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

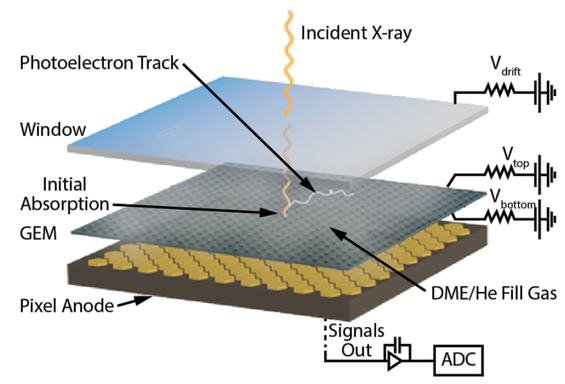
Chiara Tomaiuolo[1], Alberto Manfreda[2], Leonardo Orsini[1], and Stefano Tugliani[3]
[1]INFN-Pisa, [2]INFN-Napoli, [3]INFN-Torino

The Gas Pixel Detector

Multi-purpose X-ray gas detector in the energy band 2–8 keV based on photoelectric effect, capable of providing **imaging**, **spectroscopy** and **polarimetry**.

- The filling gas is Dymethyl Ether (DME) CH_3OCH_3 inside a sealed cell
- The amplification stage is provided by a Gas Electron Multiplier foil (GEM)
- The readout consists of a custom ASIC of $15 \times 15\,\mathrm{mm}^2$, made of a hexagonal grid of pixels with $50\,\mu\mathrm{m}$ pitch

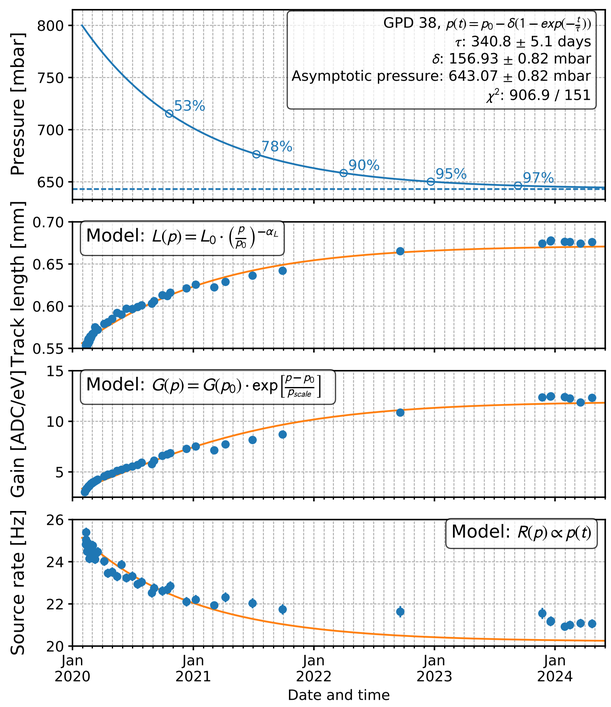
Three identical GPDs are hosted in the focal plane of the Imaging X-ray Polarimetry Explorer (IXPE) satellite [1], which has been observing the X-ray sky since its launch on December 9, 2021.



Pressure variations inside control GPDs

During the GPDs' construction, a slow pressure decrease inside the sealed gas cells has been observed, despite the absence of leaks. This effect is caused by the glue bonding the detector parts, which absorbs a fraction of the gas on a time scale of years, leading to a deficit in pressure of more than 100 mbar, from a starting pressure of 800 mbar.

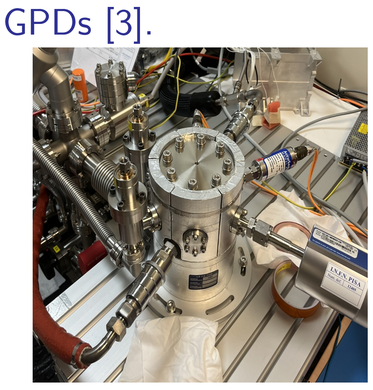
- The gas pressure inside GPDs is monitored indirectly performing a combined fit of three proxies measurements: the **detector gain**, the **track length** and the **relative event rate** in a controlled setup, assuming at the base a single exponential trend for $p(t)$ [2]. Measurements are taken periodically in a dedicated facility.
- As secular monitoring continues, a simple exponential model for $p(t)$ shows unsatisfactory results.



