RELATIONSHIP OF SCR, CME AND CORONAL SHOCK WAVES WITH THE PARAMETERS OF TYPE IV AND II SOLAR RADIO BURSTS

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ABSTRACT. This paper presents the results of a comparative analysis of the relationship between solar cosmic rays (SCR), coronal mass ejections (CME), and coronal shock waves (CSW) with the parameters of solar continual type IV radio bursts, as well as with the parameters of type II radio bursts. The sample under study contains 147 proton events accompanied by type IV continuum radio bursts in the 25-15400 MHz range, type II radio bursts in the 25-180 MHz range, as well as CME and coronal shock waves. For the analysis, we used original records of solar radio emission at 8 fixed frequencies in the range 245-15400 MHz according to data from RSTN (Radio Solar Telescope Network), original records of dynamic spectra from SRS (Solar Radio Spectrograph) in the range of 25-180 MHz, as well as original records intensity of the flux of SCR protons with proton energies in the range> 1-100 MeV according to data from the GOES spacecraft. A comparative analysis showed that the relationship between the intensity of the SCR proton flux and the CME velocity is, on average, much stronger with the parameters of type IV radio bursts than with the parameters of type II radio bursts, which indicates the dominant role of the SCR acceleration process in the flare region, rather than shock waves. However, detailed studies of the fine structure of type II radio bursts have shown that there is a fairly strong relationship between the intensity of the flux of mean-relativistic protons I_p and the frequency $f_{min,1}$ at the fundamental harmonic (at the 1-st harmonic) at the time t_{min} corresponding to the minimum relative distance b_{min} between the harmonics of type II radio bursts. Detailed studies of the fine structure of type II radio bursts have also shown that there is a strong relationship between the intensity of the SCR proton flux I_p and parameter V_{II}, which characterizes the displacement of the shock front with time t_i in a narrow frequency range of 25-60 MHz.

АНОТАЦІЯ. У даній роботі наводяться результати порівняльного аналізу зв'язку сонячних космічних променів (СКП). корональних викидів маси (КВМ) і корональних ударних хвиль (КУХ) з параметрами сонячних континуальних радіосплесків IV типу, а також з параметрами радіосплесків II типу. Досліджувана вибірка містить 147 протонних подій, що супроводжуються континуальними радіосплесками IV типу в діапазоні 245-15400 МГц, радіосплесками II типу в діапазоні 25-180 МГц, а також КВМ і корональними ударними хвилями. Для аналізу використовувалися оригінальні запи-
си радіовипромінювання Сонця на 8 фіксованих частотах в діапазоні 245-15400 МГц за даними з RSTN (Radio Solar Telescope Network), оригінальні записи динамічних спектрів з SRS (Solar Radio Spectrograph) в діапазоні 25-180 МГц, а також оригінальні записи інтенсивності потоку протонів СКП з енергією протонів в діапазоні > 1-100 MeB за даними з апаратів GOES. Порівняльний аналіз показав, що зв'язок інтенсивності потоку протонів СКП і швидкості КВМ в середньому значно сильніше з параметрами радіосплесків IV типу, ніж з параметрами радіосплесків II типу, що вказує на домінуючу роль процесу прискорення СКП у спалахової області, а не ударними хвилями. Однак детальне дослідження тонкої структури радіосплесків II типу показали, що існує досить сильний зв'язок між інтенсивністю потоку середньорелятивістських протонів I_p і частотою $f_{min,1}$ на основній гармоніці (на 1 гармоніці) на момент часу, відповідний мінімальної відносної відстані b_{min} між гармоніками радіосплесків II типу. Детальні дослідження тонкої структури радіосплесків II типу також показали, що спостерігається сильний зв'язок між інтенсивністю потоку протонів СКП I_p і параметром V_{II}, що характеризує зміщення фронту ударної хвилі з плином часу t_i у вузькому частотному діапазоні 25-60 МГц.

Keywords: Proton events, solar cosmic rays (SCR), coronal mass ejections (CME), coronal shock waves (CSW).

