Open Access Online Journal on Astronomy and Astrophysics
Acta Astrophysica Taurica
www.astrophysicataurica.org

Acta Astrophys. Tau. 5(2), 34–36 (2024)

Analysis and processing technique for the spectra of pulsations of radio, optical and X-ray radiation of the 2015 solar flare

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Received 21 September 2022

ABSTRACT

The work is devoted to the search for quasi-periodic oscillations in the emission of solar flares based on observations in the H CaII, Hβ, Hα, IR CaII 8542 Å chromospheric lines (spectrograph HSFA-2, Ondřejov), which are formed under the influence of many parameters such as temperature, density, motion of matter, which change in wide ranges. After processing the spectra and spectroheliograms, including the RHESSI and RT3 data in the X-ray and radio bands (3 GHz), respectively, oscillation periods close to each other with characteristic values of 1–2 min were revealed. Presumably 5-minute oscillations have also been found in radio and X-ray emission.

Key words: spectrograph, solar flares, quasi-periodic oscillations, chromospheric emission

1 Introduction

Repetitive variations in radiation fluxes are observed in solar flares, for example, those changing according to the harmonic law. However, it is impossible to find exact harmonic signals in observations. In practice, we deal with deviations from the harmonic signal. These are various types of trends and noises of different nature. All these deviations make the observed signal quasi-periodic. Quasi-periodic pulsations (QPPs) of flare radiation serve as an effective diagnostic tool for both the flaring processes themselves and the parameters of thermal plasma and accelerated particles. Currently, there are two main classes of mechanisms for generating QPPs in radiation. The first class associates the observed pulsations with the direct action of magnetohydrodynamic (MHD) waves, and the second one with a repetitive process of magnetic reconnection (see Kupriyanova et al., 2019, 2020). Mechanisms of both classes often coexist and complement each other. The objective is to search for and determine oscillations in the optical, radio, and X-ray ranges. For the optical range, this work is pioneering. In this study, we have used a methodology proposed by Vaughan (2005) and further developed in Pugh et al. (2017) and Kupriyanova et al. (2019).

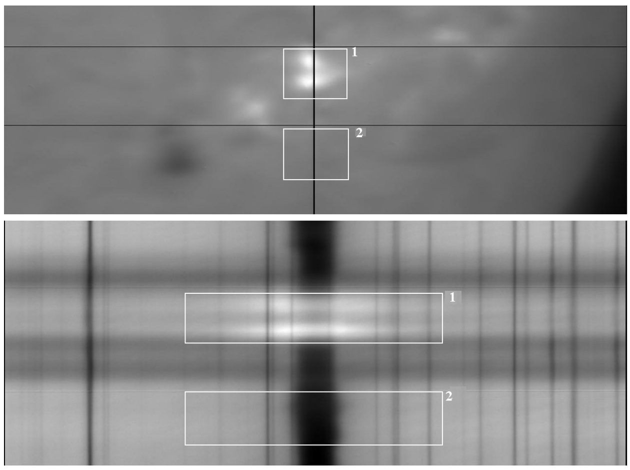

Fig. 1. Filtergram in the Hα line SJ (image at the slit) and spectrum in the Hα line. The size of images in the provided snapshots corresponds to 1280×512 pixels. The filtergram and spectrum in the active (1) and quiet (2) chromospheric regions show the regions defining the integral intensity. The size of these regions was determined based on the resolution of the telescope and spectrograph.

2 Observations and processing

For analysis, we selected a solar flare of class M4.5 occurred on 1 October 2015. The observations were obtained at the Observatory of the Czech Academy of Sciences (Ondřejov) using the Horizontal-Sonnen-Forschungs-Anlage spectrograph

(HSFA-2, 500 mm/35 m). Additionally, temporal profiles in the X-ray range of 6–12 keV were used, acquired with the Ramaty High Energy Solar Spectroscope Imager (RHESSI) (Lin et al., 2002), and microwave observations obtained with the radio telescope RT3 (Ondřejov Observatory) at the frequency 3.0 GHz (Karlický, Jiřićka, 2003). An example of the obtained spectra and filtergrams is presented in Fig. 1. The data were recorded with a 4-second interval. Having calibrated images, we determined the integral intensity in the selected region for the active and quiet chromospheric regions.

2.1 Detection of pulsation frequencies in solar flares

The problem of identifying pulsations in flare emission lies in isolating significant periods against the red-noise background. The basic methodology is outlined in Vaughan (2005), with its application to solar flares detailed in Pugh et al. (2017) and Kupriyanova et al. (2019). Red noise is characterized by spectral power that decreases with frequency following the power law. This makes it different from white noise, whose spectral power is independent of frequency. Here we briefly describe the algorithm for identifying significant periods in the emission of solar flares using the example of a radio flux at 3.0 GHz from the flare on 1 October 2015.

Initially, we have a signal as a function of time (Fig. 2, left graph). Next, we examine the graph in Fig. 3. It represents an algorithm for detecting significant periods in solar flare emission.

