COMPARATIVE RESEARCHES OF POWERFUL SOLAR FLARES

V.V. Koshovyy [(1)], **E.A. Isaeva** [(2)], **A.B. Lozynskyy** [(3)]

[(1)] Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine
5, Naukova Str., Lviv, 79053, Ukraine. E-mail: koshovy@ah.ipm.lviv.ua
[(2)] as [(1)] above, but e-mail: URAN3@sh.lt.ukrtel.net
[(3)] as [(1)] above, but e-mail: lozynsky@ah.ipm.lviv.ua

INTRODUCTION

The most important task of solar radio physics is the prediction of powerful solar flares accompanied by emission of protons, shock waves and coronal mass emissions (CME) into interplanetary space. This task can be divided into two subtasks: prediction of the actual flare on the basis of precursors parameters and prediction of the flux intensity of high-energetic protons and electrons as well as prediction of CME on the basis of the flare parameters.

Modern techniques of diagnostics and prediction of the solar cosmic radiation are based on statistical connection between parameters of continual solar radio burst of IV-type and flux parameters of protons and electrons on the terrestrial orbit [1]. The parameters of continual microwave radio burst of IV-type provide information on the number of accelerated particles and their power spectrum, while the parameters of meter-decameter bursts provide information about the emission conditions. Proton bursts have characteristic U-type radio frequency spectrum with the maximums at meter and centimetre wavelengths, and with the minimum at decimetric wavelengths at the vicinity of 1000 MHz. However, not all the bursts with such type of radio spectrum having powerful centimetric and metric components of continual IV-type burst are accompanied by protons emission. It is probably because of the adverse conditions of emission at the very top layers of solar corona. Modern prediction techniques are limited to consideration of the emission conditions at the meter wavelength. However, as the practice showed, more accurate prediction requires consideration of the decametre component of IV-type burst.

INSTRUMENTATION AND OBSERVATIONS

For registration of Sun's radiation the decameter radio telescope URAN-3 (Lviv, Ukraine) was used (10÷25MHz, array antenna - 256 wideband turnstile dipoles, effective area on frequency of 25MHz during the orientation of ray in a zenith – 14000m^2, simultaneous independent registration of two linearly-polarized signal components from two halves of the array antenna). The radio telescope URAN-3 is a part of the decameter VLBI Network URAN (Ukraine) [2]. The modulation radiometer of this radio telescope was used as the instrument for observing the solar radio-frequency emission at the decametre wavelengths. The observations were carried out in the period from October 20 till December 15, 2003. This period corresponds to increased solar activity. Few powerful flares were fixed during this period of time by world network of solar radio observers, but only in case of four flares observations were performed by the radio telescope URAN-3. The radio flux during the period of these flares is presented in table 1.

These four flares in particular, were analysed by authors with the purpose of detecting the connection between the intensity of decametre component of solar radiation, and the probability of protons emission and CME into interplanetary space. The decametre solar radio emission at the frequencies of 20 & 25 MHz for two polarizations, registered by means of the radio telescope URAN-3 is presented in Fig. 1. The data were collected in the period of powerful proton flare on October 28, 2003.

Table 1. Solar radio flux at the time of flares at different frequencies
(decametric observation were performed with use of the radio telescope URAN-3)

Time of flare	Flare coordinates	Maximum flux, SFU		
		Centimeter wavelengths	Meter wavelengths	Decameter wavelengths
23.10.03 (08:35 UT)	AR 486 S16E75	10000	10000	<100
26.10.03 (06:54 UT)	AR 486 S15E44	8000	120000	<100
28.10.03 (11:10 UT)	AR 486 S20E10	70000	490000	240000
03.11.03 (10:32 UT)	AR 488 N08W77	17000	3500	<100

DISCUSSION

All the flares presented in the table 1, had characteristic *U*-type radio spectrum with powerful both centimetre and meter components (Fig. 2). While the decameter component (marked with the arrow in Fig. 2; frequencies of 20 & 25 MHz; URAN-3) is weak during the flares on October 23, 26 and November 3, it is considerably different on October 28.