1. Introduction

Prediction of proton events is one of the topical problems in solar radiophysics. Modern methods for predicting proton events are based on the relationship between the parameters of solar cosmic rays (SCR) and the parameters of solar radio bursts (Akinyan et al., 1977, 1978; Chertok, 1982; Chertok et al., 1987; Melnikov, Epifanov, 1979; Melnikov et al., 1986, 1991). Proton events have a characteristic U and W - shaped type of frequency radio spectrum with maxima in the centimeter and meter wavelength ranges and a deep minimum in the decimeter range (Podstrigach and Fasahova, 1981). It is known that the parameters of microwave bursts can be used to judge the total number of accelerated particles and their energy spectrum (Chertok, 1982), while the parameters of meter-decameter radio bursts can be used to judge the conditions for the escape of accelerated particles into interplanetary space.

The presence of a sufficiently powerful meter-long component indicates favorable exit conditions, while the absence indicates unfavorable exit conditions (Akinian et al., 1977). It was shown in (Melnikov et al., 1986) that the presence of a strong coupling between the flux of mean relativistic electrons of solar cosmic rays (SCRs) and the integral flux of microwave bursts (μ-bursts) indicates that the SCR electrons and the electrons generating the radio burst are accelerated in a single process. Based on this, statistical models were obtained that relate the fluxes of protons and electrons to the parameters of microwave bursts (Melnikov et al., 1991).

In this paper, present the results of a comparative analysis of the relationship between SCR, coronal mass ejections (CMEs), and coronal shock waves with the parameters of type IV continuum radio bursts in the range 245-15400 MHz and with the parameters of type II radio bursts in the 25-180 MHz range. In this work, the emphasis is on studying the relationship between the SCR proton flux and the parameters of type II radio bursts and on comparing the results with what is obtained from the parameters of microwave bursts. Earlier, in (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, which, according to Tsap (Isaeva and Tsap, 2011), suggests the generation of shock waves both in the region of the flare energy release and a moving coronal mass ejection (CME). 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 the model of a two-step proton acceleration process (Wild et al., 1963). 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 by shock waves (Tsap, Isaeva, 2012). 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 I_P and the relative distance $b_i = (f_{i2}-f_{i1})/f_{i1}$ between the 1-st and 2-nd harmonics at a given time t_i, where the correlation coefficient r between the studied values $r \approx 0.70$, while the relationship between the drift velocity V_{drift} and the proton flux I_p turned out to be weak, where the correlation coefficient r between I_p and V_{drift} does not exceed $r \approx 0.40$ (Tsap and Isaeva, 2013). However, further studies of the fine spectral structure of meter-decameter type II radio bursts in the 25-180 MHz range showed that if instead of the drift velocity V_{drift}, the parameter $V_{\text{II}} = (f_2-f_1)/(t_i-t_0)$ is used, which to some extent characterizes the velocity displacement of the shock front with time t_i, where f_2 and f_1 are frequencies at the 2-nd and 1-st harmonics at a given time t_i, and t_0 is the time of the onset of a type II burst at the 1-st harmonic at a frequency of 180 MHz, then a fairly strong relationship is observed between the intensity of the flux of protons I_p and V_{II}, where the correlation coefficient $_r$ between the studied values is $r \approx 0.79$ (Isaeva, 2018), which is quite compara-

ble with what is obtained from the parameters of microwave bursts (Melnikov et al., 1991; Isaeva, 2018). It should also be noted that a strong connection between the proton flux intensity I_p and parameter V_{II} is observed in a narrow frequency range of 25-60 MHz. Moreover, detailed studies of the dynamics of the fine structure of type II radio bursts revealed a number of features. It was shown that the relative frequency b_i between the harmonics of type II radio bursts monotonically changes with time. For all 112 type II radio bursts are characterized by a monotonic decrease in the relative distance b_i between harmonics to the minimum value $b_{\min}$ with a subsequent increase (Isaeva, 2019, 2020). It was also shown that the relationship between the intensity of the proton flux I_p and the parameters of type II radio bursts changes with time t_i and reaches a maximum value when the relative distance b_i becomes minimum, i.e. $b_i = b_{\min}$ (Isaeva, 2018, 2019).

