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Solar flare pulsation spectra

Yu.A. Kupryakov[1,2], A.B. Gorshkov[2], L.K. Kashapova[3]

[1] Astronomical Institute ASCR, Fričova 298, Ondřejov 251 65, Czech Republic
e-mail: kupry@asu.cas.cz

[2] Sternberg Astronomical Institute, Moscow State University, Universitetsky pr. 13, Moscow 119234, Russia
e-mail: gorshkov@sai.msu.ru

[3] Institute of Solar-Terrestrial Physics SB RAS, Irkutsk 6640333, Russia
e-mail: lkk@iszf.irk.ru

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ABSTRACT

We present the results of the analysis of quasiperiodic pulsations of chromospheric emission from three solar flares. The study is based on observational data obtained with two ground-based spectrographs: the Multichannel Flare Spectrograph and the Horizontal-Sonnen-Forschungs-Anlage 2 of the Ondřejov Observatory (Astronomical Institute of the Czech Academy of Sciences). The analysis of the power spectra of time profiles obtained using both spectrograms and filtergrams is carried out. The revealed periods were compared with the results of periodicity analysis in the X-ray and microwave ranges. For those events where the duration of observations allowed, a period close to 5 minutes was found from both the data of chromospheric observations and the data obtained in the X-ray and microwave ranges. We also found the periods about 1.4–1.8 and 2–3 minutes, which simultaneously appeared in all studied ranges.

Key words: spectrograph, solar flares, quasiperiodic pulsations, chromospheric radiation

1 Introduction

Quasi-periodic pulsations (QPPs) are observed in the time profiles of solar flares in a wide range of radiation – from microwave and UV to radiation in chromospheric lines and gamma-ray emission. The duration of QPP periods varies from subseconds to tens of minutes, which indicates the different nature of the origin of these pulsations. There are currently two main classes of mechanisms. The first one associates the observed pulsations with the direct impact of magnetohydrodynamic (MHD) waves, and the second – with a repetitive process of magnetic reconnections (see Kupriyanova et al., 2019, 2020). Mechanisms of two classes often coexist and complement each other. For example, the process of magnetic reconnection can be initiated by MHD waves. The absence or presence of QPPs in several spectral ranges, the change of properties from one spectral range to another make it possible not only to refine the contribution but also to diagnose the properties of flare plasma. Our work is devoted to the search for QPPs in the chromospheric emission of solar flares, which, on the one hand, is the most observable and characteristic of such events. On the other hand, the emission of this region of the solar atmosphere is formed under the effect of many parameters that vary over a wide range – temperature, density, and plasma motion. For analysis we have selected three flares of classes from C to M (SOL2011-04-22, SOL2013-05-19, and SOL2013-05-17), the observations of which were obtained at the observatory of the Czech Academy of Sciences (Ondřejov) with the Multichannel-Flare-Spectrograph (MFS, 230 mm/13.5 m) and the Horizontal-Sonnen-Forschungs-Anlage 2 (HSFA-2, 500 mm/35 m). We have also made use of the time profiles in the X-ray range obtained with the Ramaty High Energy Solar Spectroscope Imager (RHESSI) (Lin et al., 2002), Gamma-Ray Burst Monitor (Fermi/GBM) of the Fermi Gamma-Ray Space Telescope (Meegan et al., 2009), and microwave observations by the Radio Solar Telescope Network (RSTN).

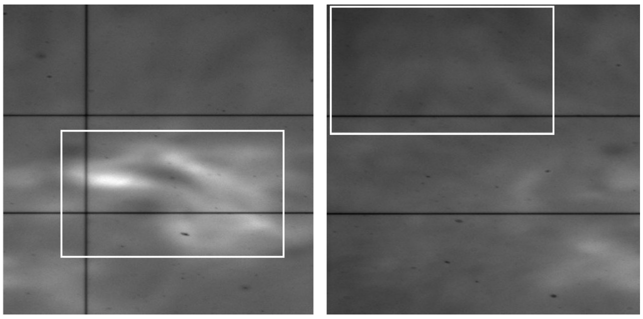

Fig. 1. An example of determining the intensity integral from the slit-jaw (filtergram in the line Hα – SJ) in the active (left) and quiet (right) regions of the flare. The area under study, in which the integral is got, has dimensions of 200 × 353 pixels.

