Quasi-periodic pulsations or homologous flares? The ambiguous nature of the event observed by STIX

Żaneta Szaforz[1,2] and Tomasz Mrozek[1]

1. Space Research Centre, Polish Academy of Sciences, Bartycka 18A, 00–716 Warszawa, Poland
2. Astronomical Institute, University of Wrocław, Kopernika 11, 51–622 Wrocław, Poland

We investigated a solar flare that occurred on 22 May 2021. Four regular maxima were observed both on STIX/Solar Orbiter and XRS/GOES light curves, which suggest the occurrence of quasi-periodic pulsations (QPPs). The AIA/SDO images, however, revealed that the first X-ray burst is correlated with the EUV brightening that occurred in other magnetic structure than the remaining three. It is therefore unclear if this is QPPs event or a series of homologous flares.

1 Introduction

In a light curve of a standard solar flare, we can typically distinguish three stages. It usually begins with the impulsive phase – a series of bursts in the radio and in the hard X-ray (HXR) radiation. During the next, thermal phase, we observe further heating of the plasma accompanied by the emission visible in the extreme ultraviolet (EUV) and the soft X-ray (SXR) radiation. The flare ends with the decay phase, during which the coronal plasma gradually returns to its pre-flare conditions.

However, the light curves of solar flares may differ from this simple scenario. Sometimes, a series of bursts in intensity which occur in a nearly periodic fashion can be observed. We call them quasi-periodic pulsations (QPPs). This kind of feature was observed in the entire electromagnetic spectrum – from radio to gamma rays. The pulses visible in different wavelengths are usually well correlated. Typically, the periods of pulsation ranged from factors of seconds to several minutes. Unfortunately, the underlying physical mechanism responsible for QPPs excitation has not yet been definitively identified. Usually, they are interpreted as the manifestation of magnetohydrodynamic (MHD) processes in flaring magnetic structures or as the result of repetitive regimes of the magnetic reconnection (see recent reviews: Zimovets et al. (2021), Kupriyanova et al. (2020), Van Doorsselaere et al. (2016)).

On the other hand, there are also cases, when an active region produces a series of flares with similar light curves. We call them homologous or recurrent flares (Martres (1989), Takasaki et al. (2004), Chandra et al. (2011)). Folded lightcurve from such a series of flares may exhibit characteristics similar to QPPs events. Therefore, imaging observations are needed to reveal a mechanism producing registered features in a X-ray light curve.

We present analysis of the flare of 22 May 2021, which manifests features of both QPPs and homologous events. In Sec. 2 the data and methodology are presented. Discussion of results and current work summary is given in Sec. 3.

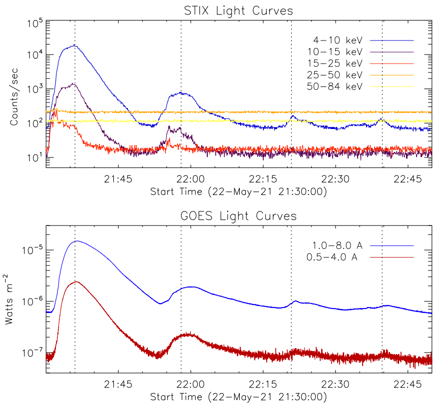

Fig. 1: The light curves recorded by STIX (top panel) and GOES (bottom panel) during the flare of 22 May 2021. The dashed vertical lines indicate the four observed maxima.

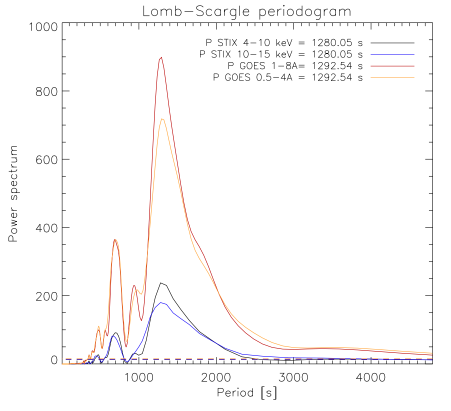

Fig. 2: The power spectrum calculated with the Lomb-Scargle algorithm. The dashed horizontal lines indicate the 0.99 level of significance.

2 The 22 May 2021 flare

The event started on 22 May 2021 at 21:30 and was observed by The Spectrometer Telescope for Imaging X-rays (STIX, Krucker et al. (2020)) onboard Solar Orbiter. We analysed STIX quick-look light curves, provided in five energy bands covering 4–150 keV range, with a time resolution of 4 s. In the energy ranges of 4–10 keV and 10–15 keV four regular bursts of the HXR radiation were evident in the light curves (Fig. 1, top panel).

