Publication Year	2022
Acceptance in OA@INAF	2023-06-21T15:45:39Z
Title	The Space Weather X-Ray spectrometer for the Helianthus sub-L1 mission with solar photonic propulsion
Authors	NOCE, Vladimiro; VARISCO, Salvatore; LANDINI, FEDERICO; HAUDEMAND, HERVÈ; CANDIA, Roberto; et al.
DOI	10.1117/12.2645141
Handle	http://hdl.handle.net/20.500.12386/34249
Series	PROCEEDINGS OF SPIE
Number	12181

The space weather x-ray spectrometer for the Helianthus sub-L1 mission with solar photonic propulsion

Vladimiro Noce, Salvatore Varisco, Federico Landini, Hervé Haudemand, Roberto Candia, et al.

Vladimiro Noce, Salvatore Varisco, Federico Landini, Hervé Haudemand, Roberto Candia, Marco Barbera, Ugo Lo Cicero, Fabio Frassetto, Luca Zangrilli, Valeria Caracci, Davide Loreggia, Alfonso Collura, Silvano Fineschi, Rocco Pellegrini, Enrico Cavallini, Marco Pizzarelli, Christian Circi, "The space weather x-ray spectrometer for the Helianthus sub-L1 mission with solar photonic propulsion," Proc. SPIE 12181, Space Telescopes and Instrumentation 2022: Ultraviolet to Gamma Ray, 121815V (31 August 2022); doi: 10.1117/12.2645141

Event: SPIE Astronomical Telescopes + Instrumentation, 2022, Montréal, Québec, Canada

The Space Weather X-Ray spectrometer for the Helianthus sub-L1 mission with solar photonic propulsion

Vladimiro Noce[a], Salvatore Varisco[b], Federico Landini[c], Hervé Haudemand[c], Roberto Candia[b], Marco Barbera[d,b], Ugo Lo Cicero[b], Fabio Frassetto[e], Luca Zangrilli[c], Valeria Caracci[c], Davide Loreggia[c], Alfonso Collura[b], Silvano Fineschi[c], Rocco Pellegrini[f], Enrico Cavallini[f], Marco Pizzarelli[f], and Christian Circi[g]

[a]INAF - Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, Firenze, Italy
[b]INAF - Osservatorio Astronomico di Palermo, Via Gian Filippo Ingrassia 31, Palermo, Italy
[c]INAF - Osservatorio Astrofisico di Torino, Via Osservatorio 20, Pino Torinese, Italy
[d]UNIPA - Dipartimento di Fisica e Chimica - E. Segrè, Via Archirafi 36, Palermo, Italy
[e]CNR - Institute for Photonics and Nanotechnologies, Via Trasea 7, Padova, Italy
[f]ASI - Italian Space Agency, Via del Politecnico, Roma, Italy
[g]La Sapienza University, Dipartimento di Ingegneria Astronautica, Elettrica ed Energetica (DIAEE) Via Eudossiana, 18, Roma, Italy

ABSTRACT

Helianthus is a phase A study of a space weather station with solar photonic propulsion. The scientific payload will be made of: an X-ray spectrometer to detect solar flares; SailCor, a coronagraph with a wide field of view; a plasma analyzer; a magnetometer. The maximum allowed mass for the entire scientific payload shall not exceed 5 kg. The two imaging devices (coronagraph and X-ray spectrometer) are of fundamental importance for the sake of remotely and timely mapping the status of the Sun and provide Earth stations with early warning of potentially disruptive events.

An extensive research on available X-Ray detectors was performed and the Amptek FAST-SDD spectrometer was selected. It is a very light, compact and vacuum compatible instrument. In order to prove the device readiness for flight, a measurement campaign was organized to investigate its performance in terms of spectral range, spectral resolution, dynamic range and response speed. The campaign was run at the INAF XACT facility in Palermo (Italy). This paper describes the facility, the measurement campaign and the results.

Keywords: Solar Flares, Space Weather, X-Ray Solar Corona, X-Ray sources, X-Ray facilities, X-Ray filters

1. INTRODUCTION

The activity of our star is deeply influencing life and technology on Earth and its environment. Many energetic events that are occurring in the solar atmosphere, like flares or coronal mass ejections (CMEs) generate high speed particle fluxes (around 500 km/s) that both affect satellites in geostationary orbits or penetrate the magnetosphere down to the ionosphere, thus generating the so-called geomagnetic storms. One of the typical consequences of such storms is the Earth telecommunication black-out that can last many hours (impact on radio, television, mobile phone networks, part of the internet, GPS, satellites, electrical networks). All hardware and software systems designed to contain the potential damage due to geomagnetic storms are based on the storm forecasting. The longer the forewarning time, the lower the level of actual damage. In order to confer continuity and reliability upon forecasting capabilities, information from many solar observatories are used: the era of a new science segment, the so-called Space Weather, has been inaugurated. So far, all observatories are

---

Further author information: (Send correspondence to F.Landini or V.Noce)
e-mail: federico.landini@inaf.it, telephone: +39 055 275 5221
e-mail: vladimiro.noce@inaf.it, telephone: +39 055 275 2240

Space Telescopes and Instrumentation 2022: Ultraviolet to Gamma Ray, edited by Jan-Willem A. den Herder,
Shouleh Nikzad, Kazuhiro Nakazawa, Proc. of SPIE Vol. 12181, 121815V · © 2022 SPIE ·
0277-786X · doi: 10.1117/12.2645141

Earth based or installed on satellites in geostationary orbits or in the Lagrangian point L1.

Helianthus is a technological development program of the Italian Space Agency (ASI), dedicated to the feasibility study of a *sailcraft*,[1] a spacecraft with solar photonic propulsion,[2] kept in an artificial equilibrium point (a Moon-Earth synchronous orbit at 7 Millions km from the Earth towards the Sun).[2] For in-situ instrumentation this is a highly convenient location with respect to instrumentation in L1 or in geostationary orbit. In fact, for Space Weather purposes, there is an advance of at least 2 hours in geomagnetic storm forecasting.
The Helianthus scientific payload is composed of 4 instruments:

1. X-Ray spectrometer for solar flares detection, subject of this work;
2. SailCor, a wide field-of-view, solar coronagraph with an extensible *boom*;[3]
3. Plasma analyzer, to provide in-situ analysis of the heliospheric plasma;
4. Magnetometer, to monitor the solar magnetic field.

