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Relationship between the Intensity of the SCR Proton Flux and the Parameters of Type II Radio Bursts in the 25-180 MHz Range

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Abstract

The relationship between the intensity of the SCR proton flux and various parameters of type II radio bursts in the 25-180 MHz range has been investigated. The sample under study contains 112 proton events registered for the period from 24-11-2000 to 20-12-2014 years. For the analysis, we used the original records on the fluxes of protons with proton energies > 1-100 MeV from the GOES series spacecraft, as well as the original records of the dynamic spectra of solar radio emission in the 25-180 MHz range according to data from the solar radio spectrograph (SRS). Comparative analysis showed that there is a fairly strong relationship between the intensity of the SCR proton flux and the drift velocity and the relative distance between the harmonics of type II radio bursts.

Introduction

Earlier, in works (Tsap and Isaeva, 2011, 2012, 2013), some issues were considered regarding the relationship between the SCR proton flux and the parameters of type II radio bursts. In the course of studies of the relationship between the frequency drift velocity of meter-decameter type II bursts and the intensity of the proton flux I_p of different energies, two families of events were discovered. This implies the generation of shock waves both in the flare energy release region and in a moving coronal mass ejection (CME) (Isaeva and Tsap, 2011). In works (Isaeva and Tsap, 2011; Tsap and Isaeva, 2012, 2013), the results of studying the efficiency of SCR acceleration by coronal and interplanetary shock waves are presented, as well as arguments in favor of a two-stage proton acceleration process (Tsap and Isaeva, 2012).

A comparative analysis showed that the acceleration of protons by coronal shock waves is more efficient than by interplanetary shock waves, and that the main acceleration of protons occurs in the flare region and additional acceleration at the fronts of shock waves. Study of the fine spectral structure of meter-decameter type II radio bursts showed that there is a fairly strong relationship between the proton flux and the average relative distance $b_i = (f_{i,2}-f_{i,1})/f_{i,1}$ between the 1-st and 2-nd harmonics over time the duration of a type II burst t_i, where the correlation coefficient r between the investigated quantities is ≈ 0.70, while the relationship between the mean drift velocity $V_{i,mII}$ and the proton flux intensity I_p turned out to be weak, where the correlation coefficient r between the proton flux and the drift velocity does not exceed 0.40 (Tsap and Isaeva, 2013). The presence of a low correlation between the proton flux intensity I_p and the frequency drift velocity $V_{i,mII}$ can be associated with a number of reasons, firstly, in (Tsap and Isaeva, 2013), the average drift velocities were used during the duration of a type II burst, and - second, to approximate the harmonics of a type II burst, a model was used that did not give a sufficiently accurate approximation.

Later, in paper (Isaeva, Tsap, 2017), a new regression model (1) was proposed to approximate the harmonics of type II bursts, where $f_{i,j}$ is the frequency of the maximum of a type II burst at a given harmonic at a given time t_i, i- is the reference number, j - harmonic number, a_j and b_j - linear regression coefficients.

$$\log_{10} f_{i,j} = a_j \cdot \sqrt{t_i} + b_j \qquad (1)$$

This model makes it possible to fairly accurately estimate the frequency drift rate for 95% of type II bursts in the 25-180 MHz range, for which the correlation coefficient *r* between the observed and calculated frequency values is $r >= 0.98$. The zero-point time reference for all events corresponded to the beginning of the first harmonic at a frequency of 180 MHz. More accurate detailed studies of the fine structure of type II radio bursts were carried out using the new model (1). It was shown that all type II bursts associated with proton events are characterized by a monotonic decrease in the relative distance between burst harmonics to a minimum value with a subsequent increase (Isaeva, 2019; Tsap, Isaeva, Kopylova, 2020).

This paper presents the results of studying the relationship between the intensity of the SCR proton flux I_p and the parameters of type II radio bursts in the 25-180 MHz range using a new regression model (1). The sample under study contains 112 type II bursts associated with proton events for the period from 24-11-2000 to 20-12-2014 years. For the analysis, we used the original records of the proton flux intensity I_p from the GOES devices with an energy E_p > 1-100 MeV (https://satdat.ngdc.noaa.gov/sem/goes/data/avg/), as well as the original records of dynamic spectra in 25-180 MHz band with SRS (Solar Radio Spectrograph) (http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-radio/rstn-spectral/).