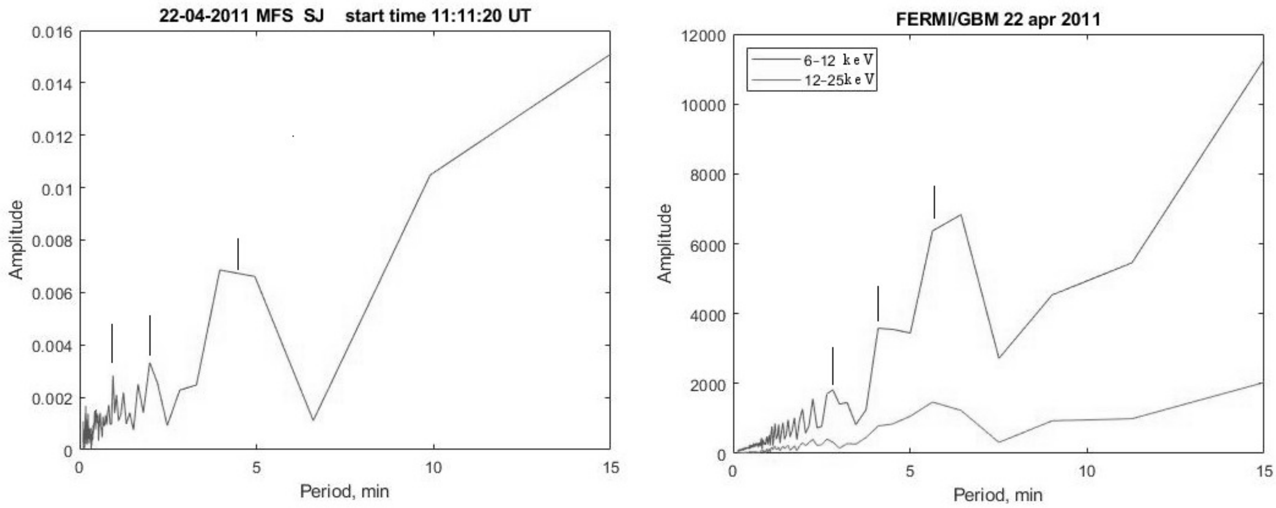

Fig. 2. a) Relationship of the power amplitude to the period *P*. The marked values of *P* correspond to 0.99, 1.98, and 4.7 min. Processed time interval: 11:11:20–11:27:39 UT (duration 16.3 minutes); b) The graph shows the power spectrum of the data obtained by FERMI. Marked values correspond to periods 2.97, 3.96, and 5 min.

2 Observations and processing

We have considered the following solar flares:

A. The class C2.6 flare on April 22, 2011 occurred in the active region NOAA 11195 (beginning at 11:07, maximum at 11:25, ending at 11:37 UT). An example of the resulting image from HSFA is presented in Fig. 1. Images were recorded with 3-second intervals. After calibrating the images we obtained the intensity integral for the active and quiet regions. Figure 2a shows the amplitude of the oscillation power relative to the period for the processed observation interval of 11:11:20–11:27:39 UT, which corresponds to the period after the flare maximum according to the GOES observations. While constructing power spectra the fast Fourier transform procedures with a preliminary trend subtraction were used. Several characteristic peaks are clearly seen in the graph with oscillation periods of 0.99, 1.98, and 4.7 minutes. From other sources for this flare we were only able to find the FERMI/GBM data. They are presented in Fig. 2b.

B. The C3.4 class flare on May 19, 2013 (beginning at 09:08, maximum at 09:15, ending at 09:24 UT) was observed in the active region NOAA 11750 with MFS. Data were recorded with 10-second intervals. The observation time interval is 09:21:49–09:29:39 UT (duration 7.8 minutes). Figure 3 shows a snapshot of the studied area, and Fig. 4a illustrates a power spectrum after data processing. The maximum that corresponds to an oscillation period of 1.4 minutes is clearly seen. From external sources we found only the RHESSI data. The power spectrum for 6–12 keV constructed by us is shown Fig. 4b. The periods of oscillations of 0.83 and 1.4 minutes are noticeable.

C. Finally, the last flare we considered was M3.2 class on May 17, 2013 (beginning at 08:43, maximum at 08:57, ending at 09:19 UT) in the active region NOAA 11748. The observations were carried out with the MFS and HSFA-2 spectrographs.

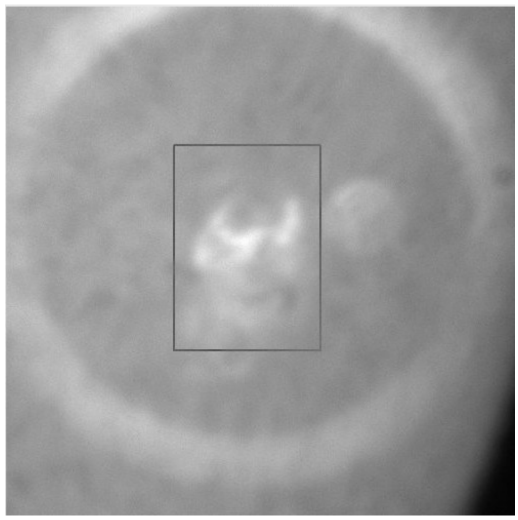

Fig. 3. The intensity integral for the flare in the active region and the region of the quiet chromosphere (200×143 pixels). The white circle around the active region is formed by the aperture of the instrument.