Due to the peculiarity of the mission, the scientific payload shall respect very strict constraints on mass and dimension. In order not to jeopardize the sailcraft orbit, the whole scientific payload weight shall be kept within 5 kg.
Dedicated investigations are ongoing for each instrument in order to provide solutions that satisfy scientific requirements while matching the mass constraint.
This paper is dedicated to the activity that has been carried out to select and characterize the X-Ray spectrometer.
The device under investigation will be used to detect solar flares, whose characteristics are summarized in section 2. Section 2.1 describes the requisite of the X-Ray spectrometer in order to pursue the flare detection objective. The selected device is described in section 3. The test campaign has been run at the XACT (X-ray Astronomy Calibration and Testing) facility in Palermo, Italy that is outlined in section 4. Materials and methods used for the tests are listed and detailed in section 5, while the results are presented in section 6.

2. SOLAR FLARES

The solar corona is the outer Sun atmosphere and its temperature is about 3 orders of magnitude higher with respect to the underlying photosphere ($\gtrsim 10\ MK$). The hot solar corona is the origin of almost all the geo-effective events generated on the Sun. The X-ray emission spectrum is particularly sensitive to the coronal high-temperature plasma and is therefore a fundamental diagnostic tool for monitoring coronal temperature and elemental abundances behaviour.

Solar flares are coronal phenomena characterized by a rapid energy release. Large flares are often followed by CME (Coronal Mass Ejections) that eject large amount of plasma particles in the heliosphere.[5] Detecting the X-ray emission spectrum[6] is an optimal diagnostic tool for monitoring coronal temperature and elemental abundances, anticipating solar flares occurrences.

2.1 Flare detection in X-Ray

As shown by Woods et al.,[4] solar flares in soft X-Rays may cause an emission increase of about 2 orders of magnitude, while the quiet solar corona emission in the same spectral band is covering about 4 orders of magnitude. An X-Ray spectrometer able to detect solar flares in soft X-Rays shall therefore be able to cover about 6 orders of magnitude. The same paper shows that typical soft X-Rays emission lines during solar flares are characterized by a FWHM of about 250 eV. Thus, the SensorX spectral resolution must be sufficient to distinguish the characteristic spectral lines[7] (such as CaXIX, FeXXV or FeXXVI, see Figure 1).

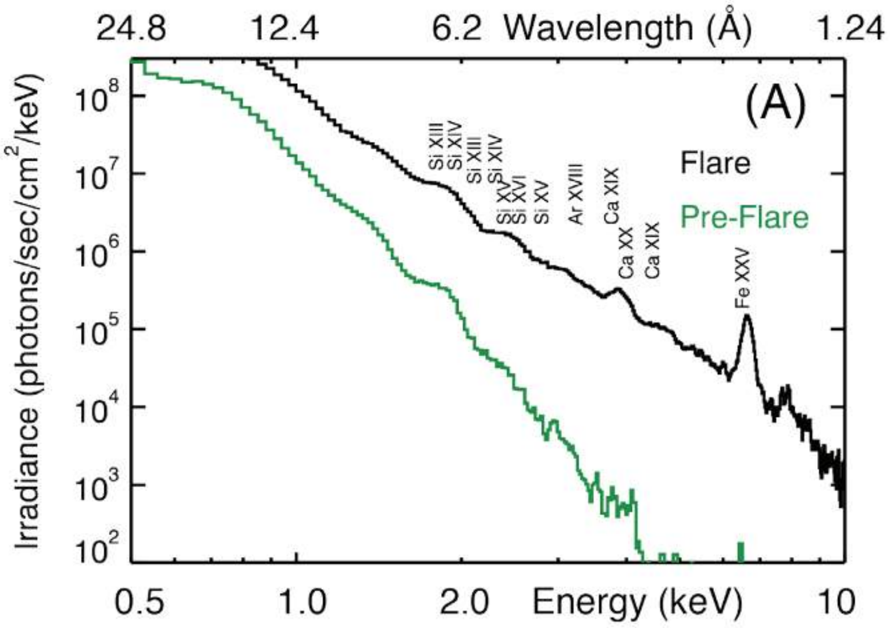


Figure 1: X-ray Sun emission before and after a solar flare (from Woods et al.[4]).

3. THE X-RAY SPECTROMETER

Our group performed an extensive research on available X-Ray detectors to identify the type of sensor that better fits the requirements for the Helianthus payload. The Amptek FAST-SDD (Silicon Drift Detector)[8] spectrometer was chosen due to several reasons:

- It is a light and compact instrument, fully vacuum compatible;
- It has already been used in several space missions[9];[10]
- It is provided with a complete acquisition system.

The FAST-SDD version we adopted has a sensitive area of 25 mm^2 surface (17 mm^2 effective), a Si absorber with a depth of 500 µm and a 12.5 µm (0.5 mils) thick Beryllium window.

Both these characteristics contribute to determine the energy interval of detectable photons, see Figure 2. The thickness of the front window (and its material) has an influence on the low energy side (blue curve on the left), while the depth of the Silicon substrate determines the maximum energy that can be detected (blue curve on the right). The combination of these characteristics in our detector is a trade-off between robustness of the detector and the range of energies needed for our purposes.

In order to reduce the thermal noise, the sensor is usually operated at temperatures between -50°C and -60°C. FAST-SDD sensor has the advantage to have a Peltier cell integrated under its substrate so not needing an external cooler to work properly (see Figure 3 right panel).

3.1 X-123

The control and acquisition system, called X-123, allows to interface the sensor to an ordinary PC by means of USB, Ethernet or RS232.

