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Dependence on temperature of the response of a gas pixel detector to polarized radiation

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ABSTRACT

The Gas Pixel Detector (GPD) is an X-ray polarimeter that exploits the photoelectric effect to measure the polarization and to obtain the image of astrophysical sources. This detector is on board the IXPE (Imaging X-ray Polarimetry Explorer) mission selected by NASA in the framework of the Explorer program scheduled for the launch in 2021. We report on tests carried out with a laboratory prototype of the GPD to verify the performance as a function of the temperature in a large temperature range between 15°C and 40°C.

Keywords: IXPE, GPD, X-ray polarimetry

1. INTRODUCTION

The IXPE (Imaging X-ray Explorer) mission is part of the Small Explorer program of NASA that includes the participation of ASI for the realization of the focal plane instrumentation.[1,2] The X-ray optics will be supplied by the NASA's Marshall Space Flight Center that will supply also the facility to perform the telescope/detector end-to-end calibration and the Science Operations Center. The Italian collaboration that includes the INAF-IAPS in Rome, the Osservatorio di Cagliari and the INFN of Pisa and Turin will provide three X-ray detectors (Gas Pixel Detector, GPD) sensitive to polarization.[3,4]The Laboratory for Atmospheric Physics (LASP), Boulder Colorado, will conduct the mission operations. The science goals of IXPE include the breakthrough measurements of the X-ray polarization of black holes and neutron stars as well as the measurement of the polarization of extended sources such as supernova remnants and pulsar wind nebulae.

The GPD[5] exploits the photo-absorption in gas to perform image resolved polarimetry, timing and spectroscopy with a moderate energy resolution (about 20% at 6 keV). The dependence of the photoelectric differential cross section to the polarization vector of the absorbed photon allows to measure the polarization of radiation. A photoelectron is emitted with a higher probability along the direction of the photon polarization vector (following a $\cos^2$ modulation in the plane normal to the photon wave vector) and its ionization track in the gas can be imaged to retrieve the emission point and the initial direction of emission.

The GPD comprises a Be entrance window 50 μm thick that is equipotential to a titanium frame that delimits the upper side of a 1 cm thick gas cell. The absorption gap is filled with a $20\% - 80\%$ He-DME gas mixture at 1 bar of pressure. The high voltage (HV) applied between the titanium frame and the metalized top layer of a Gas Electron Multiplier (GEM[6,7]) allows for the charge drift, whereas the HV applied between the top and the bottom side of the GEM allows for charge multiplication. The multiplied charge is actually collected on a finely subdivided hexagonal pixel plane (105600 pixels) with 50μm of pitch. The GPD basically measures the projection of the photoelectron tracks of ionization on the pixel plane.

In this work we report on a test carried out with a laboratory prototype of the GPD to verify its basic performance in a wide range of detector temperature between 15°C and 40°C.

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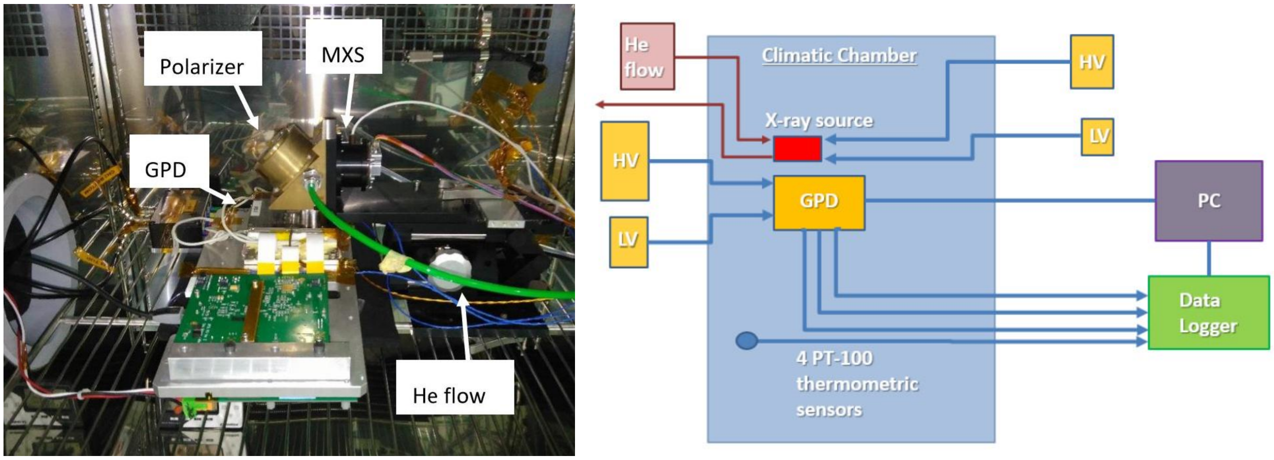

Figure 1. On the left: picture of the experimental set-up. On the right: block scheme of the experimental set-up.