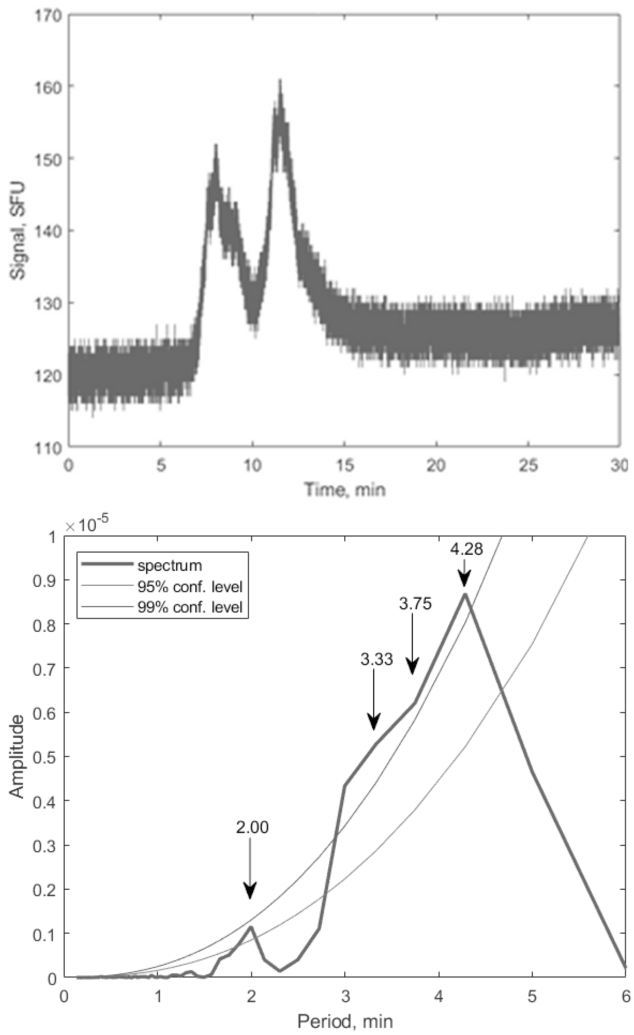

Fig. 2. Data from RT3 (top graph). SFU signal (solar flux units) on 1 October 2015 at a frequency of 3.0 GHz. Power spectrum for RT3 (bottom graph). The signal shown on the left graph indicates that the flare had two peaks. We used the signal during the flare to search for periodicity.

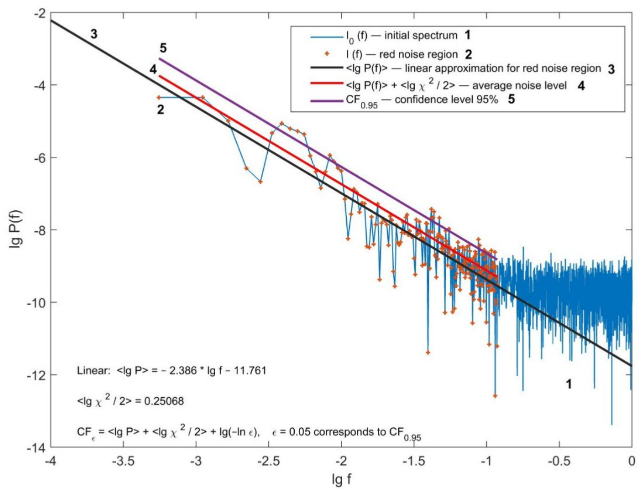

Fig. 3. Example of the algorithm for detecting significant periods in solar radio emission. From the points located on line 5, we selected the most significant ones.

The sequence of actions is as follows:

1. Calculate the spectral power of the signal using the Fast Fourier Transform and plot its logarithm as a function of the logarithm of frequency (line 1). We observe a noisy spectrum, whose power initially linearly decreases (red noise region) and then becomes constant (white noise region).
2. Identify the red noise level in the spectrum (points 2 on line 1), discard a point with minimum frequency (Nyquist frequency).
3. Approximate the obtained spectrum segment with a straight line (line 3).
4. Add the average noise level (line 4), which is a constant, whereas the possibility of using addition is determined by working in a double logarithmic scale.
5. In the final stage of analysis, calculate the level of spectral power above which noise may occur only with a low probability of epsilon. This is the so-called confidence level of spectral peaks (line 5). If epsilon is chosen as 0.05, we say that the spectrum peaks above this level have a confidence level above 95%.

The final spectrum is presented in the right panel of Fig. 2. The graph shows the amplitude of oscillation power depending on the period for the processed observation interval 13:03–13:14 UT (confidence levels 95% and 99% are indicated). Several characteristic peaks with oscillation periods of 2.0, 3.33, 3.75, and 4.28 minutes are clearly visible on the spectrum. A similar analysis was carried out for the Hα line filtergram and spectral lines of H CaII, Hβ, Hα, IR CaII, as well as data from RHESSI (Table 1).

Table 1. Values of oscillation periods in minutes for spectral lines, SJ and RHESSI.

H CaII	Hβ	Hα	IR CaII	SJ	RHESSI	RT3
1.31	1.13	1.31	2.33	1.23	0.66	2.00
1.50	1.31	2.09	3.49	1.82	0.75	3.33
1.90			5.23	3.49	1.41	3.75
						4.28

3 Conclusions

After processing the spectra in the lines (H CaII, Hβ, Hα, IR CaII) and spectroheliograms (SJ), as well as data from RHESSI and RT3, similar values of oscillation periods in the range of 1–2 minutes were obtained taking the confidence level into account. The divergence in values may be due to the fact that radiation in different spectral ranges originates from different chromospheric levels. Presumably, the detected 5-minute oscillations in the 3 GHz radio flux have the same nature as in Chelpanov et al. (2020), i.e., the flare became a modulator of pre-existing chromospheric oscillations. Certainly, red noise may also have instrumental origin. Therefore, observations from different instruments were used, and the oscillation periods were compared with data from Kupriyanova et al. (2019, 2020). The results can be used to study the propagation of MHD waves in solar flares following the methodology outlined in Chelpanov et al. (2020).

Acknowledgments. The authors are grateful to the teams of RHESSI, SDO, and Ondřejov Observatory for providing the opportunity to carry out observations and use data.

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