The Amptek X-123 system, supporting (between others) the FAST-SDD sensors, is composed of:

1. A preamplifier, in an Aluminium structure, holding the sensor, too, that amplifies the sensor signal to match the ADC input dynamics;

2. An analog filter that reduces the electronics noise and that is, in turn, composed by
   (a) Unity gain buffer, uncoupling impedances;
   (b) High pass filter;
   (c) Integrating filter; inverts the signal, sets the offset voltage and eliminates the noise generated from previous stages;
3. 12-bit DC ($> 20\ MHz$);
4. A sensor supply voltage section (PC5), including the High Voltage generation (150 V, 25 µA);
5. A Digital Pulse Processor to treat and analyze the digital signal (DP5X)

Figure 4 describes the signal processing by X-123 system.

The free data acquisition program (DPPMCA) is a MCA (Multi-Channel Analyzer), useful to acquire spectra, but, at the same time, can be used to monitor and set sensor's parameters. A Software Development Kit (SDK) is available to create custom applications and to integrate the unit in other environments (C++, VisualBasic, LabView, etc.).

4. XACT FACILITY

The XACT (X-ray Astronomy Calibration and Testing) facility is a property of INAF-OAPa (National Institute for Astrophysics - Palermo Astronomical Observatory), located in Palermo, Italy,[11] used for the development and characterization of instruments on-board space missions devoted to Universe observation in X-ray band, to the search of exoplanets and to the study of Sun corona and chromosphere.

It has a 35 meter long beam-line, for measurements and calibration in the soft ($0.1 - 20\ keV$) X-ray band, consisting in: a multi-anode X source, a monochromator, the pipeline, a chamber to test grazing incidence telescopes and a chamber for detectors testing (Fig. 5).

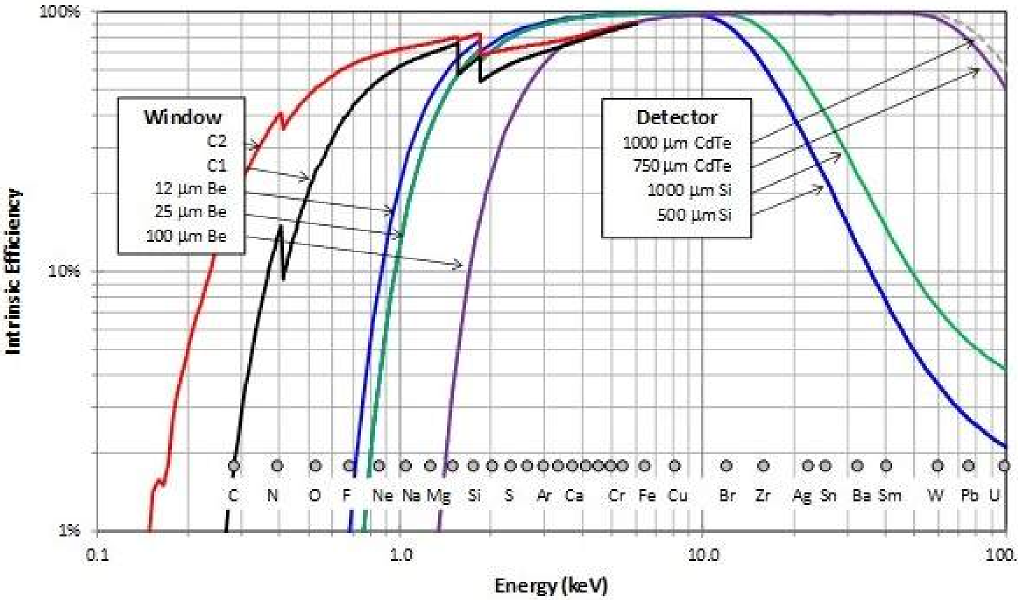


Figure 2: Efficiency of Amptek sensors in function of the energy for different windows defining the low energy responce (left) and absorbers defining the high energy responce (right). The sensor subject of this work is represented by the blue curve with 12 µm thick Be window and 500 µm thick Si absorber.

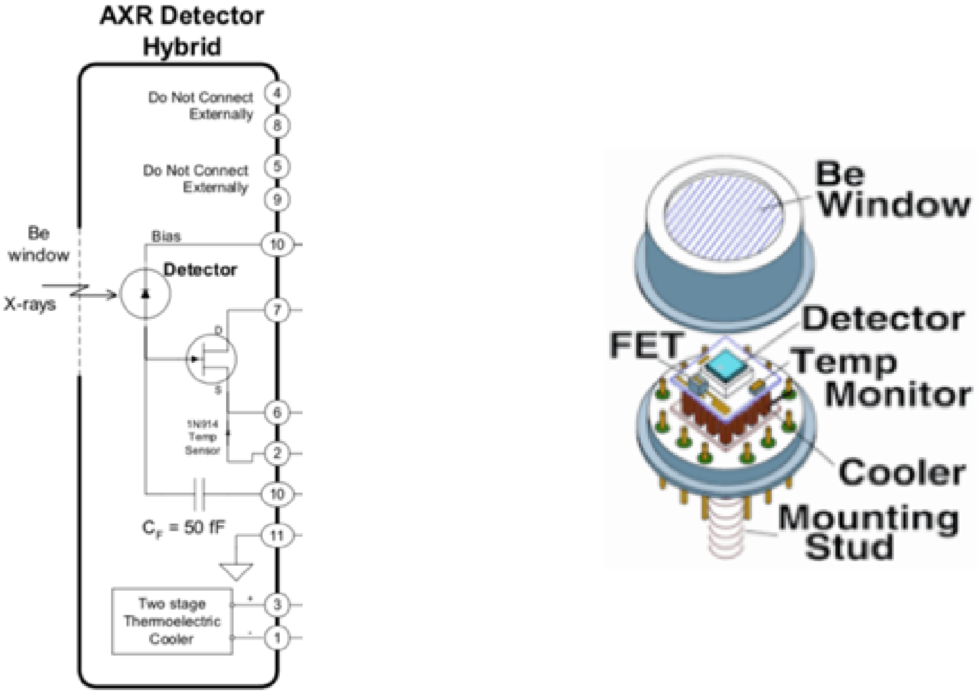


Figure 3: Left: Scheme of the preamplification circuit. Right: Amptek FAST-SDD structure.