2. THE EXPERIMENTAL SET-UP

The GPD was operated in a climatic chamber. The measurements were carried out by controlling temperature and humidity. The picture of the experimental set-up is shown in the left panel Fig. 1 and a block diagram is reported on the right panel. The X-ray sources employed in the test were a ^{55}Fe radionuclide emitting unpolarized radiation at 5.9 keV and 6.4 keV (seen as a single line due to the energy resolution of the GPD) and the Modulated X-ray Source (MXS).[8,9] The MXS is a compact X-ray tube comprising two light-emitting diodes (LEDs) that illuminate the photocathode and extract electrons which in turn are accelerated by a 11.3 kV high voltage. The target consists of a layer of 25 nm of chromium on top of 150 nm of copper deposited on a 300 μm thick beryllium window. The MXS is coupled with a polarizer exploiting the Bragg diffraction at nearly 45° on a graphite crystal to have X-rays completely polarized at 2.6 keV, 5.2 keV and 7.8 keV. A He flow in the polarizer allowed to reduce the air absorption of the X-rays, especially at low energy. A capillary plate ensures a collimation of about 3° at the output of the polarizer to select the direction of outgoing X-rays with the proper angle (and thus energy). A foil made of polypropylene with high transparency even at 2.6 keV allows to prevent the spilling of He from the collimator of the polarizer. Four PT-100 thermistors are placed in contact with the GPD in relevant positions (previously defined by means of a thermal simulation). These sensors are read out by means of a data logger, displayed and saved in a file on a PC.

3. EXPERIMENTAL RESULTS

The stability of the gain, energy resolution and modulation factor are assessed as a function of temperature (15°C, 20°C, 30°C, 35°C and 40°C) of the detector for each one of the three energies of the MXS source (see the left and right panels of Fig. 3 thet show the energy spectra acquired at 15°C and 40°C). The Fig. 2 shows the image of the radiation source produced by the GPD. The graphite crystal of squared shape diffracts X-rays that are actually collimated by the capillary plate at the output of the polarizer. Data analysis of this extended source is performed by normalizing the pulse height (PHA) of each event by the map of the gain. The gain map is obtained by illuminating the detector with the ^{55}Fe X-ray source without any collimation to produce a flat field. A PHA map is obtained and used to normalise the PHA of other measurements.

Each measurement was carried out when the thermal stability was reached and lasted for about 4.5 hours to collect about 180×10^3 counts with a count rate of about 12 counts/s. The Fig. 4 shows the stability of the GPD gain (measured by means of the ADC peak values of the energy lines) as a function of temperature for the three energies assessed. Each line in the energy spectra was fitted iteratively with a Gaussian distribution within 1.5σ from its peak value. The gain shows variations no larger than 2% and no dependence on the ASIC temperature was highlighted.

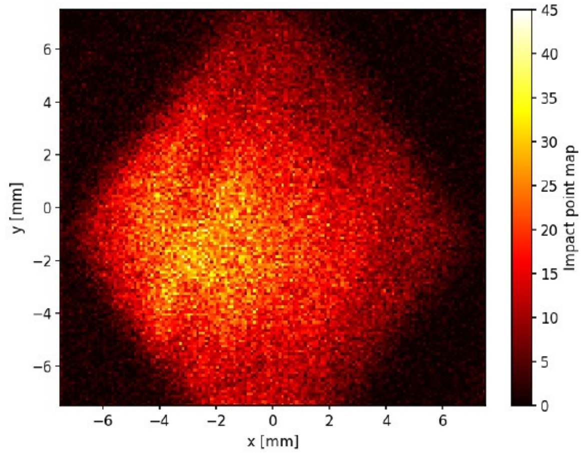

Figure 2. Example of the map of the impact points acquired at a detector temperature of 15°C