The integral intensity was obtained in the way described above (Fig. 5), and then a power spectrum was constructed. As can be seen from the plot in Fig. 6, the oscillations with periods of 1.0, 1.2, 2.0, 2.8, and 4.8 minutes can be distinguished.

The calibrated spectra obtained with the HSFA-2 spectrograph with an interval of 3 seconds are shown in Fig. 7.

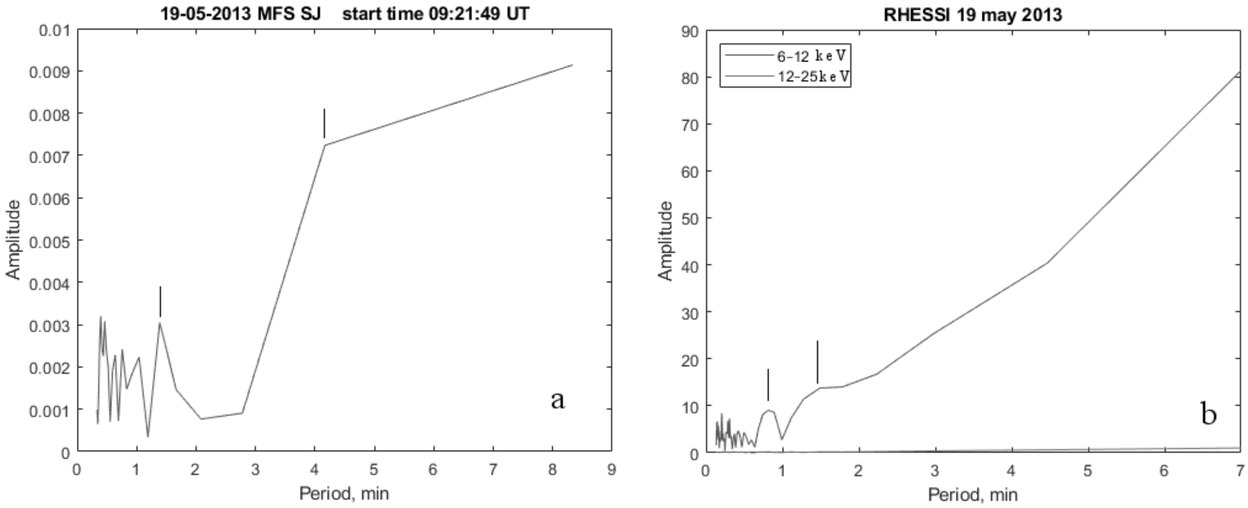

Fig. 4. a) Data power spectrum over SJ frames (duration 7.8 minutes). Marked values correspond to $P = 1.4$ min; b) RHESSI power spectrum for 6–12 keV, $P = 0.83$ and 1.4 min.

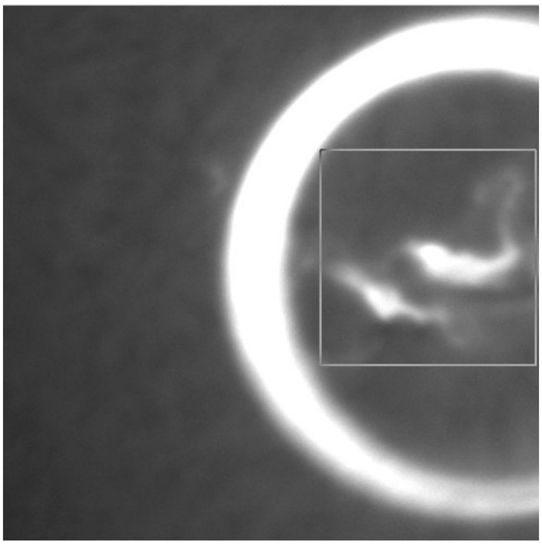

Fig. 5. Determination of the integral flare intensity on 05-17-2013, MFS, M3.2 for the interval 08:42:43–09:27:09 UT. The white circle is the instrument aperture.