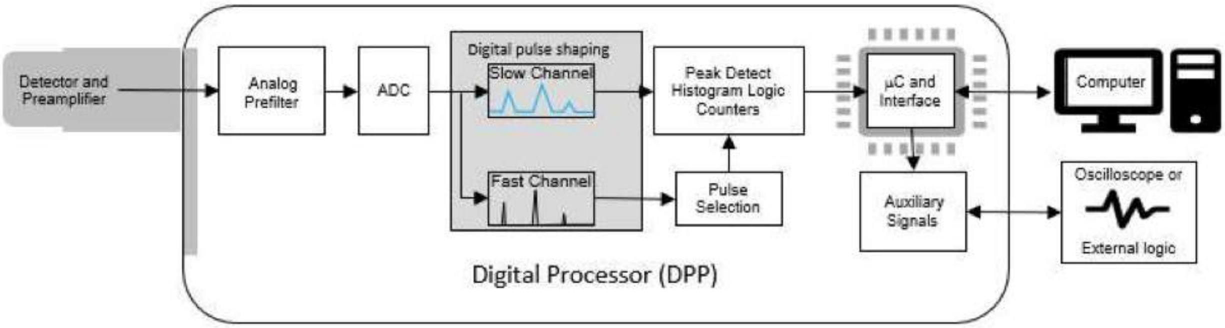


Figure 4: The X-123 system signal chain.

4.1 X-ray source

The X-ray source employed in the measurements is a an electron impact source, equipped with six anodes and four filters for each beam (primary and secondary). The source, a Manson model 5 built by J.E. Manson CO. Inc. (Concord, MA, USA), was modified in order to obtain X-rays having an energy up to 20 keV. Up to six anodes and four filters can be selected without breaking the vacuum.

A picture of the beam line and a particular of X-ray source is shown in figures 6. The X-ray source can produce a flux up to 10^5 $photons/(cm^2 s)$ at about 20 meters distance. Another single-anode water-cooled source producing greater fluxes ($10^7/cm^2 s$ at 20 meters distance) was available, but we didn't exploit this opportunity because, due to the short distance between our sensor and the source, the flux was already too high. On the contrary, most of the effort in changing the experimental setup was directed to trying to diminish the flux as discussed in Section 4.3.

The source produces two perpendicular beams matched within 2%, coming from the same spot on the anode. In normal operations the main beam is used for measurements, while the secondary is used for monitoring

Figure 5: An image of the experimental apparatus at XACT.

purposes; then, the main line develops in a long vacuum tube (to simulate as much as possible the considerable distance between an astronomical X-ray source and the instruments that detects it) which leads to test chambers housing the device under test (DUT).

4.2 The X-ray beam-line

In its full extension, XACT propagates in vacuum the X-ray beam up to 35 meters: after the X source, there is the monochromator chamber ($\varnothing 0.8\ m \times 1\ m$), the pipeline consisting in 16 tubes, 1, 2, or 2.5 meters long, a big chamber to test grazing incidence telescopes ($\varnothing 2\ m \times 3.5\ m$) and, finally, a chamber for the detectors tests ($\varnothing 1\ m \times 1\ m$) (Fig. 6a). The piping grows, from the source (150 mm) to the test chamber, so to have, at the end, an illuminated area of 800 mm diameter. All tubes and chambers are equipped with lateral flanges: large (CF standard from 100 to 250 mm diameter, ISO standard from 300 to 500 mm diameter), to permit the access, and small (CF standard from 40 to 200 mm) for feed-through. The vacuum system is based on rotative oil-free pumps and on magnetic levitation turbomolecular pumps. The minimum pressure attainable is $5 \times 10^{-8}\ mbar$, but, usually, the facility is operated in the $10^{-7}\ mbar$ range.

4.3 Measurements Set-up

The high degree of modularity with which the facility was built, with an extensive use of valves and pumps, gives to the XACT facility the capacity to adapt to different measurements needs. For our tests on the X-Ray spectrometer we exploited only the first part of the Facility (see Figure 1), specifically the X-ray source and the first sections - a few centimeters in length - of the main and secondary beams.

We used two different configurations. In the first two days the device under test was put in the main line at about 25 centimeters from the X-ray source spot. In the second part of the measurements, aiming to reduce the intensity of the X-ray beam, the detector under test was mounted on the secondary line at a longer distance (about 65 centimeters). Another method used to reduce the flux was interposing a neutral density mesh with