Absorption measurements - setup and results

We have performed gas absorption measurements in order to seek a more reliable model for $p(t)$ inside a dedicated chamber, part of a bake-and-fill system built ad hoc for producing and testing the GPDs [3].

- Fillable with Ar/CO_2 or DME, thermally controlled and equipped with pressure and temperature sensors.
- Gas absorption measurements for three sets of cured epoxy samples (Masterbond Supreme 10HT) with different volumes and surfaces.



The DME absorption by glue is modeled with a **stretched exponential**:

$$P_{gas}(t; P_0, \Delta_P, \alpha, \tau) = P_0 - \Delta_P \cdot (1 - \exp^{-(\frac{t}{\tau})^{\alpha}})$$

- $\alpha < 1$ for all sets, stretching the characteristic times wrt the simple exponential;
- χ^2/ndof for GPD 38 reduces to 424/150 with $\alpha_{\mathrm{GPD}} = 0.478 \pm 0.028$.

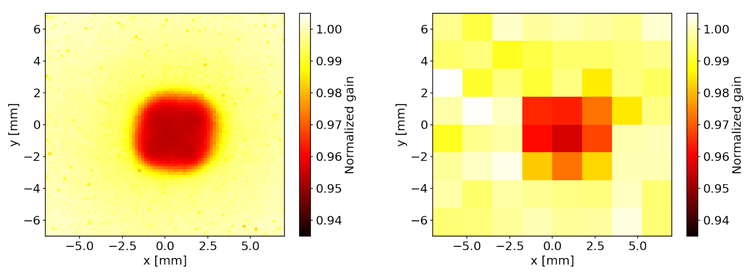
Correction of GEM charging effects

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** [2]:

- Charge builds up when the detector is irradiated and slowly dissipates over several tens of hours
- Each point on the detector surface accumulates charge independently of the rest

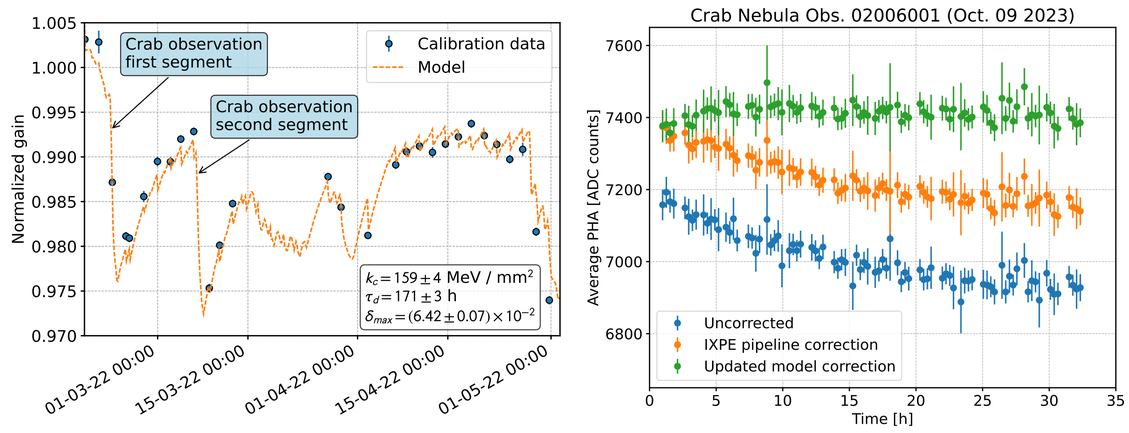
The process is regulated by a set of 3 parameters:

- the charging constant k_c (the 'capacity' of the model)
- the discharge characteristic time τ_d
- the maximum asymptotic gain decrease δ_{max}



Simulated (left) and measured (right) map of the gain of one of IXPE GPDs after the observation of the Crab Nebula in February 2022

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 residual trend of a few percent remains after the correction.
An improved estimation of the model parameters has been obtained using one of the on-board calibration sources [1], 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. 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.



References

[1] Weisskopf, M. C. et al., *Imaging X-ray Polarimetry Explorer: prelaunch*, https://arxiv.org/abs/2112.01269
[2] Baldini, L. et al., *Design, construction, and test of the Gas Pixel Detectors for the IXPE mission*, https://arxiv.org/abs/2107.05496
[3] Lucchesi, L. et al. *Advances in gas pixel detectors for X-ray polarimetry: development of the bake and fill system (BFS)*, https://www.spiedigitallibrary.org/conference-proceedings-of-spie/12678.toc#_=_