2. Relation of the SCR proton flux with the parameters of type IV continual radio bursts in the range 245-15400 MHz and with the parameters of type II radio bursts in the 25-180 MHz range

It is currently believed that SCRs can be accelerated either in the region of flare energy release or at the fronts of shock waves, which can be generated by both flares and CME (Reames, 1999). The results obtained to date do not allow making an unambiguous conclusion about which of the acceleration processes is dominant.

Significant progress in solving this problem can be achieved due to detailed studies of the relationship between the SCR proton flux and the parameters of type IV and II radio bursts in a wide wavelength range. In this regard, the author of this work carried out studies in a wide range of wavelengths. For the analysis, we used the original records of solar radio emission at 8 fixed frequencies 245, 410, 610, 1415, 2695, 4995, 8800, 15400 MHz (https://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-radio/rstn-1-second/), original records of dynamic spectra of solar radio emission in the 25-180 MHz range according to data from SRS (Solar Radio Spectrograph), original records of proton flux intensity I_p with proton energy $E_p > 1$ - 100 MeV according to data from GOES (https://satdat.ngdc.noaa.gov/sem/goes/data/new_avg/), as well as a list of proton events (ftp://ftp.swpc.noaa.gov/pub/indices/SPE.txt). The sample under study contains 147 proton events for the period from 06-02-1986 to 14-10-2014. Proton events were selected according to the generally accepted criteria for protonity. It is known that for events with a U or W-shaped type of radio frequency spectrum with maxima in the meter and centimeter wavelength ranges and with a minimum in the decimeter range, the best correlation is observed between the parameters of μ-bursts and the intensity of the flux of mean-relativistic electrons and SCR protons. Confirmation of this fact can be seen in fig. 1a) (left), which shows the relationship between the integral flux of continuous μ - bursts at a frequency of 8800 MHz and the intensity of the flux of protons I_p with an energy $E_p > 30$ MeV. For such events, the correlation coefficient r between $\int F_\mu dt$ and $I_p \approx 0.80$. At the same time, the relationship between the proton flux intensity I_p and the integral flux of continual radio bursts largely depends on the radio burst frequency f see fig. 1b) (left) and the proton energy E_p
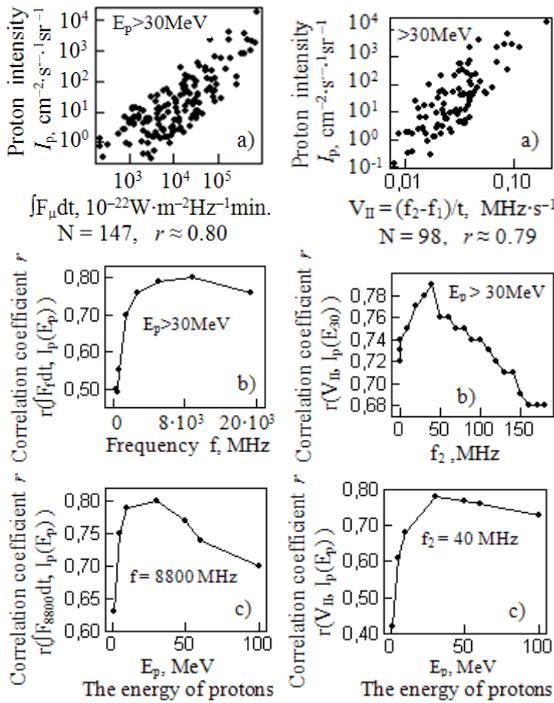
Figure 1: Relationship between the intensity of the SCR proton flux I_p with the integral flux of μ-bursts $\int F_\mu dt$ (left) and with parameter V_{II}, which characterizes the displacement velocity of the shock front (right).

