---|
| | @ visible light (Meas. by Luxel Corp.) | @ 2.7 keV | | @ 6.4 keV | |
| | | Measured | Expected | Measured | Expected |
| 38560-1A | $4.27 \cdot 10^{-2}$ | $95.88 \pm 0.44$ | 96.06 - 96.37 | $99.44 \pm 0.14$ | 99.69 - 99.71 |
| 38560-1B | $4.77 \cdot 10^{-2}$ | $96.15 \pm 0.44$ | 96.06 - 96.37 | $99.29 \pm 0.14$ | 99.69 - 99.71 |
| 38560-2A | $4.68 \cdot 10^{-2}$ | $96.06 \pm 0.44$ | 96.06 - 96.36 | $99.26 \pm 0.14$ | 99.68 - 99.71 |
| 38560-2C | $4.87 \cdot 10^{-2}$ | $95.64 \pm 0.44$ | 96.06 - 96.36 | $99.01 \pm 0.14$ | 99.68 - 99.71 |
| 38560-2D | $5.65 \cdot 10^{-2}$ | $96.11 \pm 0.44$ | 96.06 - 96.36 | $99.89 \pm 0.14$ | 99.68 - 99.71 |

those needed to substitute the ions-UV filter when transmittance is measured. The count rate's time trend is shown in Figure 11a, and, contrary to the source at 2.7 keV (see Figure 9), it is not constant. Therefore, we fitted the data points with an exponential function ($a(1 - e^{-t/\tau}) + b$) to measure the time constant of the X-ray tube. A second set of measurements is obtained between the acquisition with some ions-UV filter, collecting the same number of counts ($3 \cdot 10^6$ counts) (see Figure 11b). Only a few points were acquired. For this second set of measurements, the time trend is fitted with an exponential function with the time constant $\tau$ obtained from the previous fit. This second fit function is used to estimate the reference count rate at the time of the measurements with the ions-UV filters. The uncertainty of the reference rate is taken as the standard deviation of points with respect to the expected values computed by the fit of the function. These reference count rates are used to obtain the value of the transmittance at 6.4 keV, as shown in Table 3. Also for this energy, the transmittance is compared with the expected value calculated by the tabulated values for the cross section of the interactions in the materials of the ions-UV filters.[12] An example of the spectrum transmitted by one of the tested ions-UV filters at 6.4 keV is shown in Figure 6b.

## 5. CONCLUSION

During the on ground calibration activities of the IXPE detector units performed at INAF-IAPS, the X-ray transparencies of the DU-FM ions-UV filters were measured with monochromatic radiation at 2.7 keV and 6.4



(a) (b)

Figure 11: (a) Series of measurements obtained at 6.4 keV by collecting the same number of counts of the acquisition with the ions-UV filters ($3 \cdot 10^6$ counts) and a time interval of 2 minutes during which the X-ray source is turned off. They are fitted with an exponential function to obtain the time constant. (b) Reference measurements acquired in between the acquisitions with some ions-UV filters collecting the same number of counts ($3 \cdot 10^6$ counts). The fit function is an exponential function with time constant $\tau$ that obtained by the previous fit.

keV. The transparencies are compatible with respect to the nominal values, including the mechanical tolerances of the thicknesses of the materials.

## ACKNOWLEDGMENTS

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