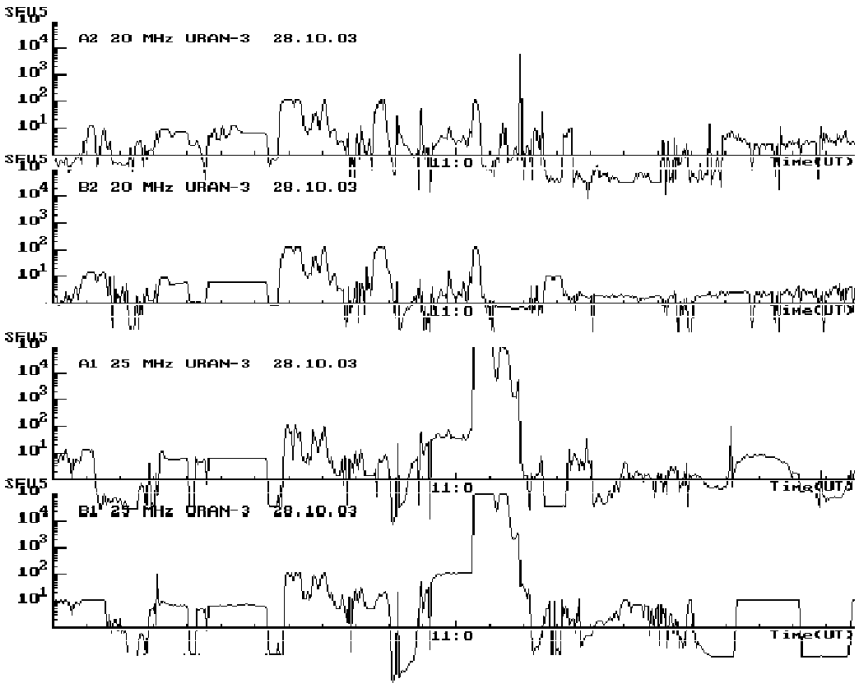

Fig. 1. Continual IV-type burst registered on 28 of October 2003 by means of the radio telescope URAN-3 at the frequencies of 20MHz (A2, B2) and 25 MHz (A1, B1) (polarizations A (A1, A2) and B (B1, B2)).

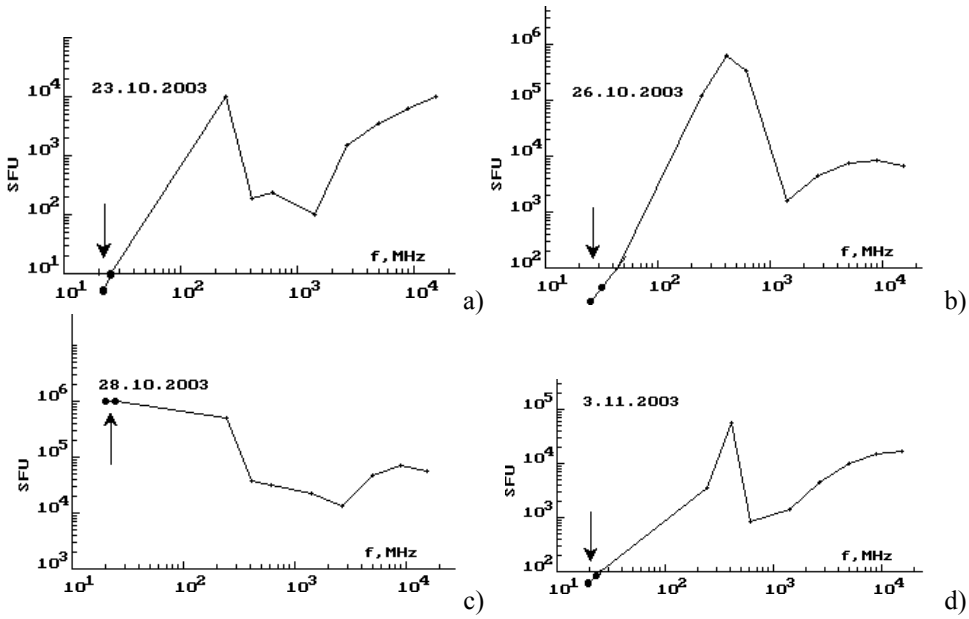

Fig. 2. Frequency dependencies of integral radio flux during the flares, described in table 1; a) 23 October 2003; b) 26 October 2003; c) 28 October 2003 and d) 3 November 2003 (the measurements by the radio telescope URAN-3 (20 & 25 MHz) are marked with the arrow).

