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A polarimeter for IXO

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Abstract

The X-ray POLarimeter (XPOL) is an instrument that will fly on-board the International X-ray Observatory (IXO). We will describe the XPOL setup in IXO and we will compare the IXO requirements with the actual prototype performance. The environmental tests performed on the XPOL prototype (thermo-vacuum, vibration and heavy ions irradiation) show that this technology is ready for a space application.

39.1 XPOL on the IXO focal plane

IXO is a collaboration of NASA, ESA and JAXA, and is foreseen to fly in 2020 [1]. The optics area will be 2 m^2 at 2 keV with a 20 m focal length and with an angular resolution of 5". The focal plane of IXO will be a rotating platform hosting several instruments that will take data alternatively: a Wide Field Imager, an X-ray Microcalorimeter Spectrometer, a Hard X-ray imager, a High Time Resolution Spectrometer, and the polarimeter XPOL. Further an X-ray grating spectrometer will be continuously in operation.

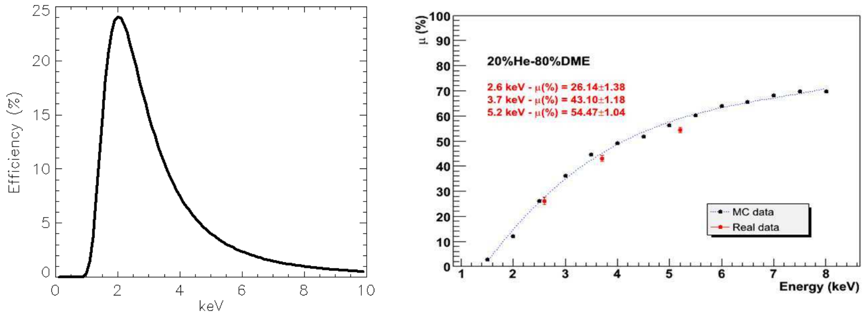
XPOL is a sealed Gas Pixel Detector (GPD) [2; 3], with a 50 μm beryllium window, a photo-absorption gap of 1 cm, a Gas Electron Multiplier (GEM) for the charge preamplification and a readout ASIC with a 15 × 15 mm^2 active area, covered by 105600 hexagonal pixels with a 50 μm pitch. Each pixel has a complete electronic chain (preamplifier, shaper, sample and hold) with a very limited noise (50 el ENC). The gas used is a He20-DME80 (Di-Methyl Ether) mixture at 1 bar. The photons that have a photoelectric interaction with the gas atoms, cause the emission of a photoelectron with an angle relative to the X-ray polarization modulated as a $\cos^2\phi$ function. The ionization electrons left along the photoelectron track, are drifted towards the GEM that multiplies them, and are collected, amplified and recorded by the pixels which store the track map. The ASIC has an auto-triggering

Table 39.1. *Summary of performance requirements (assuming a focal length of 20 m and 2 m^2 of area at 2 keV)*

	Performance reqs	Reqs satisfied by the actual XPOL prototype
Field of view	2.6'×2.6'	YES
Polarization sensitivity	1% MDP (99%CL) for 1 mCrab source in 100 ks	YES
Energy range	2–10 keV	YES
Energy resolution	20% at 6 keV	YES
Angular resolution	6"	YES
Timing resolution	5 μs	YES
Efficiency	see Fig. 39.1(a)	YES
Modulation factor	see Fig. 39.1(b)	YES
Polarization angle resolution	2° in 100 ks 1 mCrab P=10%	YES
Dead time	10 μs	NO $\tau = 200$ μs

capability: when a charge > 3000 el is collected by a mini-cluster of 4 pixels, the ASIC holds the amplified charges and provides the trigger signal and the coordinates of the corners of a Region Of Interest (ROI) which comprehends the pixels over threshold plus a ±10 or ±20 pixels fiducial area to collect the tails of the charge distribution. The readout system reads only the ROI, not the whole ASIC, saving in average a factor 100 in readout time. An algorithm identifies the start point of the track (impact point), calculates the direction of emission of the photoelectron from the pixels near the impact point and the charge of the whole track, which is proportional to the photon energy.