Figure 2: The relationship between the intensity of the proton flux I_p and the frequency $f_{min,1}$ at the 1-st harmonic at the time t_{min} of the minimum relative distance b_{min} between the harmonics of type II radio bursts and b_i with an increase in the proton energy E_p, according

see fig. 1c) (left). The relationship between I_p and the integral flux of radio bursts $\int F_f dt$ sharply decreases in the decimeter range and is practically absent in the meter range, see Fig. 1b) (left). The strongest relationship between I_p and $\int F_f dt$ is observed for average relativistic protons with an energy $E_p > 30$ MeV and an integral flux of μ-bursts, see fig. 1c) (left), which is quite consistent with the results of other authors (Melnikov et al., 1991).

The presence of a strong connection between the flux of SCR protons and the parameters of μ-bursts definitely indicates the acceleration of SCR protons in the flare region. However, there are many indications that shock waves also play an important role in the acceleration of solar cosmic rays (Gopalswamy et al., 2002; Cliver et al., 2004). In this regard, detailed studies of the parameters of the fine structure of type II radio bursts and their relationship with SCR were carried out.

Earlier in the article (Tsap, Isaeva, 2013), the relationship between the intensity of the SCR proton flux I_p ($E_p > 1$-100 MeV) with the drift velocity V_{drift} and with the relative distance b_i between the harmonics of a type II radio burst at a given time t_i was investigated. Comparative analysis showed that with an increase in the proton energy ($E_p > 40$-100 MeV), a significant increase in the correlation coefficient r between I_p and b_i from 0.40 to 0.70 is observed, while the correlation coefficient r between I_p and the drift velocity V_{drift} at the maximum does not exceed 0.30. A significant increase in the correlation r between I_p to Tsap (Tsap, Isaeva, 2013), indicates a significant contribution of shock waves to the acceleration of high-energy protons. The presence of a low correlation ($r < 0.30$) between
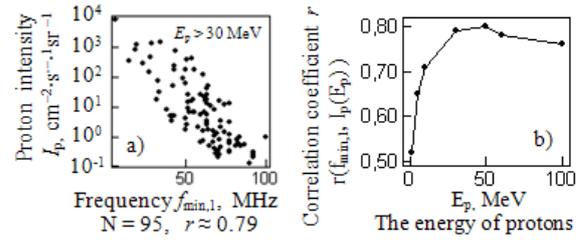
I_p and the drift velocity V_{drift}, according to Tsap (Tsap, Isaeva, 2013), can be explained by significant changes in the conditions of shock wave propagation from event to event due to the strong dependence of the shock wave intensity on the parameters of the medium. In the case of using the relative distance b_i, which characterizes the plasma inhomogeneity, this effect is leveled.

Later, in works (Isaeva, Tsap, 2017; Isaeva, 2018; 2019), on the basis of a larger sample of proton events, containing 112 proton events (previously there were 69) accompanied by type II radio bursts in the range 25-180 MHz, detailed studies of the fine structure of radio bursts were carried out type II using a new regression model (1) (Isaeva, Tsap, 2017). This model (1) gives a fairly good approximation for 95% of type II radio bursts, which made it possible to study the dynamics of the parameters of type II radio bursts over time t_i.

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

In model (1), $f_{i,j}$ are the frequency values at the 1-st and 2-nd harmonics at time t_i, i - is the count number, j- is the harmonic number, a_j and b_j are the linear regression coefficients, which were found using the method of least squares (MLS).

Detailed studies have shown that there is a fairly strong connection between the intensity of the proton flux I_p and parameter V_{II} (2), which to some extent characterizes the displacement of the shock front over time t_i, where f_1 and f_2 are the frequency values at the 1-st and 2-ndth harmonics at a given time t_i, t_0 is the start time at the fundamental (at the 1-st harmonic) at a frequency of 180 MHz.

$$V_{II} = \frac{f_2 - f_1}{t_i - t_0} \qquad (2)$$

In fig. 1a) (right) shows the dependence of the proton flux intensity I_p with an energy $E_p > 30$ MeV on the value of the parameter V_{II}, where the correlation coefficient r between I_p and $V_{II} \approx 0.79$, which is quite comparable with what is obtained from the parameters of μ-bursts. A comparative analysis also showed that the relationship between I_p and VII reaches maximum values in the range 25-60 MHz (see fig. 1b) (right) for protons with energies $E_p > 30$ MeV (see fig. 2c) (right) (values for the frequency f_2.