Three of four flares, namely on October 23, 26 and 28, occur in active area 486 with the complex magnetic polarity, where strong rotation of polarization vector was observed of transverse component of magnetic field, so called “shear”. Powerful gradual bursts of GRF-type, having explosive formation phase, forewent all the flares at the microwave frequency band. Explosive phase was accompanied by powerful continual burst of IV-type and by burst of II-type, as well as by powerful burst of hard X-ray radiation. The combination of bursts of II-type and IV-type is an evidence of shock-wave propagation and high-energetic particles acceleration, while the burst of hard X-ray radiation is an evidence of precipitation of these particles into dense layer of the chromosphere and photosphere. The heating-up of the photosphere by precipitated particles has evoked the burst, which was visible in optical band. At the same time the satellite SOHO has registered expanding fibres. However, further expanding of these fibres with the following mass emission into interplanetary space was observed only during the flare on 28 of October. The data on CME for remaining three flares are pretty contradictory. Some of the data is showing that the emission took place, other – that didn’t. Comparing this data to decametre measurements one can conclude that observing the powerful decametre component of IV-type burst indicates the existence of the CME, what was actually observed during the flare on October 28, while the absence of decametre component, that was characteristic for remaining three flares, indicates that most likely no CME has occurred.

The same concerns to the protons emission, which took place exactly on October 28, when powerful decametre component of IV-type burst was observed. The remaining three bursts indicate no protons emission, and the reason is most likely the adverse emission conditions and CME in the very top layers of solar corona. However one have to be careful while bringing this kind of correlation to the consideration. Firstly, just 4 flares don’t create sufficient statistics, and secondly – two flares from four, namely on October 23 and 26, occurred in the high eastern longitudes of 75° и 44° correspondingly, hence considerable attenuation of protons flux for about 10 times may happened on the terrestrial orbit, or protons could just passed by the Earth at all. However this is not always the case, the eastern events which take place even on solar limb may cause powerful protons flux on the terrestrial orbit. In general it depends on the configuration and direction of magnetic field at the vicinity of emission protons’ origin. It is planned later on to perform similar investigations with greater number of samples of solar flares accompanied by CME. Only western and central events should be selected for investigation to avoid significant longitudinal attenuation of protons flux on the terrestrial orbit that is typical for eastern events.

The dynamics of particle precipitation into dense layers of chromosphere is not the only factor that determines the number of high-energetic particles emitted into interplanetary space. The number of particles to a great extent depends as well on emission conditions, i.e. on magnetic field configuration and large-scale turbulence in the very top layers of solar corona [3]. In case if magnetic field has open configuration in the vicinity of particles acceleration area, then emission conditions are more auspicious in contrast to the conditions in case of closed configuration of magnetic field. As it was mentioned above, the presence of metric and probably decametric components of continual burst of IV-type is an indispensable condition of protons emission into interplanetary space. That is why the next step in our research was investigating the dependence flux intensity of emitted protons with the energy >25 MeV from the intensity of meter-decameter component of continual burst of IV-type. It was not possible to perform this investigation based on measurements of the radio telescope URAN-3, as we had only one proton burst detected, therefore we used the data from published sources. We used records of solar radio emission for 8 specified frequencies (245, 410, 610, 1415, 2695, 4995, 8800, 15400 MHz) with resolution of 1 second [4], the records of dynamic spectra in the range of 25-180 MHz with the resolution of 3 seconds [5], and records of flux intensity of protons with the energy of 15-40 MeV at the orbit of the satellite GOES-10 with averaging over 1 minute and 5 minutes intervals [6]. Integral flux of meter-decametre continual burst of IV-type was chosen as most appropriate parameter to describe the number of accelerated particles. Integral flux of a burst is proportional to the total number of radiating and emitted electrons $\int F dt \approx N_e dt$ where N_e - the total number of radiating electrons in the source. As it was shown in the number of works [7], electrons and protons are accelerated simultaneously and we can assume that integral flux of meter-decameter burst is proportional not only to the number of radiating accelerated electrons but to the number of accelerated protons as well (protons do not radiate). Therefore we selected 20 western proton flares to perform our investigation. For each flare in the meter frequency range integral flux of the burst was calculated at the frequency of 245 MHz while at the decameter band averaged integral flux was calculated in the frequency range of 25-37 MHz. Then the maximum flux intensity of protons within the energy range of 15-40 MeV was calculated for each flare. The results of calculations are presented in Fig. 3.

CONCLUSIONS

Analysis of the dependencies show that in the meter-decameter frequency band the increase of integral flux of continual IV-type burst leads to increase of number of emitted protons. The similar dependencies have been obtained earlier in the

microwave range [8]. It is stated in the work [8] that the accuracy limit was reached in predicting the intensity of emitted protons flux by the parameters of microwave bursts and the residual dispersion remains pretty high. The explanation is that microwave bursts do not reflects the emission conditions in the very top layers of solar corona. The further improvement of prediction should involve quantitative calculations of emission conditions based on parameters of meter-decameter radio bursts. The dependencies achieved for meter-decameter frequency range (Fig. 3), confirms the idea stated in the work [8], that protons flux could be quite precisely calculated on the basis of parameters of meter-decameter radio bursts.

