Nuclear Instruments and Methods in Physics Research A 1069 (2024) 169881

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Time-dependent instrumental effects in IXPE: Pressure variation and GEM charging inside GPDs

Chiara Tomaiuolo [a,*], Alberto Manfreda [b], Leonardo Orsini [a], Stefano Tugliani [c]

[a] INFN sez. Pisa, Largo Bruno Pontecorvo, 3, Pisa, 56127, Italy
[b] INFN sez. Napoli, via Cintia, Napoli, 80126, Italy
[c] INFN sez. Torino, via Pietro Giuria 1, Torino, 10125, Italy

ARTICLE INFO

Keywords:
X-ray polarimetry
Gas pixel detectors
Grazing-incidence optics
X-rays
Sensors
Calibration
Polarimetry
Polarization
X-ray imaging
Modulation
Space operations
X-ray sources
Spatial resolution

ABSTRACT

We present the results of two studies conducted on long-term effects of a Gas Pixel Detector (GPD), central point of the X-ray detection of the Imaging X-ray Polarimetry Explorer (IXPE) mission: the pressure variation inside the sealed gas cells of the instrument and the charge build-up in the dielectric layer of the Gas Electron Multiplier (GEM), used as the amplification stage of the detector.

1. Introduction

The GPD [1] is a gas detector capable of providing imaging, spectroscopy and polarimetry in the energy band 2–8 keV. The instrument is made by a sealed gas cell filled with pure Dimethyl Ether (DME), where X-rays are absorbed producing photo-electrons. Their ionization tracks are drifted and collected on a segmented anode made by a custom Application Specific Integrated Circuit (ASIC), with a pitch of 50 μm. The required charge amplification stage is provided by a Gas Electron Multiplier (GEM). Three identical GPDs are hosted in the focal plane of the IXPE satellite [2], which has been observing the X-ray sky since its launch on December 9, 2021.

2. Pressure variation inside the gas cell

During the construction of the detectors, an unexpected pressure decrease inside the gas cells has been pinpointed thanks to the indirect observation of an increase of the detector gain, on a time scale of months. After the IXPE launch, several control GPDs, twins of the on-board ones, have been periodically re-calibrated in order to correct the data sampled by the mission. The pressure inside the gas cell is not directly measured, it is obtained performing a combined fit of three proxies: the detector gain, the signal track length and the event rate in controlled setup, assuming a single exponential trend for $p(t)$ [1]:

$$p(t; p_0, t_0, \Delta_p, \tau) = p_0 - \Delta_p \left(1 - e^{-(t-t_0)/\tau}\right) \tag{1}$$

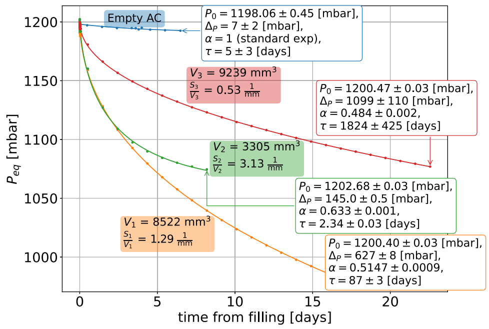
As secular monitoring continued, this time law for the pressure deviated considerably from the expected trend.

2.1. Absorption measurements

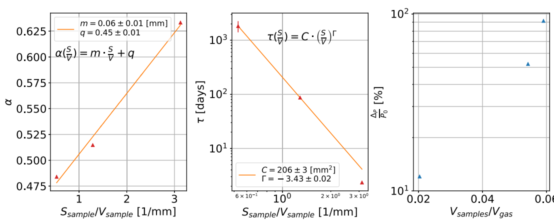
We have performed absorption measurements inside a bake-and-fill system (BFS) [3], built ad hoc for producing and testing the GPDs, in an independent sealed chamber called Absorption Chamber (AC) equipped with pressure and temperature sensors for assuring and quantify the hypothesis of gas absorption by the glue Masterbond Supreme 10HT, used for bonding all the GPDs, and searching for the $p(t)$ law. The measurements have been performed with three different sets of glue samples having different volumes and exposed surfaces, with starting pressure of 1200 mbar. The curves are well-fitted by a *stretched*

* Corresponding author.
E-mail address: chiara.tomaiuolo@pi.infn.it (C. Tomaiuolo).

https://doi.org/10.1016/j.nima.2024.169881
Received 29 June 2024; Received in revised form 28 August 2024; Accepted 12 September 2024
Available online 16 September 2024



(a) Pressure as a function of time from filling.



(b) Trends of the stretched exponential model parameters as a function of the size of the epoxy samples.

Fig. 1. Fit of the equivalent pressure inside the AC filled with DME with and without the glue samples. In the colored boxes of (a) the volume V_i and the ratio $\frac{S_i}{V_i}$ of the samples is shown and in the white boxes the fit results for all the samples are given. The curve without samples confirms that the glue is the absorber. In (b), the trends of the parameters α, τ and $\frac{\Delta_p}{P_0}$ as functions of the size of the samples are shown.

exponential model:

$$p_{gas}(t; p_0, \Delta_p, \alpha, \tau) = p_0 - \Delta_p \cdot (1 - \exp^{-(\frac{t}{\tau})^{\alpha}}) \tag{2}$$

As shown in the boxes of Fig. 1, the fit results in $\alpha < 1$ for every set of samples, causing the enlargement of the time scale of the process with respect to Eq. (1). Intuitively, the gas attaches rapidly to the glue surface and diffuses slowly down the material: the absorption parameters trends show for the three datasets at our disposal that the asymptotic amount of absorbed gas Δ_p depends on the volume of the samples, whereas the characteristic time τ depends on the ratio $\frac{S_{\text{sample}}}{V_{\text{sample}}}$ with a power law, showing that maximizing the exposed surface, with fixed volume, reduces the characteristic time and also increases the stretching parameter α.