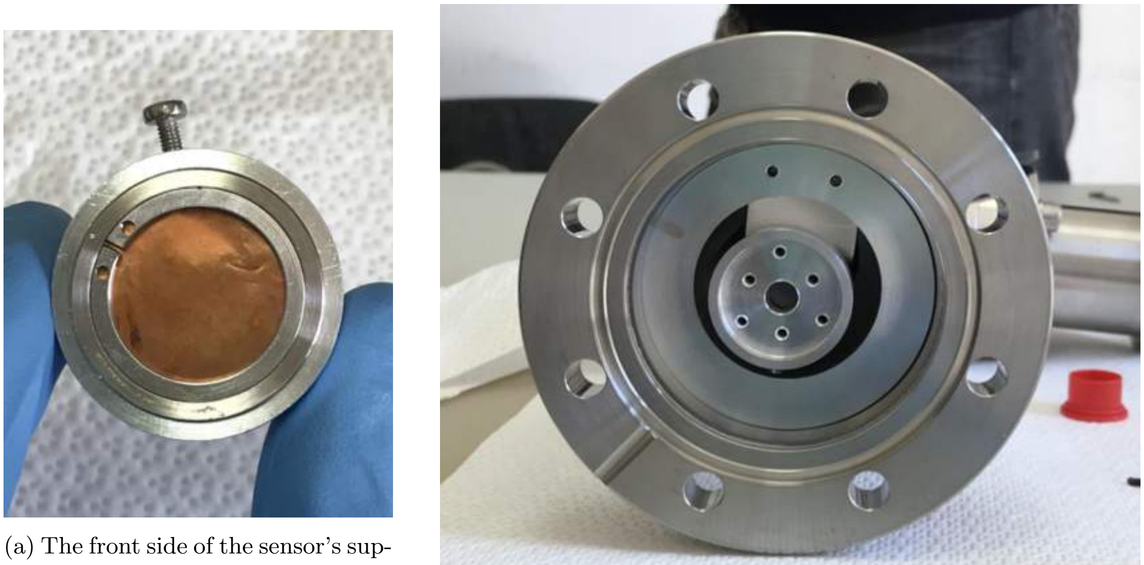
(a) The X-ray beam line

(b) A detail of the X-ray source

Figure 6: The XACT Facility of the INAF - Osservatorio Astronomico di Palermo

10% nominal open area (chemically etched copper foil with a regular matrix of small pin-holes, see Figure 7a, left panel) in front of the detector's window (see section 5).

The mechanical support used to co-align the sensor inside the vacuum chamber (see Figure 7b) was realized on the first day. This support, made of Aluminium, allows to mount one or two meshes or, alternatively, the pinhole, that are retained in position by means of screws.



(a) The front side of the sensor's support with the mesh inserted.

(b) The support without the mesh located inside the vacuum chamber.

Figure 7: The mechanical support.

The secondary line was used for an additional detector - a Si-PIN Solid State Detector (SSD) model XR-100CR manufactured by Amptex, with 13 mm^2 sensitive area and 12.5 µm thick Be entrance filter - in order to monitor the X-ray beam and its potential variations over time.

In this configuration the FAST-SDD detector was tested several times before deciding to change the configuration due to the high flux (10^6 $photons/s$) hitting the detector, at the limits of its measurement capability. In the second configuration, with the aim of reducing the intensity of the X-ray beam, the detector under test was mounted on the secondary line, in place of the reference Si-PIN SSD detector, where it was possible to move it further from the source, at about a distance of 70 cm. In addition, to further reduce the flux, two overlapping 10% meshes were used and, subsequently, a 50 µm pin-hole was mounted. Measurements without meshes and pin-hole were performed as well.

5. TEST OUTLINE

In order to properly monitor the solar activity and, in particular, to identify and characterize the solar flares, as seen in section 2.1, the spectrometer must be able to acquire spectra between about 1 to 20 keV with a resolution of at least 250 eV (see the FWHM of FeXXV peak at 6.7 keV in Figure 1). This should be accomplished in a wide dynamic irradiance range of at least five orders of magnitude.

A measurement campaign was organized to investigate the main sensor characteristics needed to perform science correctly, in particular we investigated:

1. A spectral resolution sufficient to distinguish characteristic spectral lines;
2. The capability to manage very different levels of light flux (5-6 orders of magnitude).

We studied these characteristics at different spectral range, resolution, dynamic range and response speed.

- Scope of the tests (in synthesis, verify that the spectrometer is working, verify spectral resolution, measure dynamic range)
- Mechanical adaptations for holding a filter
- Used filters, see table 2
- Used sources, see table 1
- Tests list

In order to characterize the spectrometer and verify that it is a suitable candidate for pursuing the objective listed in section 2.1, the following tests have been conducted:

- General behaviour of the spectrometer, by getting acquainted with the facility, the sources and the acquisition software.
- Verification of the base working principle of the spectrometer (capability of acquiring X-Ray spectra).
- Spectral resolution measurement.
- Dynamic range measurement.

In the following, each of the listed tests is described in a dedicated paragraph.

A too intense flux of photons can cause *pile-up* phenomena, that can be managed using the right parameters setting (e.g. reducing the peak-time) but, if prolonged, it could result in the sensor damaging.

The FAST-SDD sensor, and its associated electronics are capable to manage count rates exceeding $10^6 cps$ (counts per second) . This level of flux will then represent the maximum limit for the number of photons that must impact on the sensor during the Sun activity monitoring phase on-board the Helianthus sailcraft. This flux will be eventually reduced in the flight version using additional: pinholes, meshes, etc. For the time being, once fixed the upper limit for our sensor operativity (10^6 cps), much of the setup activity in the laboratory consisted in trying to test the sensor in an extremely large range of fluxes (from $\lesssim 10^6$ cps to $\lesssim 1$ cps) using several methods:

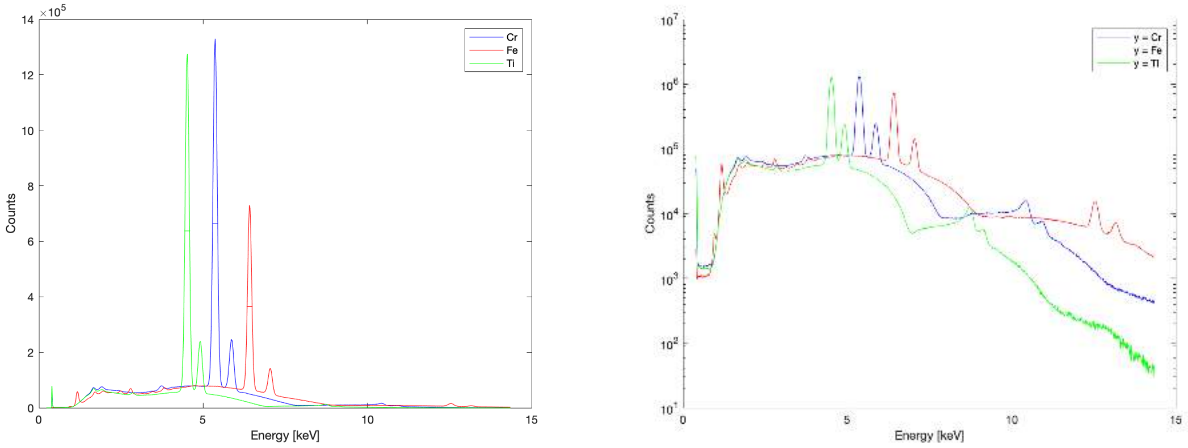


Figure 8: Fe, Cr and Ti spectra in linear and logarithmic scale.