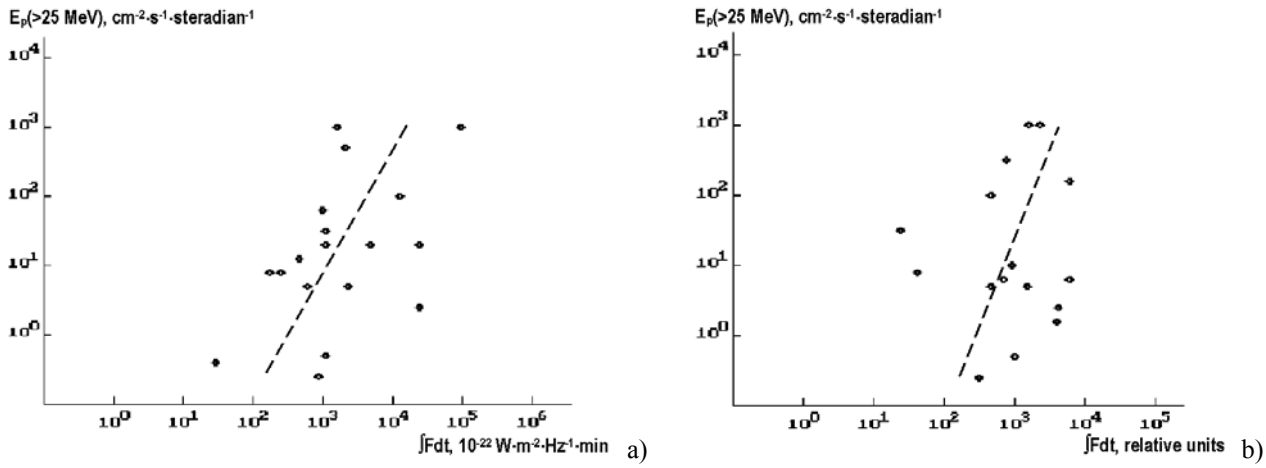

Fig. 3. Dependence of flux intensity of emitted protons with the energies >25 MeV:
a) from the intensity of burst integral flux at the frequency of 245 MHz;
b) from the intensity of averaged integral flux of the IV-type burst at the frequency of 25-37 MHz.

It should be mentioned, that all the protons flares had powerful decametre component of continual IV-type burst. However, to make the statement, that presence of decametre component of continual burst of VI-type is the indispensable condition for protons emission and CME into interplanetary space, the adequate number of powerful non-proton flares has to be investigated that are not accompanied by CME. This will make it possible to give the final answer if the presence of decametre component is one of the criteria of proton flares or it is not.

Based on achieved results it can be concluded that, firstly – more accurate prediction of probability of protons emission and CME into interplanetary space requires consideration of decametre component of continual VI-type flare, secondly – meter-decameter component of VI-type burst determines not only the conditions of emission, but it is quantitatively connected as well with the flux intensity of emitted high-energetic protons.

The work is executed at financial support of the project INTAS № 03-5727.

REFERENCES:

[1] B.I. Lipatov, V.F. Melnikov, T.S. Podstrigach, S.D. Snegirev, Yu.V. Tikhomirov, V.M. Fridman, O.A. Sheyner. *Izvestiya vuzov. Radiofizika.* 2002, v. XLV, N2, pp. 83-100.
[2] A. Megn, S. Braude, S. Rashkovsky, V. Shepelev, N. Sharykin, G. Inyutin, "VLBI Network URAN and Interferometric Studies in the Decameter Waveband," *Journal of Physics,* pp. 813-818, 1994.
[3] V.F. Melnikov, T.S. Podstrigach, V. Kurt, V.G. Stolpovskiy. *Kosmicheskiye issledovaniya*. 1986, v. 24, pp. 610-619.
[4] http://www.ngdc.noaa.gov/stp/SOLAR/ftpsolarradio.html#onesec
[5] http://www.ngdc.noaa.gov/stp/SOLAR/ftpsolarradio.html#spectralgraphs
[6] http://goes.ngdc.noaa.gov/data/avg/
[7] I.M. Chertok. *Geomagnetism i aeronomiya*. 1982, v. 22, p. 182-186.
[8] V.F. Melnikov, T.S. Podstrigach, E.I. Daybog, V.G. Stolpovskiy. *Kosmicheskiye issledovaniya*. 1991, v. 29, pp. 95-103.