We separated HXR pulses from STIX light curves by subtracting a trend (the de-trending procedure was described in Szaforz & Tomczak (2015)). For period estimation the Lomb-Scargle periodogram method (Scargle, 1982) was used. The obtained power spectrum (Fig. 2) reveals 1280 s periodicity in the both energy ranges. A similar pattern of four maxima, with the period of 1292 s, was observed in GOES light curves (Fig. 1, bottom panel) registered in two bands: 0.5–4 Å and 1–8 Å.

The pattern visible on the STIX and GOES light curves suggests the occurrence of QPPs. AIA/SDO images showed, however, that although all the HXR impulses come from the same active region, the first maximum was produced by a slightly different magnetic structure than the other three (Fig. 3). Therefore it is unclear if this is a QPPs event or a series of homologous flares.

3 Discussion and Conclusions

STIX provides an excellent tool to observe QPPs of solar flares. It provides spectroscopic information in the range of 4–150 keV with the 1 keV spectral and up to 0.1 s time resolution. However due to telemetry limitations, the high-resolution data is available only for selected flares. On the other hand, the STIX quick-look light curves having a worse temporal and spectral resolution have been provided almost continuously since 1 January 2021.

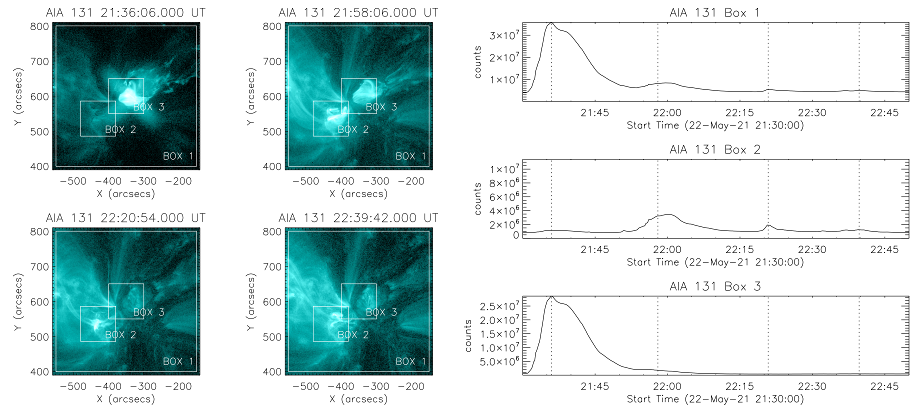

Fig. 3: *Left*: AIA/SDO 131 Å at the times of the four HXR maxima. *Right*: AIA/SDO 131 Å fluxes inside three boxes marked on the images. The dashed vertical lines indicate the times of the four maxima observed in HXR.

The 22 May 2021 solar flare proves, that for the QPPs analysis spatial information is essential. Without this context information, it is difficult to distinguish whether all observed HXR bursts come from the same magnetic structure. Unfortunately, the STIX imaging system still undergoes tests and calibrations on orbit. The MARLIN algorithm (Siarkowski et al., 2020), currently being developed in the Solar Physics Division of the Space Research Centre, will soon allow the reconstruction of X-ray images with the high spatial resolution. It will enable us to investigate individual HXR sources located as close as 7 arcsec.

Acknowledgements. The authors are grateful to the STIX, SDO, and GOES teams for providing excellent observational data. This investigation has been supported by Polish National Science Centre grant No. 2020/39/B/ST9/01591.

References

Chandra, R., et al., *Sol. Phys.* **269**, 1, 83 (2011)

Krucker, S., et al., *A&A* **642**, A15 (2020)

Kupriyanova, E., Kolotkov, D., Nakariakov, V., Kaufman, A., *Solar-Terrestrial Physics* **6**, 1, 3 (2020)

Martres, M. J., *Sol. Phys.* **119**, 2, 357 (1989)

Scargle, J. D., *ApJ* **263**, 835 (1982)

Siarkowski, M., et al., *Open Astronomy* **29**, 1, 220 (2020)

Szaforz, Ż., Tomczak, M., *Sol. Phys.* **290**, 1, 115 (2015)

Takasaki, H., et al., *ApJ* **613**, 1, 592 (2004)

Van Doorsselaere, T., Kupriyanova, E. G., Yuan, D., *Sol. Phys.* **291**, 3143 (2016)

Zimovets, I. V., et al., *Space Sci. Rev.* **217**, 5, 66 (2021)