The main performance of XPOL are described in Table 39.1, Fig. 39.1(a) and Fig. 39.1(b). The 1 keV cutoff in the efficiency curve (Fig. 39.1(a)) is due to the Be window absorption. In the modulation factor plot (Fig. 39.1(b)) some experimental points are compared with the Monte Carlo prediction. The Minimum Detectable Polarization (MDP) =1% (99% CL) for 1 mCrab source in 100 ks, the high angular resolution (6"), the spectroscopic capability in the 2-10 keV range, make XPOL a real break through in the X-ray polarimetry.



(a) (b)

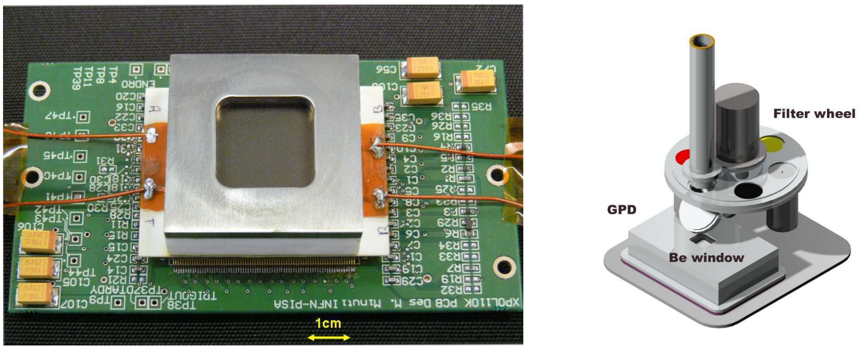
Fig. 39.1. (**a**) Detection efficiency of XPOL with a 50 μm Be window and a He20-DME80 1 bar gas filling. (**b**) Modulation factor measured at 2.6 keV, 3.7 keV and 5.2 keV compared with the Monte Carlo prediction.

The last column of Table 39.1 states the correspondence of the performance of the actual detector with the IXO requirements. The only parameter that must be improved is the dead time. The actual dead time is 200 μs and is dominated by the ADC readout time of the pixels of the ROI. A new ASIC is under study with a 10 μs dead time that will be obtained with a factor 2 increase of the clock rate from 10 MHz to 20 MHz and by the optimization of the ROI. The operational experience demonstrated that the ROI can be reduced by a factor 5 without loosing any relevant information. In the actual ASIC there is a second readout of the ROI to evaluate the pedestals just after the event. In the new version the increased stability of the pedestal levels will avoid this second readout, with a factor 2 gain in the frame rate. The minimum threshold level will also be lowered to few hundreds electrons to obtain a high trigger efficiency even at low GEM gain.

39.2 The XPOL configuration

The GPD is a very compact device (Fig. 39.2(a)) weighting 50 g only. It is assembled by Oxford Instruments Analytical Oy (Finland), an industry with a long heritage in building sealed proportional counter for space. Only low outgassing materials and adhesives are used. The GPD is left several days in vacuum at high temperature for deep outgassing, is filled with the gas mixture and sealed. The first sealed GPD is still working at nominal voltages after 2 years from assembly.

XPOL on IXO will be hosted in a protection box (Fig. 39.2(b)). A filter



(a) (b)

Fig. 39.2. (**a**) The XPOL prototype. (**b**) Drawing of the XPOL configuration in IXO. The GPD is closed in a protection box leaving open the Be window area. The filter wheel moves over the window the slots open, diaphragmed, closed, with calibration sources (one polarized and two unpolarized)

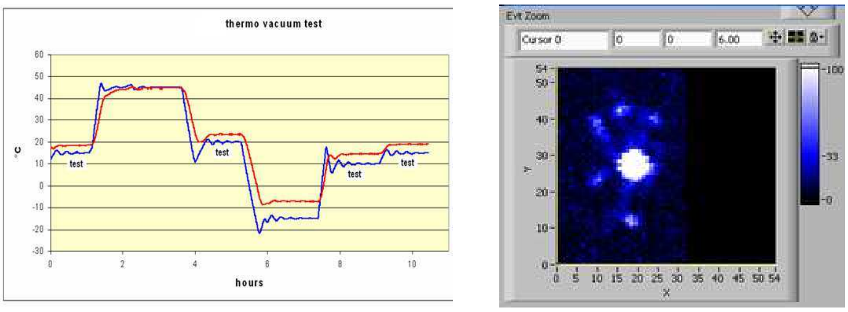
wheel will be mounted in face of the instrument. The filter wheel will have 7 positions: one open and one closed positions, one diaphragm to see a faint source close to a bright one, a filter to reduce the rate of too bright sources, two fluorescent unpolarized calibration X-ray sources, one compact polarized source.