Table 1: List of anodes used in the X-Ray source.

Anode	Char. K lines [keV]	L lines [keV]
C	0.277	
MgO	1.25, 1.30, 0.53	
Al	1.49, 1.56	
Si	1.74, 1.84	
Ti	4.51, 4.93	0.51
Cr	5.41, 5.95	0.57
Fe	6.40, 7.06	0.71
Cu	8.05, 8.91	0.93
Zr	15.8, 17.7	2.04, 2.1, 2.3

6. RESULTS

We obtained several spectra from multiple anodes (C, MgO, Si, Al, Ti, Cu, Fe, Cr, Zr) and different electron currents of the source.

The anodes that we used more extensively for energy calibration were the ones having characteristic lines in the interval of sensitivity of the sensor ($\approx 0.8 - 20\ keV$), that is from Mg (Z=12) to Zr (Z=40).

The main results, useful to demonstrate that the space-borne instrument can satisfy the science needs[5] are:

1. The attainable energy resolution, sufficient to discriminate elements' characteristic lines;
2. The system's capability to manage photons fluxes in all conditions: from quiet Sun to the most energetic flares.

Table 2: List of filters available.

Material	Thickness
Al	10μm - 20 μm - 0.2 mm
Ti	1μm - 10 μm - 20 μm
Fe	25 μm
Cu	20 μm

6.1 Energy resolution

Figure 9 shows spectra taken with the Cu anode and three different formation times of the read-out filter. The $K\alpha$ (8.05 keV) and $K\beta$ (8.91 keV) characteristic lines are well separated and a preliminary analysis shows a FWHM of both lines below 200 eV, in accordance with the Fano limit energy resolution of 123 eV. Similarly Figure 10 shows the spectra taken with the Al anode and four different different formation times of the read-out filter. Beside the Al $K\alpha$ and $K\beta$ complex of Aluminum (1.49 and 1.56 keV), which cannot be well separated by the intrinsic energy resolution of the detector, we notice other lines such as the Si K fluorescence line (1.74 and 1.84 keV). Lines at twice or three times the energy of the Al or Si K lines are multiple photons detected in the time window of the integrating filter.

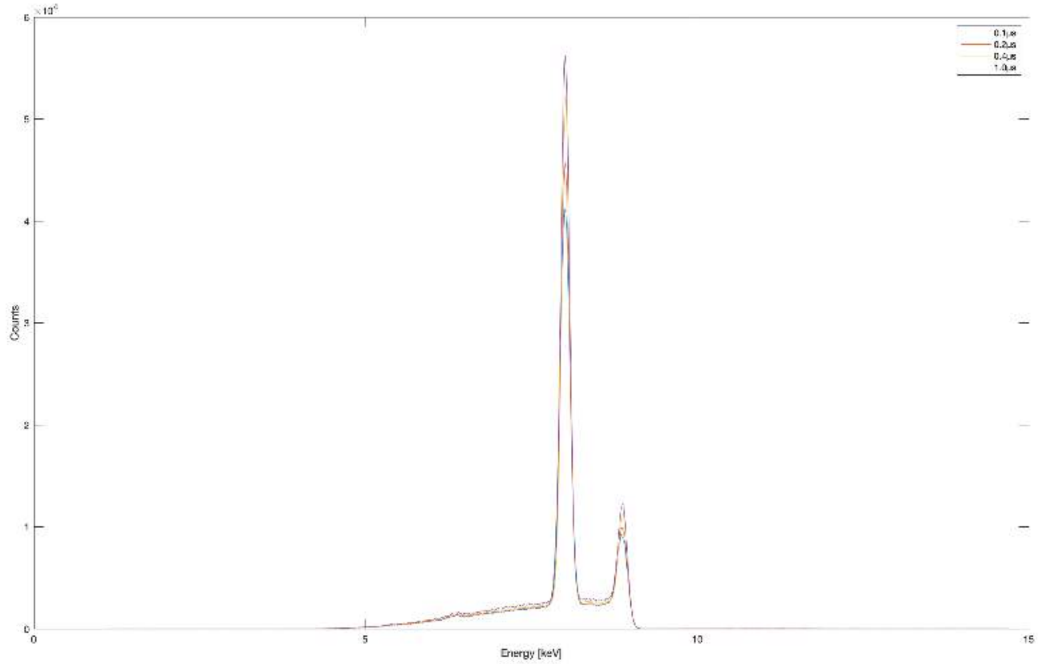


Figure 9: Cu spectra acquired with four different formation times, from 0.1 to 1.0 µs: in linear scale.

6.2 Dynamic range

The second important result of the measurement campaign was that the system is capable of managing several orders of magnitude of flux (from less than 1 cps to over 1 Mcps).

In Figure 11 we show the superposition of measurements taken in very different conditions; it is apparent how, despite the flux varies of several orders of magnitude, the Fe characteristic lines at 6.40 and 7.06 keV are easily recognizable. The peaks on the right are *pile-up* artefacts.

6.3 Further results

We observed that the energy resolution depends only slightly from setup conditions and this implies that, during operations, the system will be able to perform well under very different ambient conditions (e.g. photon flux) without the need of a case-by-case set-up of parameters.

We realized sensitivity measurements with respect the variation of some parameters: 1. Gain, setting the maximum energy; 2. Resolution, up to a maximum of 8192; 3. Peak-time; 4. Substrate bias voltage; 5. Substrate temperature.