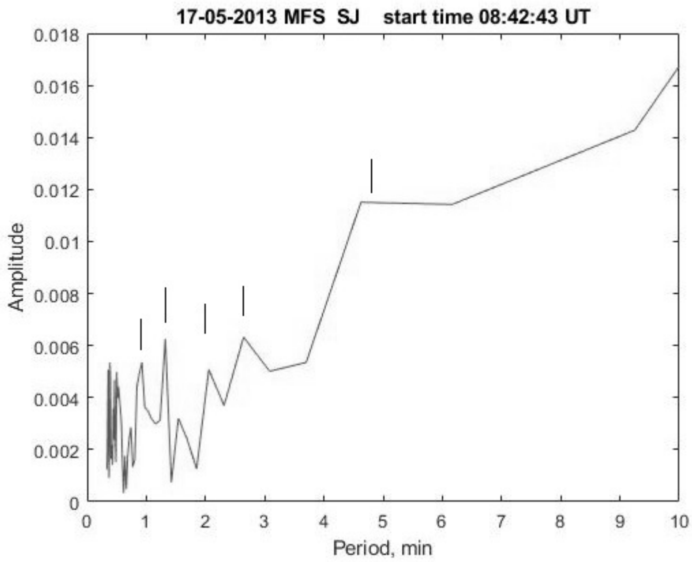

Fig. 6. Power spectrum, the marked values: 1.0, 1.2, 2.0, 2.8 and 4.8 min.

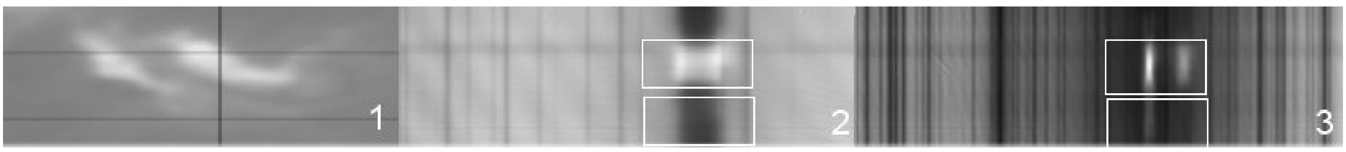

Fig. 7. An example of the calibrated images of SJ (1), Hα (2), and CaII H (3) obtained with HSFA-2 on May 17, 2013 at 08:59:37.753 UT. We mark the areas for which the integral intensity was taken in the active and quiet regions of the flare.

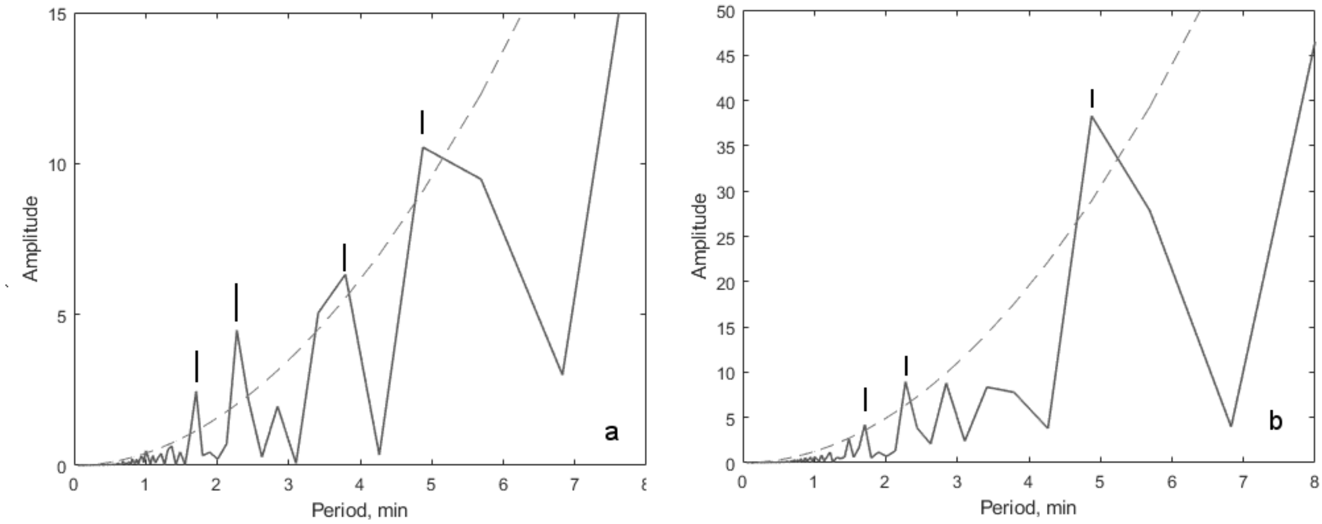

Fig. 8. Power spectra for the interval 0841:53–0901:36 UT (duration 19.9 min). Marked values: (a) Hα – 1.66, 2.3, 3.66, 5 min; (b) CaII H – 1.83, 2.33, 5 min. The dotted line marks the significance level 95%.

