# Looking for the cause of the quasi-periodic pulsations in solar flares

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We investigated quasi-periodic pulsations (QPPs) of a solar flare that occurred on 28 May 2011. The X-ray lightcurves of *RHESSI* and *GOES* satellites revealed a period of oscillations of about 5.5 min. Attempts to explain these oscillations by using the commonly acknowledged MHD models come to the end without any success. We suggest that the observed QPPs can be caused by the external modulation of the reconnection process with the new emerging magnetic flux.

## 1 Introduction

Lightcurves of solar flares show sometimes distinguish impulsive changes of intensity, occurring in a nearly periodic fashion. We call them quasi-periodic pulsations (QPPs). This kind of feature can be visible in many energy bands – from radio to gamma rays. The pulses in different energies are usually well correlated. Typically, the periods of pulsation ranged from factors of seconds to several minutes. Unfortunately, it has not been possible yet to definitively identify the underlying physical mechanism responsible for QPPs excitation. 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 (Van Doorsselaere et al., 2016).

In this paper we present the flare showing quite large periods of oscillations – of the order of few minutes, which was observed on 28 May 2011, simultaneously by both: *RHESSI* (The Reuven Ramaty High Energy Solar Spectroscopic Imager, Lin et al., 2002) and *GOES* (Geostationary Operational Environmental Satellites). Similar case was observed on 5 Feb. 2016. Preliminary analysis of this event can be found in Szaforz & Tomczak (2016). In Sec. 2 of this paper data and methods of our analysis are presented. Discussion of our results and current work summary is given in Sec. 3.

## 2 The 28 May 2011 flare

The C1.6 flare of 28 May 2011 occurred in the active region AR1226 close to the eastern limb of the solar disk. The analysis revealed that the three energy bands of *RHESSI* (3–6, 6–12 and 12–25 keV) and both *GOES* lightcurves (0.5–4 and 1–8 Å) show oscillations with three main maxima of intensity. The pulses visible in soft X-rays were in good correlations with the hard X-ray (HXR) observations. The determined periods for individual lightcurves ranged between 330 and 355 s. The periods were obtained using two methods: by determining the auto-correlation function and by calculating the Lomb-Scargle periodogram. In order of a fact that

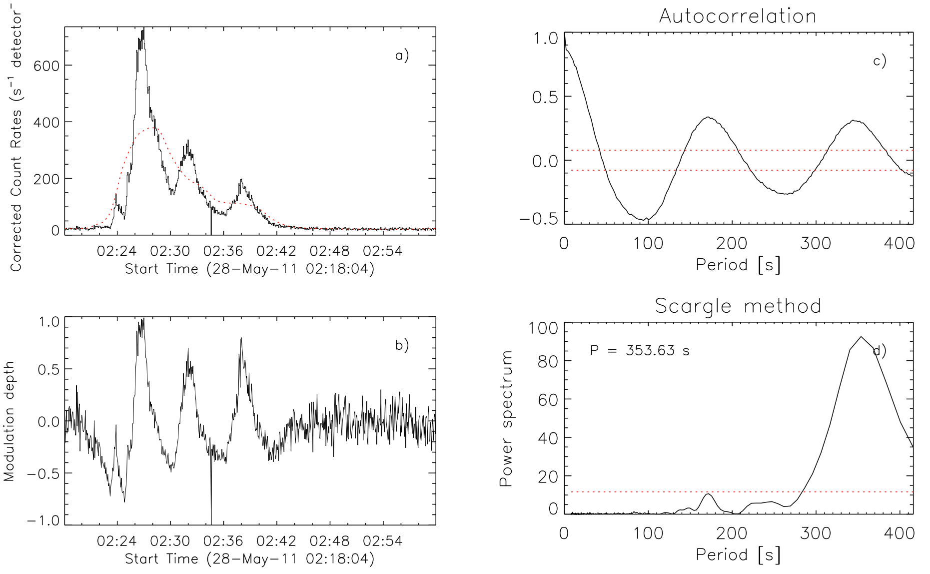


Fig. 1: a) The hard X-ray lightcurve recorded by *RHESSI* in the energy band 12–25 keV during the flare on 28 May 2011. The dashed red line shows the running average. Panel b) shows the normalized time series $S(t)$, c) – the auto-correlation function, and d) – the power spectrum calculated for the normalized lightcurve $S(t)$, with the Lomb-Scargle algorithm. The red horizontal lines in the c) and d) panels represent the levels of significance (0.95 for the auto-correlation and 0.99 for the Lomb-Scargle algorithm).

QPPs usually occur simultaneously with a gradual component in the HXR flux (Tomczak, 2001), we defined first normalized time series, $S(t)$, as follows

$$S(t) = \frac{F(t) - \hat{F}(t)}{\hat{F}(t)}, \tag{1}$$

where $F(t)$ is the measured HXR flux and $\hat{F}(t)$ is the running average of $F(t)$. The original lightcurve of the flare of 28 May 2011 recorded by *RHESSI* in the energy band 12-25 keV (black line) and the running average (dashed line) of the investigated flare are shown in Fig. 1a. Fig. 1b shows the normalized time series $S(t)$. The auto-correlation function and the Lomb-Scargle periodogram are shown in Fig. 1c and 1d, respectively.

The Expextation Maximalization method was used to reconstruct the hard X-ray images from the *RHESSI* observations. The images revealed small HXR source that overlaps with the small magnetic loop visible in EUV images recorded by *AIA/SDO* (Atmospheric Imaging Assembly/Solar Dynamics Observatory, Lemen et al., 2012). The size of the HXR source (inside the contour of 50% of the brightest pixel on the HXR image) was about 5 Mm $\times$10 Mm at the time of the main maximum of the flare.

The temperature and emission measure of the flaring plasma can be determined from the *GOES* observations using the filter ratio method. We estimated also the electron number density and the Alfvén speed, using the formulae described by

Szaforz & Tomczak (2016). At the maximum of the flare, the temperature of the plasma reached 12.5 MK, the emission measure was $7.5 \times 10^{47}\,\mathrm{cm}^{-3}$, the electron number density – $9.9 \times 10^{10}\,\mathrm{cm}^{-3}$, and the Alfvén speed was $612\,\mathrm{km\,s}^{-1}$.

## 3 Discussion and Conclusions

We presented an interesting example of the flare with clear quasi-periodic pulsations in both soft and hard X-ray bands. To explain the observed periodicity of QPPs we employed several interpretations proposed in the literature.

The observed QPPs were not excited by the fundamental kink and sausage modes of MHD waves in the flaring loop (Nakariakov et al., 2016; Nakariakov & Melnikov, 2009, and references therein). For this kind of modes to excite the oscillations with period of 5.5 min, the oscillating loop should be much larger that the loop visible in *AIA/SDO* observations. For the same reason, we claim here that the QPPs are not a result of periodic compressions and expansions of magnetic traps, located in the upper part of the flare loop (the Oscillating Magnetic Traps model proposed by Jakimiec & Tomczak, 2010).

We suggest that a new emerging magnetic flux is responsible for the observed QPPs. It works as a trigger, which initiates the reconnection process, when MHD equilibrium is temporary disturbed.

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