Investigation of the dynamics of the relationship between the intensity of the flux of SCR protons I_p with the drift velocity $V_{i,mII}$ and the relative distance b_i between the harmonics of type II bursts in the range 25-180 MHz over time t_i

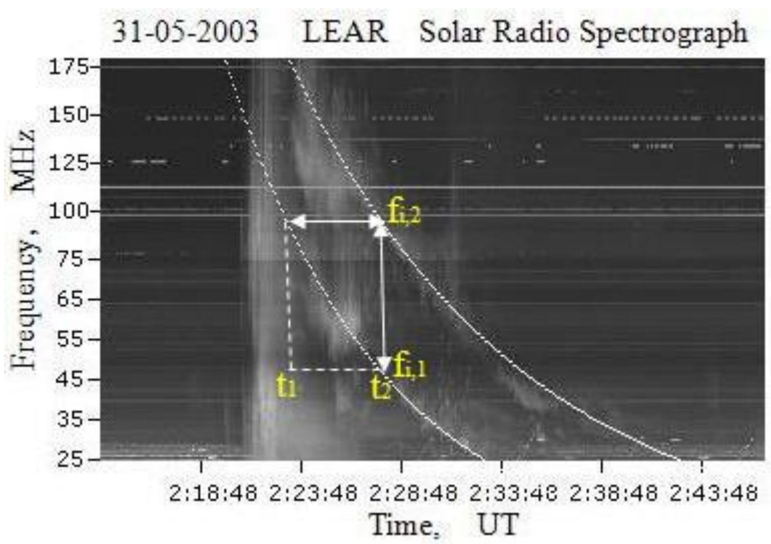


Fig. 1. Methodology for determining the drift velocity $V_{i,mII}$ and the relative distance b_i

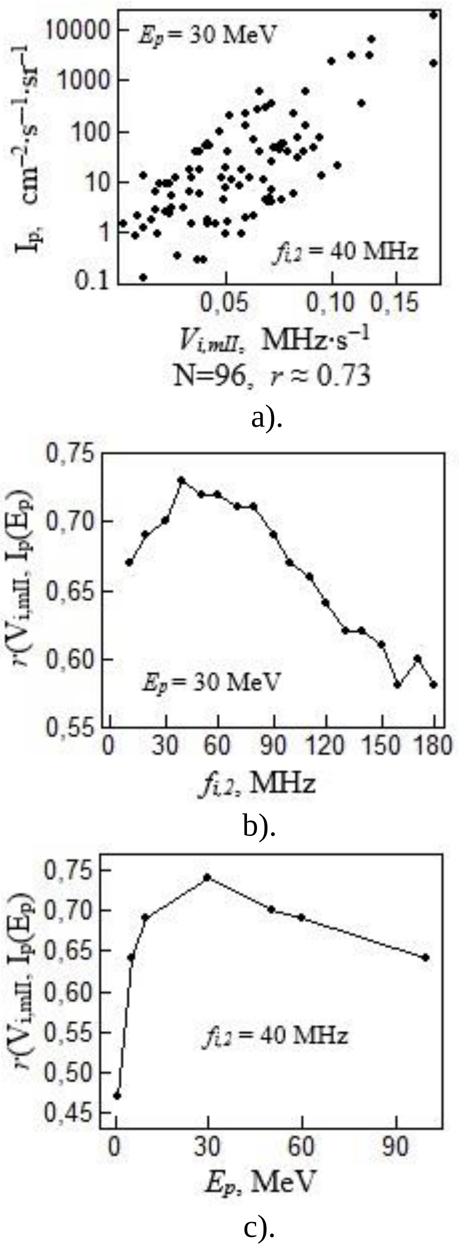
The relationship between the intensity of the SCR proton flux I_p and the drift velocity $V_{i,mII}$ and the relative distance b_i over time t_i in the range 25-180 MHz is investigated. For all investigated proton events, the drift velocities $V_{i,mII}$, and b_i were calculated with a 10 MHz step in the 10–180 MHz range using formulas (2) and (3), respectively,

$$V_{i,mII} = \frac{f_{i,2} - f_{i,1}}{t_2 - t_1} \quad (2)$$

$$b_i = \frac{f_{i,2} - f_{i,1}}{f_{i,1}} \quad (3),$$

where $f_{i,1}$ and $f_{i,2}$ are frequencies at the 1-st and 2-nd harmonics at a given time t_2, which were determined from formula (1). In fig. 1 shows a technique for calculating the drift velocity $V_{i,mII}$ and the relative distance b_i. In fig. 1 that the frequency difference between the harmonics at time t_2 is equal to the frequency difference at the 1-st harmonic in the time interval t_2 - t_1. Therefore, the drift velocity $V_{i,mII}$ is related to the relative distance b_i by relation (4).