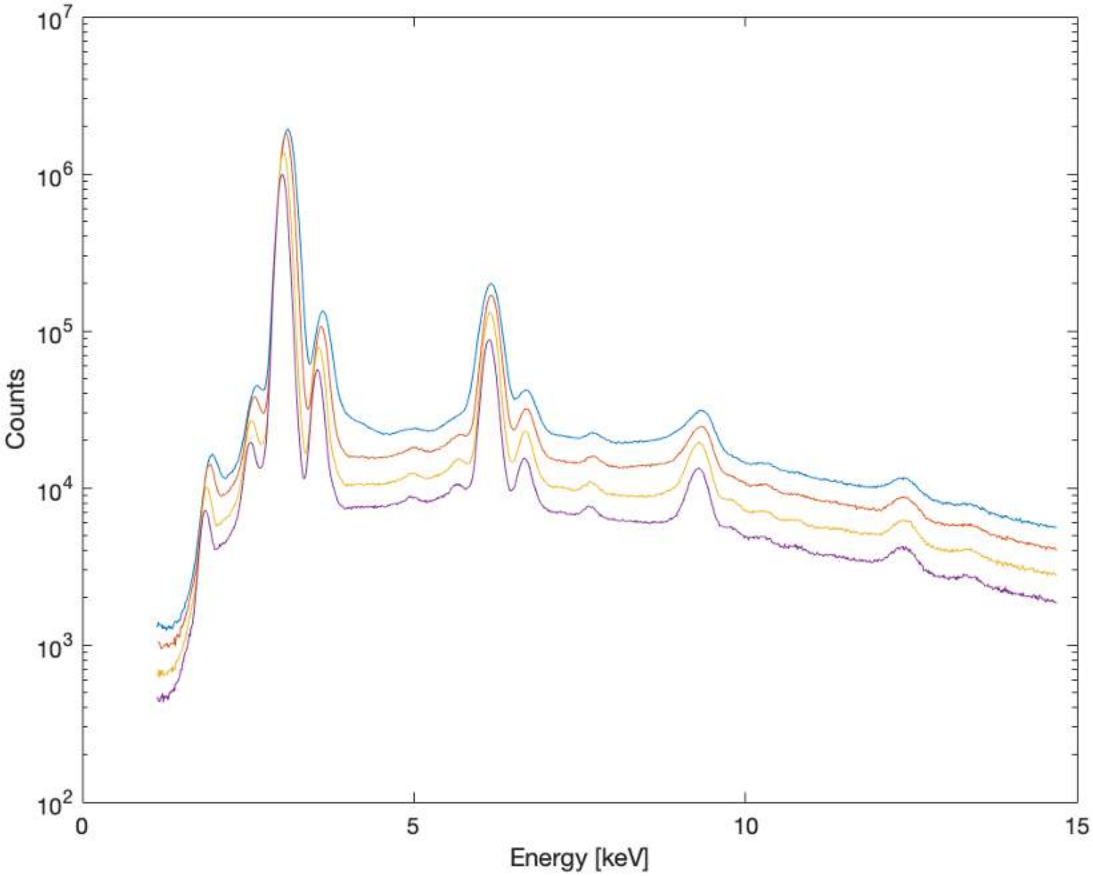


Figure 10: Al spectra acquired with four different formation times: in logarithmic scale.

From a preliminary analysis of data shown in Figure 10 we could estimate that the effect of reducing the peak-time from 0.6 to 0.1 µs (e.g. to reduce dead-time) leads to a FWHM rising of about 20%.

A thorough analysis of the sensitivity of the detector's response will be performed in the near future. We can anyway anticipate that the system turned out to be robust with respect to these variations, allowing us to obtain high-quality spectra, irrespective of the particular parameters settings.

7. CONCLUSIONS

In this paper we describe the experimental activities held at XACT facility to characterize the X-ray detector (SensorX) being adopted on-board the Helianthus mission. The measurements performed with the detector using multiple anodes, variable electron current, and different configurations to reduce the total flux, have allowed us to prove the effectiveness of the selected spectrometer. In particular, the measured energy resolution of the detector is $\sim 200eV$ FWHM at the Fe K α and K β complex, and the system is capable of managing several orders of magnitude of flux (from less than 1 cps to over 1 Mcps). Furthermore, we have good indications that the energy resolution depends only slightly from parameters setup, which implies that the system will not need a case-by-case configuration during operation in very different ambient conditions (e.g. photon flux).

Before the end of the Phase A, a more detailed analysis of the wealth of spectra collected during the measurement campaign will be performed, in order to confirm the preliminary results presented in this work. Additionally, the results will also constitute a milestone in defining the strategy for on-board measurements and sensor's management.