The stretched exponential model has been used for the combined fit of the three pressure proxies on a control GPD named GPD 38 in [1], the χ^2/ndof improves from 907/151 to 424/150. In the following weeks, the measurements of the time trend of the pressure for a GPD filled inside the BFS will be performed and analyzed in order to confirm the model goodness and if so, the fit parameters given by the proxies fit. Together with direct measurements on a GPD, a new set of samples prepared with a different glue will be tested.

3. GEM charging effect

Charge deposit in the dielectric layer of the GEM decreases the detector gain by lowering the effective amplification field. The effect can be described by a capacitor-like model [1]: charge builds up when the detector is irradiated and slowly dissipates over several tens of hours. The process is regulated by a set of 3 parameters: (*i*) the charging constant k_c (the 'capacity' of the model); (*ii*) the discharge characteristic time τ_d; (*iii*) the maximum asymptotic gain decrease δ_{max}.

The model currently employed to account for GEM charging in the IXPE data processing pipeline does not perfectly reproduce the observed behavior. For bright sources, such as the Crab Nebula, a

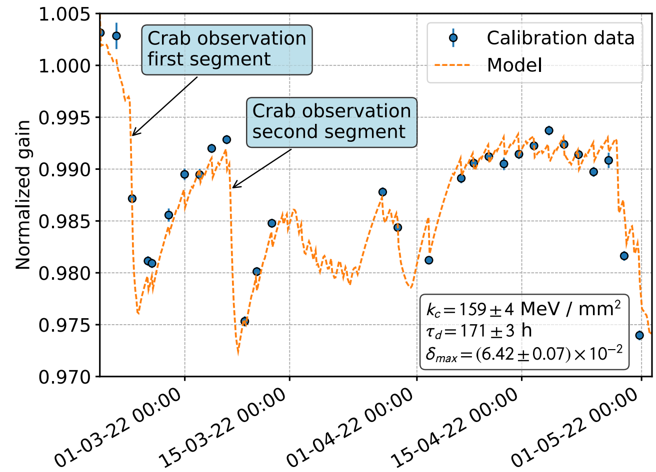


Fig. 2. Normalized gain, averaged across the detector surface, as a function of time, during the time period used for fitting the charging model. Each blue dot correspond to an observation (typically lasting ∼15–20 min) of one of the on-board ^{55}Fe calibration sources. The gain is measured by fitting the peak of the observed spectrum with a Gaussian function.

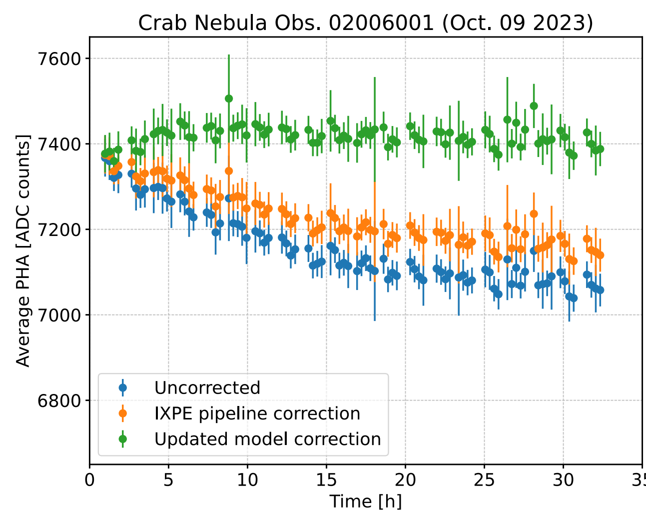


Fig. 3. Average measured energy in Detector Unit 2 as a function of time during an IXPE observation of the Crab Nebula.

residual trend of a few percent remains after the correction (Fig. 3). We attribute this discrepancy entirely to imperfections of the gain model, as other known systematic effects on the gain are not expected to show a similar dependency from the source rate.

An improved estimation of the model parameters has been obtained using one of the on-board calibration sources [2], which provides a ^{55}Fe line (5.9 keV) with nearly uniform illumination across the detector surface. Calibration data are routinely acquired while celestial targets are obscured by the Earth.

We used 11 weeks of data between February and May 2022 to fit the model to data (Fig. 2). The parameters obtained by the fit have been tested on a different observation of the Crab Nebula, showing that the correction algorithm with the updated constants significantly flattens the gain variation over time (Fig. 3).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] L. Baldini, et al., Astropart. Phys. 133 (2021) 102628, http://dx.doi.org/10.1016/j.astropartphys.2021.102628.

[2] M.C. Weisskopf, et al., J. Astron. Telesc. Instrum. Syst. 8 (2) (2022) 026002, http://dx.doi.org/10.1117/1.JATIS.8.2.026002.

[3] L. Lucchesi, et al., in: O.H. Siegmund, K. Hoadley (Eds.), UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy XXIII, vol. 12678, International Society for Optics and Photonics, SPIE, 2023, 126781A, http://dx.doi.org/10.1117/12.2676673.