$$\boldsymbol{V_{i,mII}} = \frac{\boldsymbol{b_i \cdot f_{i,1}}}{\boldsymbol{t_2 - t_1}} \qquad (4)$$



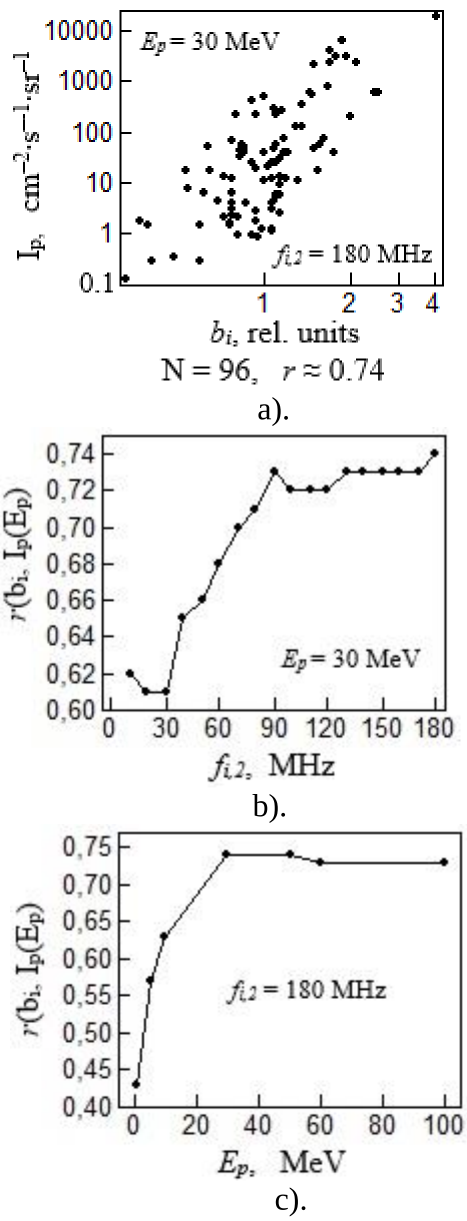


Fig. 2. Relationship between the drift velocity $V_{i,mII}$ and the intensity of the SCR proton flux I_p.

Fig. 3. Relationship between the relative distance b_i and the intensity of the SCR proton flux I_p.

Detailed studies have shown that the relationship between the intensity of the SCR proton flux I_p and the parameters of type II bursts $V_{i,mII}$, and b_i largely depends on the frequency range in which the studies were carried out. In fig. 2 a) and 3 a) show the relationship between the intensity of the flux of protons with energy E_p > 30 MeV and the drift velocity $V_{i,mII}$ and b_i, calculated using formulas (2) and (3) at the frequency $f_{i,2}$, at which the maximum correlation I_p is observed with a drift velocity $V_{i,mII}$ ($f_{i,2}$ = 40 MHz) and a relative distance b_i ($f_{i,2}$ = 180 MHz). In fig. 2 a) and 3 a) N is the number of events, r is the correlation coefficient between the studied parameters. In fig. 2 b) and 3 b) show the dependence of the correlation coefficient r between the proton flux intensity I_p and the parameters $V_{i,mII}$, and b_i on the frequency $f_{i,2}$. Comparative analysis showed that the strongest relationship between the proton flux intensity I_p and the drift velocity $V_{i,mII}$ is observed at the frequency $f_{i,2}$ in the range 30-80 MHz, and with the relative distance b_i at the frequency $f_{i,2}$ in the range 90-180 MHz (see Fig. 2 b) and 3 b)). The relationship between the intensity of the proton flux I_p and the parameters $V_{i,mII}$, and b_i, depending on the proton energy E_p, was also investigated. In fig. 2c) and 3c) show the dependence of the correlation coefficient r between the proton flux intensity I_p and the parameters $V_{i,mII}$, and b_i on the proton energy E_p. Comparative analysis showed that the strongest relationship between I_p and the parameters $V_{i,mII}$, and b_i is observed for protons with energies E_p > 30 MeV (see Fig. 2 c) and 3 c)).

Conclusions

1. It is shown that the relationship between the intensity of the SCR proton flux I_p and the drift velocity $V_{i,mII}$ and the relative distance b_i between the harmonics of type II radio bursts changes over time.
2. The strongest relationship between the proton flux intensity I_p and the frequency Drift $V_{i,mII}$ is observed in the range 30-90 MHz, and with the relative distance b_i in range 90-180 MHz.

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