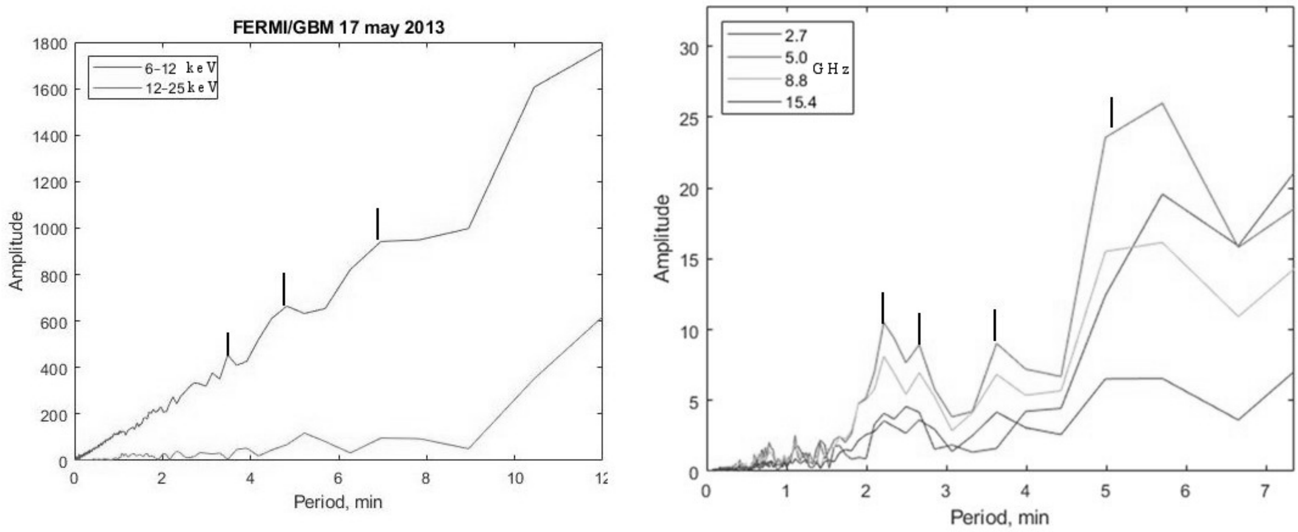

Fig. 9. a) Power spectrum from the FERMI data. The top plot corresponds to the range of 6–12 keV. Marked values: 3.25, 5.0, 7.0 min; b) Graphs are based on the RSTN data. Marked values correspond to the oscillations with periods of 2.23, 2.84, 3.67, 5.0 min.

The result of constructing the power spectra is presented in Fig. 8.

For the FERMI 6–12 keV data, the maxima on the graph (Fig. 9a) correspond to 3.25, 5.0, and 7.0 minutes, and for microwave data at 2.7, 5.0, 8.8, and 15.4 GHz we revealed oscillations with frequencies of 2.23, 2.84, 3.67, and 5.0 minutes (Fig. 9b).

3 Conclusions

During the study, filtergrams (SJ) in the Hα line and spectra in the Hα and CaII H lines were processed. Time profiles for different parts of three solar flares were obtained: May 19, 2013 RHESSI; May 17, 2013 and April 22, 2011. The data of chromospheric observations were supplemented with information about emission in the X-ray range (FERMI / GBM, RHESSI), as well as for the flare on May 17, 2013 with observations in the RSTN microwaves. Power spectra constructed for the studied events indicate a sufficiently wide range of the periods of chromospheric emission from 1 to 5 minutes. For different flares the values have close periods and vary slightly. Comparison of the results obtained for the event of May 17, 2013 according to the data of two spectrographs (Fig. 6 and Fig. 8) gives close values of the periods according to the power spectra oscillations. We note that for the events in which the duration of observations was more than 15 minutes it was possible to detect reliably the presence of a period of about 5 minutes. The periods of about 1.4–1.8 and 2–3 minutes observed in both chromospheric emission and microwave and X-ray bands have also been found. The detected 5-minute oscillations have the same nature as in the study of Chelpanov et al. (2020), i.e., the flare was a modulator of oscillations already existing in the chromosphere. Thus, the obtained results can be used to study the propagation of MHD waves in solar flares according to the method proposed in this study. We note that the other found periods of oscillations of chromospheric emission are associated with the propagation of MHD waves, but their origin needs further study.

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