Further studies of the fine structure of type II radio bursts showed that the intensity and the relative distance between the harmonics of a type II radio burst changes over time, as well as the relationship between the proton flux intensity I_p and the parameters of type II radio bursts (Isaeva, 2019). It was shown that there is a fairly strong relationship between the proton flux intensity I_p and the frequency $f_{min,1}$ at the fundamental (at the 1-st harmonic) at the time t_{min} of the minimum value of the relative distance b_{min} (3) between the harmonics of a type II radio burst, where the correlation coefficient r between I_p and $f_{min,1} \approx$ 0.79 (see fig. 2 a) and 2b)).

$$b_{min} = \frac{f_{min,2} - f_{min,1}}{f_{min,1}} \quad (3)$$

3. Connection of CME with the parameters of type IV continual radio bursts in the range 245-15400 MHz and with the parameters of type II radio bursts in the 25-180 MHz range

Earlier in the article (Isaeva, Tsap, 2017), the relationship between the CME velocity V_{CME} and the parameters of continual radio bursts in the range 245-15400 MHz was investigated. Comparative analysis showed that there is a strong relationship between V_{CME} and the integrated flux of μ-bursts $\int F_\mu dt$ in the 2695-15400 MHz range.
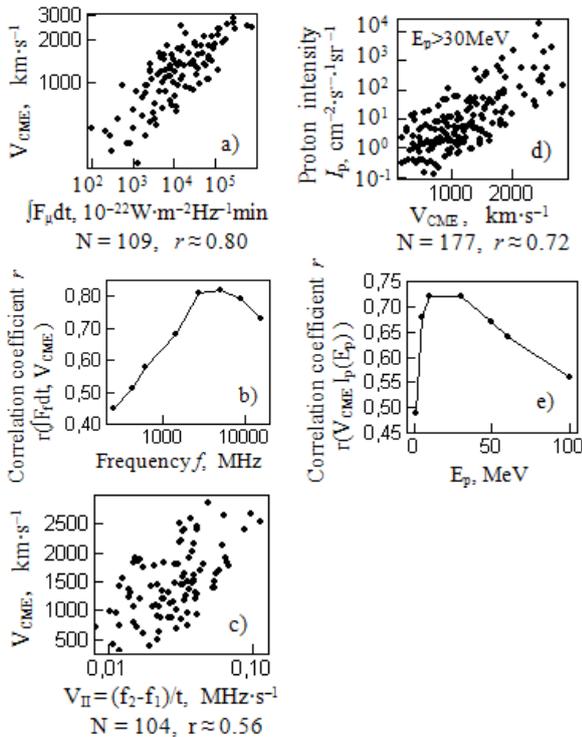
Figure 3: On a) and b) shows the relationship between the CME velocity V_{CME} and the integral flux $\int F_f dt$ of continual radio bursts in the 245-15400 MHz range, as well as with the parameter V_{II} of type II radio bursts in the 25-180 MHz range (see c));
On d) and e) the relationship between the proton flux intensity I_p and the CME velocity V_{CME} is shown;

In fig. 3a) shows the relationship between V_{CME} and $\int F_\mu dt$ at 8800 MHz, where N is the number of events and r is the correlation coefficient between the quantities under study. For the overwhelming majority of proton events, the correlation coefficient r between V_{CME} and $\int F_\mu dt$ is $\approx$ 0.80. The relationship between the integral flux of microwave bursts and the CME velocity can be well represented using a linear regression model (4), where $V_{CME,\mu}$ - calculated value of CME velocity.

$$\log_{10} V_{CME,\mu} = 0.2322 \cdot \log_{10} \int F_\mu \, dt + 2.1108 \quad (4)$$

It was also shown that the relationship between V_{CME} and the integral flux of continual radio bursts $\int F_f dt$ decreases significantly with decreasing frequency, and already in the meter range at a frequency of 245 MHz, the correlation coefficient between V_{CME} and $\int F_f dt$ does not exceed 0.45 (see fig. 3b).