In the IXO project, near the GPD, there is the Back End Electronics (BEE) that provides the low and high voltages and the commands to the ASIC. The BEE receives and digitizes the ASIC signals. The BEE amplifies and digitizes the spectroscopic signal coming from the top side of the GEM and tags the event with a time stamp. The BEE regulates the GPD temperature (±2°C) by means of a Peltier cooling system.

The BEE communicates with a Control Electronic unit (CE) which stores the data in a 16 GBytes buffer memory. The CE is the interface to the spacecraft. The CE is also able to do a preprocessing of the events to reduce the data volume for the telemetry sending to earth the track angle and the coordinates of the impact point instead of the list of coordinates and amplitudes of the pixels over threshold (factor 7 data reduction). The maximum data flow to telemetry will be 1 Mbit/s, equivalent to a 0.3 Crab of not preprocessed data.

39.3 Space environmental tests: vibe tests

The actual XPOL prototype was tested to prove its capability to survive the launch and to the space environment. XPOL was glued on an aluminum flange that ensures the needed stiffness and the thermal path. A Finite El-



(a) (b)

Fig. 39.3. (**a**) Thermo-vacuum cycle: the blue line is the temperature of the aluminum interface between the cool plate of the cryostat and XPOL (driving temperature). The red line is the temperature measured on top of the Be window. The test periods are indicated. (**b**) Fe ion test (500 MeV/Nucleon): a single event shown by the online monitor. Scale in pixels (50 μm). The event saturates the electronics in a 5 pixels radius. Several delta rays are also visible

ement Model (ASNYS) of XPOL predicted the first resonance mode over 3000 Hz, well over the 20-2000 Hz test range. We mounted XPOL on the table of a TYRA-TV5220 shaker, registering the acceleration with three Piezotronics-352A24 ICP accelerometers. A sine sweep test at 0.25 g confirmed the absence of resonances in the 20-2000 Hz range. XPOL survived with no damages to a random vibration test up to 11.4 g_{rms} = +3Db over the minimal workmanship acceptance test as defined in the NASA GEVS [4].

39.4 Space environmental tests: thermo-vacuum test

XPOL was tested in a climatic chamber for 8 cycles in the not operative temperature range -15°C, +45°C. XPOL was tested in operative way at +10°C , +15°C, +20°C with a Fe^{55} source. XPOL survived to the test showing a gain dependence from temperature of -2%/°C. After this test, XPOL was mounted over the cold head of a Cryodine cryostat, inside a vacuum vessel with the high voltage and the communication feed trhough. A set of resistors glued around the cold head could heat it to the desired temperature. Two PT100 thermistors measured the temperature of the interface flange below XPOL (driving temperature, blue curve in Fig. 39.3(a)) and of the Be window (red curve). The vessel was evacuated to a pressure $\sim 10^{-5}$ mbar with a leakage check system Varian 979. XPOL reached the +45°C and the -15°C not operative temperatures, and was operated at +10°C, +15°C, +20°C with a Fe^{55} source, showing the same behavior registered in the thermo-cycle test.

39.5 Space environmental tests: heavily ionizing particles test.

A slow proton or a nucleus from the cosmic rays can produce a large amount of ionization that can operate as a temporary short circuit in the GEM holes. The consequent spark can damage the GEM, if the GEM is operated at a too high gain.

We have exposed XPOL at operative voltages in the 500 MeV/Nucleon Fe beam at the Heavy Ions Medical Accelerator in Chiba (HIMAC), Japan. In Fig. 39.3(b) the online monitor of the XPOL data taking is shown. A single event saturating the electronics is registered, together with several delta rays. XPOL was exposed to 1.7×10^4 Fe ions equivalent to a 42 years exposure in space in a LEO orbit [5], without registering any damage or performance loss.

39.6 Conclusion

The XPOL prototype have been tested with polarized and non polarized X-ray sources to measure all the performance. The performance are in agreement with theoretical predictions. XPOL was demonstrated in relevant environment: vibe test over the minimal acceptance test as per NASA GEVS, 8 thermo cycles and 1 thermo-vacuum cycle, exposure to Fe ions, at 500 MeV/N; this means that this technology is ready for a space application. Only the dead time parameter of the actual device does not meet the IXO requirements and a new ASIC version, with minor upgrades, is under study to overcome this limitation.

References

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