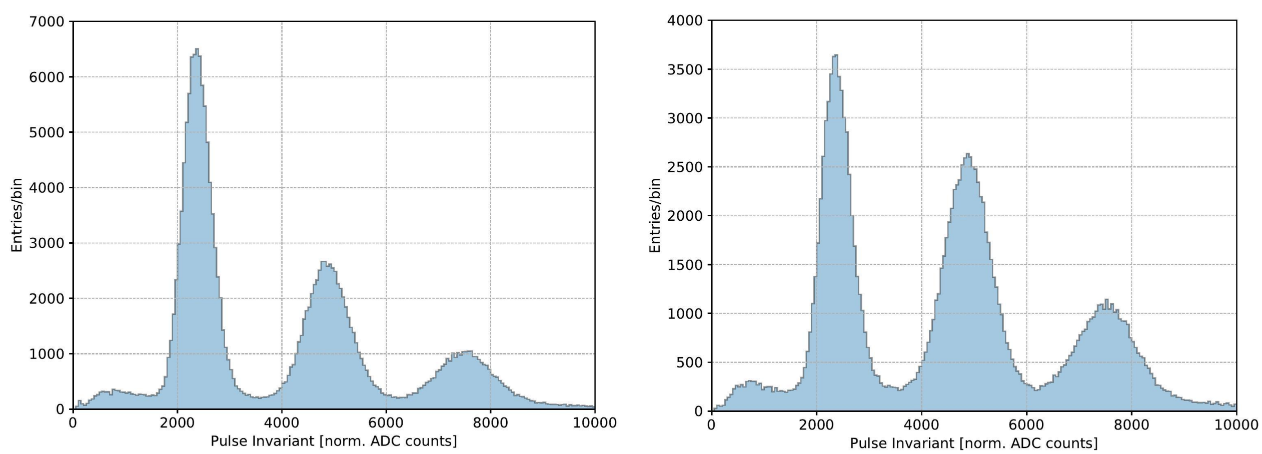

Figure 3. Two examples of the energy spectrum of the X-ray source comprising the MXS and the Bragg polarizer acquired at 15°C and 40°C

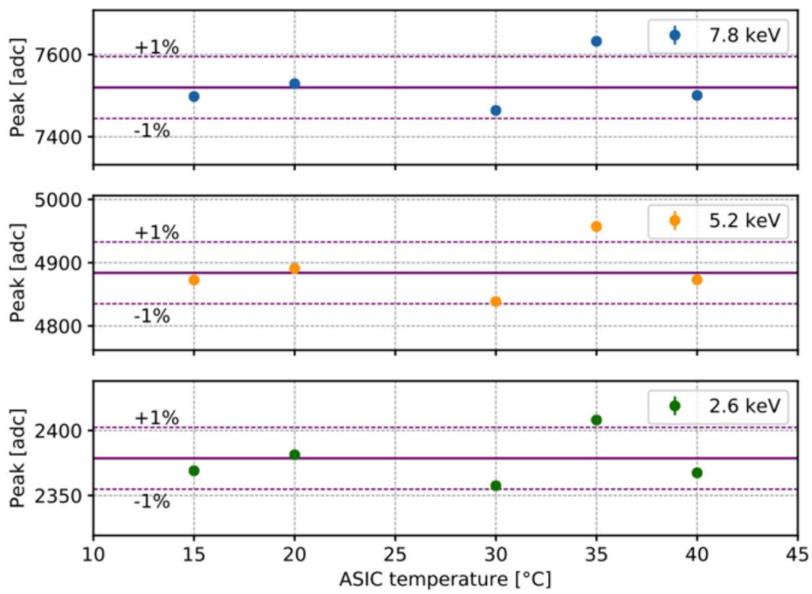

Figure 4. Gain stability of the GPD at the three energies of the MXS diffracted lines as a function of temperature.