In fig. 3c) shows the relationship between the CME velocity and the parameter of type II II radio bursts, which characterizes the displacement of the shock front with time. Figures 3a) and 3c) show that the relation between the CME velocity is much higher with type IV radio bursts than with type II radio bursts, where the correlation coefficient does not exceed 0.60.

Almost all proton events are accompanied by coronal mass ejections (CMEs). The presence of a high correlation between the CME velocity and the integral flux of μ-bursts during proton events indicates the flare origin of CME. Such CMEs are formed in the region of flare energy release and are associated with the ejection of high-energy particles into interplanetary space.

In this regard, in work (Isaeva, 2018), the relationship between the proton flux intensity I_p and the CME velocity V_{CME} was investigated. The sample under study contained 177 CMEs associated with proton events from 04-11-1997 to 26-01-2015. For the analysis, we used the tabular data of the CME velocity V_{CME} (https://cdaw.gsfc.nasa.gov/CME_list/UNIVERSAL/text_ver/univ_all.txt). Comparative analysis showed that there is a fairly strong relationship between the intensity of the flux of mean-relativistic protons I_p and the CME velocity V_{CME}. In fig. 3d) shows the relationship between I_p with the proton energy $E_p > 30$ MeV and the CME velocity, where the correlation coefficient r between the investigated quantities is $\approx$ 0.70, which is in good agreement with the results in (Grechev et al., 2015). In fig. 3e) shows the dependence of the correlation coefficient r between I_p and V_{CME} as a function of the proton energy E_p.

4. Relationship between coronal shock waves and the parameters of type IV and II radio bursts

It is known that shock waves can be generated by both solar flares and CMEs. It is believed that type II meter bursts are associated with shock waves arising in flares (Wagner et al., 1983; Vrsnak et al., 1995), while bursts in the decameter-hectometer range are associated with the propagation of interplanetary shock waves generated by CME (Gopalswamy et al. al. 1998; Classen et al. 2002). The most reliable indicator of shock waves in the Sun's

corona are slowly drifting type II bursts. It is believed that the plasma mechanism of radio emission is responsible for their generation (Cairns et al., 2003).

Earlier in work (Isaeva, Tsap, 2017), the relationship between coronal shock waves and the parameters of μ-bursts was investigated. For the analysis, we used the original records of solar radio emission at 8 fixed frequencies in the range 245-15400 MHz. Comparative analysis showed that there is a fairly strong relationship between the parameter a_j in the regression model (1), which characterizes the decrease of the frequency drift rate in the 25-180 MHz range and the rise time t_μ μ - bursts at 8800 MHz. The correlation coefficient between t_μ and a_j is $\approx$ 0.66 see fig. 4a).

Due to the fact that flares differ significantly in intensity and duration, therefore, the rise time t_μ is expressed as a percentage of the duration of μ - bursts. In this case, the duration of the burst for each event was equal to 100%. The relationship between the velocity of shock waves V_{shock} and the integral flux $\int F_\mu dt$ μ - bursts at a frequency of 8800 MHz was also investigated. The correlation coefficient between $\int F_\mu dt$ and $V_{shock} \approx$ 0.55 see fig. 4b). The lower relationship between the shock wave velocity and the integral flux of μ - bursts is most likely due to the fact that different stations give averaged estimates of the shock wave velocity at different times. And due to the fact that the velocity of the shock wave decreases very quickly over time, therefore, when using tabular data, a fairly large variance between $\int F_\mu dt$ and V_{shock} will be observed. But in spite of this, the connection between $\int F_\mu dt$ and V_{shock} is quite clearly traced for most proton events, see fig. 4b).

In the present work, also investigated the relationship between the velocity of coronal shocks waves V_{Shock} and various parameters of type II radio bursts. Comparative analysis showed that the strongest relationship is observed between the velocity of coronal shock waves V_{shock} and the frequency $f_{min,1}$ at the fundamental harmonic (at the 1-st harmonic) at the moment t_{min} of the minimum value of the relative distance b_{min}, where the correlation coefficient r between $f_{min,1}$ and $V_{shock} \approx$ 0.68, see fig. 4c).