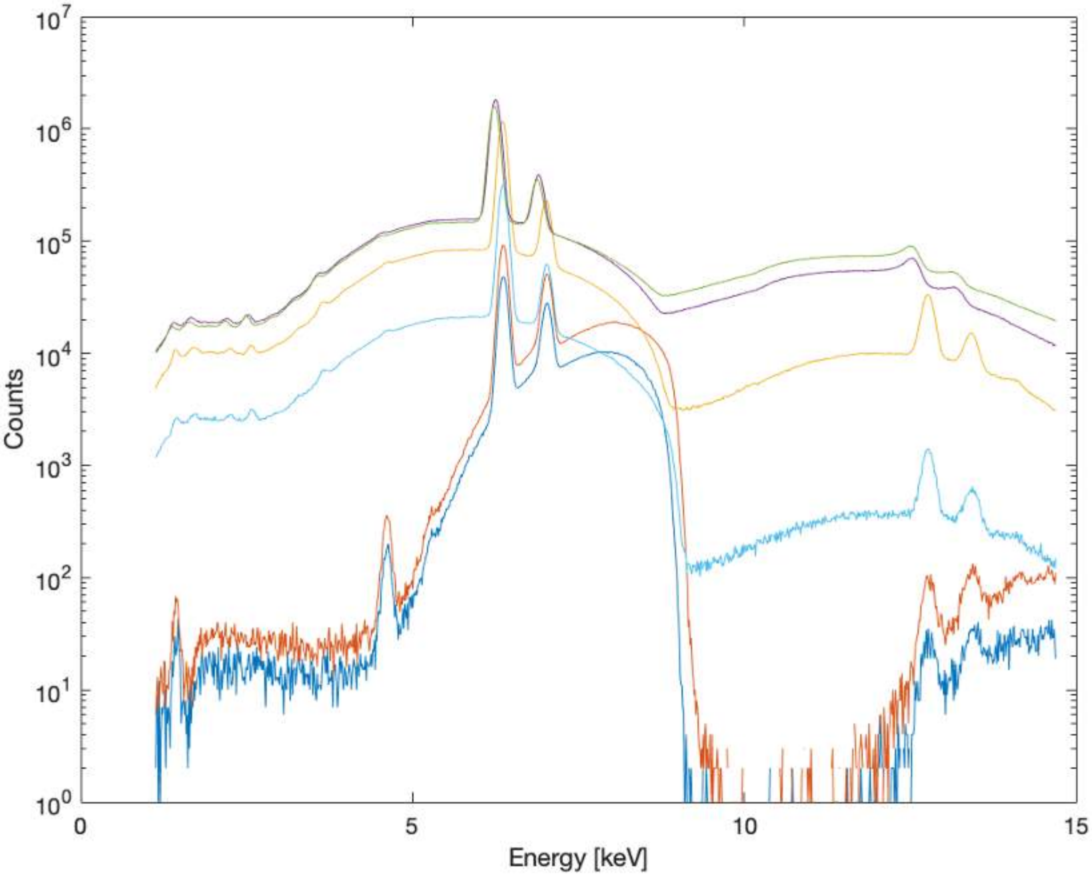


Figure 11: Fe spectra acquired with different filters and currents: in logarithmic scale.

ACKNOWLEDGMENTS

This work is performed jointly under the Implementing Agreement between the Italian Space Agency and DIAEE – Sapienza University of Rome n. 2019-28-HH.0 - CUP n. F84I19001070005 related to R&D activities on solar photonic propulsion. The Implementing Agreement is based on the Framework Agreement between ASI and "La Sapienza" n. 2015-1-Q.0.

REFERENCES

[1] Santonicola, M. G., Toto, E., Laurenzi, S., Circi, C., Pizzarelli, M., Simone Pizzurro, R. P., and Cavallini, E., "High-Performance Polyimide Membranes for Use in Solar Sail Propulsion," 73rd International Astronautical Congress, IAC 2022, Paris (France) 18-22 September 2022 (submitted).

[2] Bassetto, M., Niccolai, L., Boni, L., Mengali, G., Quarta, A. A., Circi, C., Pizzurro, S., Pizzarelli, M., Pellegrini, R. C., and Cavallini, E., "Sliding mode control for attitude maneuvers of helianthus solar sail," *Acta Astronautica* **198**, 100–110 (2022).

[3] Palmeri, F., Tortorici, D., Laurenzi, S., Circi, C., Santonicola, M. G., Pizzarelli, M., Pizzurro, S., Pellegrini, R., and Cavallini, E., "Structural design of booms for the solar sail of Helianthus sailcraft," 73rd International Astronautical Congress, IAC 2022, Paris (France) 18-22 September 2022 (submitted).

[4] Woods, T. N., Caspi, A., Chamberlin, P. C., Jones, A., Kohnert, R., Mason, J. P., Moore, C. S., Palo, S., Rouleau, C., Solomon, S. C., Machol, J., and Viereck, R., "New Solar Irradiance Measurements from the Miniature X-Ray Solar Spectrometer CubeSat," *The Astrophysical Journal* **835**, 122 (Feb. 2017).

[5] Aschwanden, M. J., Caspi, A., Cohen, C. M. S., Holman, G., Jing, J., Kretzschmar, M., Kontar, E. P., McTiernan, J. M., Mewaldt, R. A., O'Flannagain, A., Richardson, I. G., Ryan, D., Warren, H. P., and Xu, Y., "Global energetics of solar flares. v. energy closure in flares and coronal mass ejections," *The Astrophysical Journal* **836**, 17 (feb 2017).

[6] Abrusci, L., Gutierrez, G. J., Marchioni, F., Mercuri, M., Naspi, L., Pantusa, M., and Piccoli, F., "Progetto SolarX," tech. rep., Polytechnic of Turin, Department of Engineering (01 2018).

[7] Caspi, A., Woods, T. N., and Warren, H. P., "NEW OBSERVATIONS OF THE SOLAR 0.5–5 KEV SOFT x-RAY SPECTRUM," *The Astrophysical Journal* **802**, L2 (mar 2015).

[8] Gatti, E. and Rehak, P., "Semiconductor drift chamber — an application of a novel charge transport scheme," *Nuclear Instruments and Methods in Physics Research* **225**(3), 608–614 (1984).

[9] Moore, C. S., Woods, T. N., Caspi, A., and Mason, J. P., "The Miniature X-ray Solar Spectrometer (MinXSS) CubeSats: spectrometer characterization techniques, spectrometer capabilities, and solar science objectives," in [*Space Telescopes and Instrumentation 2016: Ultraviolet to Gamma Ray*], den Herder, J.-W. A., Takahashi, T., and Bautz, M., eds., **9905**, 82 – 93, International Society for Optics and Photonics, SPIE (2016).

[10] Mason, J. P., Woods, T. N., Chamberlin, P. C., Jones, A., Kohnert, R., Schwab, B., Sewell, R., Caspi, A., Moore, C. S., Palo, S., Solomon, S. C., and Warren, H., "Minxss-2 cubesat mission overview: Improvements from the successful minxss-1 mission," *Advances in Space Research* **66**(1), 3–9 (2020). Advances in Small Satellites for Space Science.

[11] Barbera, M., Candia, R., Collura, A., Di Cicca, G., Pelliciari, C., Sciortino, S., and Varisco, S., "The Palermo XACT facility: a new 35 m long soft x-ray beam-line for the development and calibration of next-generation x-ray observatories," in [*Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*], Turner, M. J. L. and Hasinger, G., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **6266**, 62663F (June 2006).