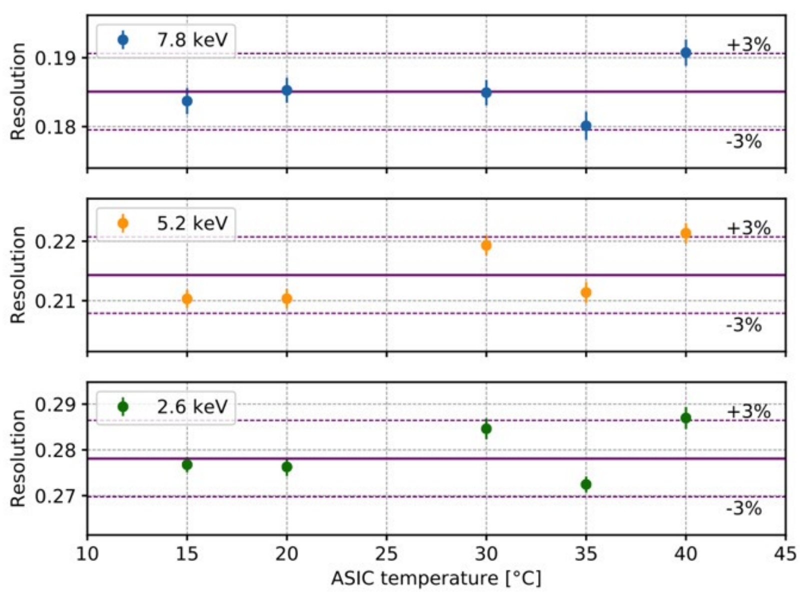

Figure 5. Energy resolution of the GPD at the three energies of the MXS diffracted lines as a function of temperature.

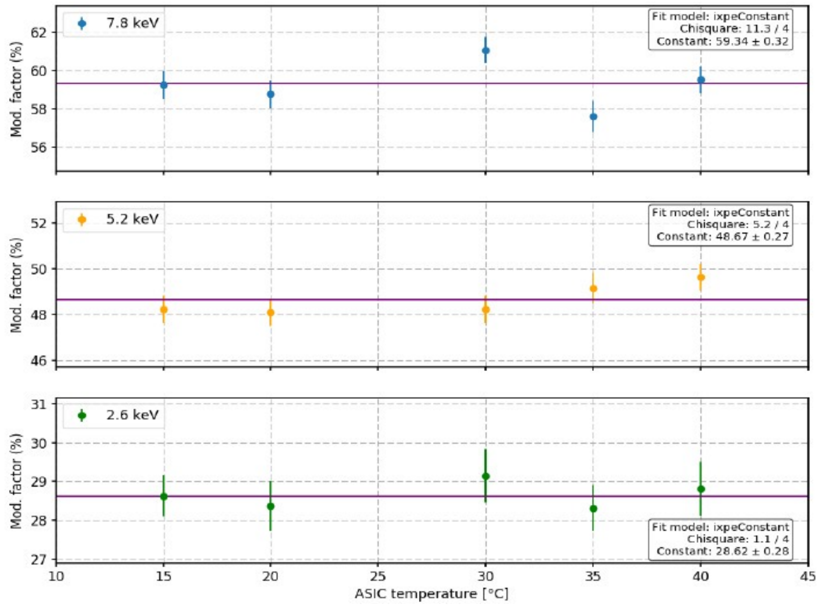

Figure 6. Modulation factor of the GPD at the three energies of the MXS diffracted lines as a function of temperature. Tracks are selected in ellipticity, within an energy interval of 2×FWHM around each line peak and by excluding an external squared frame in the image of Fig. 2 with a thickness large as the electron range at the energy of the line peak.

The Fig.5 shows the energy resolution stability of the GPD as a function of temperature for the three energies assessed. It varies within the 3% and no dependence on the ASIC temperature was highlighted.

The modulation factor at different temperatures was assessed for the three energy lines. At each one of them the proper quality filter was applied to select photoelectron tracks to perform the analysis. Standard cuts as for monochromatic energy spectra were applied to remove about the 20% of tracks from the further analysis of the 5.2 keV and 7.8 keV energy lines. A larger fraction of tracks was removed for the 2.6 keV line, due to the larger contribution of the incomplete charge collection from the higher energies in the signal range corresponding to this low amplitude line. Tracks were selected depending on the ellipticity, within an ADC interval of 2×FWHM around each line peak and by excluding an external squared frame in the image of Fig. 2 with a thickness large as the electron range at the energy of the line peak. This selection on the image is applied to remove from the analysis those tracks that are truncated by the beryllium window, the GEM and that exit from the active volume of the gas cell. The modulation factor is reported in Fig.6 as a function of temperature for the three energies assessed. No significant change with temperature is observed.

4. CONCLUSIONS

The behavior of the GPD at temperatures of the ASIC of 15°C, 20°C, 30°C, 35°C and 40°C was assessed at three energies (2.6 keV, 5.2 keV and 7.8 keV) with a polarized radiation source. The modulation factor measured was compatible with a constant value at each energy in a large temperature range of the ASIC. The gain shows variations no larger than 2% and no dependence on the ASIC temperature was highlighted as for the energy resolution, the variations of witch are within the 3%.

This study allows to confirm that the thermal control of the GPD is not a critical issue in the thermal design of the IXPE spacecraft.

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