5. Conclusion

On the basis of the carried out comprehensive studies of the relationship between SCR, CME, and coronal shock waves with the parameters of solar radio bursts of type IV and II, a number of regularities were revealed, part of which fully agree with the previously obtained results of other authors. For example, the presence of a strong connection between the SCR proton flux and the parameters of type IV continual μ-bursts (Isaeva, Melnikov, Tsvetkov, 2010). Also in (Isaeva, Melnikov, Tsvetkov, 2010), it was confirmed that the accuracy of estimating the SCR proton flux is largely determined by the conditions for the release of accelerated particles, which can be judged from the parameters of type IV meter-decameter continuum radio bursts. Also, based on the studies carried out, it can be concluded that, for the overwhelming majority of proton events, the main acceleration of particles occurs in the region of flare energy release and additional acceleration
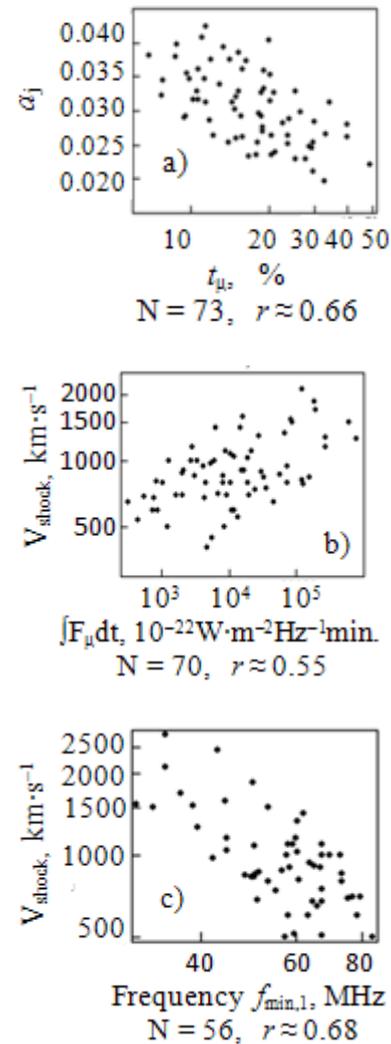
Figure 4: On a) the relationship between the parameter a_j and the rise time t_μ of type IV microwave bursts at a frequency of 8800 MHz is shown;

On b) the relationship between the velocity of coronal shock waves V_{Shock} and the integral flux $\int F_\mu dt$ of type IV μ-bursts at a frequency of 8800 MHz is shown;

On c) shows the relationship between the velocity of coronal shock waves V_{Shock} and the parameter of type II radio bursts $f_{min,1}$, where $f_{min,1}$ is the frequency at the fundamental harmonic at the moment the minimum relative distance b_{min} between the harmonics of a type II radio burst:

at the fronts of shock waves (Tsap, Isaeva, 2012; Tsap, Isaeva, 2012). At the same time, new patterns were identified. For example, detailed studies of the dynamics of the fine structure of type II radio bursts in the 25-180 MHz range over time have shown that all proton events accompanied by type II radio bursts are characterized by a monotonic decrease in the relative distance b_i between harmonics to a minimum value b_{min} with a subsequent increase (Isaeva, 2019; Tsap, Isaeva, Kopylova, 2020). It was shown that there is a strong relationship between the intensity of the proton flux I_p ($E_p> $ 30 MeV) with the fre-

quency $f_{min,1}$ at the fundamental harmonic (at the 1-st harmonic) at the time of the minimum value of the relative distance b_{min} (3) between the harmonics of radio bursts II type, where the correlation coefficient r between fmin,1 and $I_p \approx 0.79$ (Isaeva, 2019), which is more fully commensurate with what is obtained from the parameters of μ-bursts. It was also shown that there is a strong relationship between the intensity of the SCR proton flux and parameter V_{II} (2), which characterizes the displacement of the shock front with time t_i, where the correlation coefficient r between V_{II} (2) and $I_p \approx 0.79$ (Isaeva, 2018). It should also be noted that the presence of a strong coupling between V_{II} and I_p is most likely realized in a narrow frequency range of 25-60 MHz for all 112 proton events.

As a result of detailed studies, a fairly strong connection was also revealed between the rise time t_μ of μ-bursts at a frequency of 8800 MHz and the parameter a_j in the regression model (1), which characterizes the decrease in the drift velocity of type II radio bursts with time t_i, where the correlation coefficient r between t_μ and $a_j \approx 0.66$ (Isaeva, Tsap, 2017). The revealed regularity may also indicate that for the overwhelming majority of proton events, coronal shock waves are generated in the region of flare energy release and are associated with flares, which is quite consistent with the conclusions of other authors in (Wagner et al., 1983; Vrsnak et al., 1995).

In this work, it was also shown that there is a fairly strong relationship between the velocity of coronal shock waves V_{Shock} (tabular data with NGDC) and the frequency $f_{min,1}$ at the fundamental harmonic at the time of the minimum relative distance b_{min} between the harmonics of a type II radio burst, where the correlation coefficient between $f_{min,1}$ and $V_{Shock} \approx 0.68$.

It should be noted that the revealed new patterns require further detailed studies in order to confirm or refute the results.

References

Akin'yan S., Fomichev V., Chertok I.: 1977, *Geomagnetizm i aeronomiya*, **17**, № 1, 10.

Akin'yan S., Fomichev V., Chertok I.: 1978, *Geomagnetizm i aeronomiya*, **18**, № 4, 577.

Cairns I., Knock S., Robinson P., Kuncic Z.: 2003, *Space Sci. Rev.*, **107,** 27.

Classen H. et al.: 2002, *A&A*, **384,** 1098.

Cliver E., Kahler S. and Reames D.: 2004, *Astrophys. J.*, **605**, 902.

Gopalswamy et. al.: 1998, *Geophys. Res.*, **103**, 307.

Gopalswamy, N., Yashiro, S., Michalek, G., et al.: 2002, *Astrophys. J.,* **572**, 103.

Grechev V., Kiselev V., Meshalkina N. et al.: 2015, *Solar Physics*, **290**, 2827.

Isayeva E., Mel'nikov V., Tsvetkov L.: 2010, **106**, № 1, 42.

Isaeva E., Tsap Yu.: 2011, *Bull. of the Crimean Astrophys. Observ.*, **107**, 78.

Isaeva E., Tsap Yu.: 2017, Odessa Astron. Publ., **30**, 222.

Isaeva E.: 2018, Odessa Astron. Publ., **31**, 132.

Isaeva E.: 2019, Odessa Astron. Publ., **32**, 122.

Mel'nikov V., Yepifanov O.: 1979, *Simp. po KAPG po solnechno-zemnoy fizike*, M.: Nauka, 115.

Mel'nikov V., Podstrigach T., Kurt V., Stolpovskiy V.: 1986, *Kosmicheskiye issledovaniya*, **24**, 610.

Mel'nikov V., Podstrigach T., Daybog E., Stolpovskiy V.: 1991, *Kosmicheskiye issledovaniya*, **29**, 95.

Podstrigach T., Fasahova M.: 1981, *Geomagnetizm i aeronomiya*, **21**, № 1, 22.

Reams D.: 1999, Spase Sci. Rev., **90**, 413.

Tsap Yu., Isaeva E.: 2012, *Bull. of the Crimean Astrophys. Observ.*, **108**, 52.

Tsap Yu., Isaeva E.: 2012, *Geomagnetism and Aeronomy*, **52**, № 7, 921.

Tsap Yu.T., Isaeva E.A.: 2013, *Cosmic Research*, **51**, № 2. 108.

Tsap Yu., Isaeva E., Kopylova Yu.: 2020, *Astron. Lett.*, **46**, № 2, 144.

Chertok I.: 1982, *Geomagnetizm i aeronomiya*, **22**, № 2, 182.

Vrsnak B. et al.: 1995, *Solar Phys.*, **158,** 331.

Wagner W. et al.: 1983, *A&A*, **120**, 136.

Wild J., Smerd S., Weiss A.: 1963, *Ann. Rev. Astron. Astrophys.*, **1**, 291.