The Study of the Hectometric Radio Bursts and Energetic Electrons from Solar Flares.

V.S. Prokudina, M. Slivka [2], V.N. Kuril'chik

Abstract - **We analyzed the temporal profiles of solar radio bursts at frequency range 1500-100 kHz, registered by AKR-X and its relation to energetic electrons, registered by DOK-2 on INTERBALL-1. We evaluated the delay of arrival of electrons with E>40 keV to the Earth relativily to the impulsive phase of the solar flare and compared it with spreading of radio bursts**.

1. INTRODUCTION

The objective of our investigation is the analysis of observational data from *INTERBALL-1* and comparison of radio bursts in the frequency range 1500 –100 kHz, registered by AKR-X during solar flares, with the fluxes of energetic electrons, observed by DOK-2 near Earth orbit. It is known that hectometric radio bursts spread at interplanetary space and are generated at local plasma frequency by energetic electrons, accelerated during the solar flares and arrived to the Earth with delay relatively to the impulsive phase of the flare.

The estimation of the delay time is the important practical interest, because it is known, that energetic electrons, moving along the open magnetic field lines of IMF, arrived to the Earth more quickly, than plasma thrown out during the flares and observed as CME, MC, IP-shocks. These disturbances at solar wind are spreading to the Earth during about 2 days and may caused the geomagnetic storms. The peculiarities of hectometric radio bursts are discussed at several publications., especially from data of WIND/WAVE[http:// www-lep.gsfc.nasa.gov/wave/]. The features of energetic electrons from ACE [http://sd-www.jhuapl.edu/], WIND, SOHO and IMP-8 are analysed at [1,2], where the electron events and its connection with active solar phenomena are discussed. Also the questions about the relation between the radio bursts and electrons are studied [4,5,6].

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2. THE ANALYSIS OF OBSERVATIONAL DATA

The data were obtained with AKR-X and DOK-2 on *INTERBALL-1*. The radio bursts were registered with 6-channel radiometer at frequencies 100, 252, 500, 749, 1463 and 1500 kHz (passband 10 kHz, dynamical range 80 dB, sensibility at 749 kHz $P=10^{-19}$ W/m^2.Hz). The fluxes of electrons were observed with DOK-2 at three energy ranges : e1=21-34 keV, e2=39-46 keV, e3=76-96 keV. (unit-e/cm^2.str.keV) ; orientation to the direction of axis X [8]. For analysis of data we consider only the periods of *INTERBALL-1* localization beyond the magnetosphere.

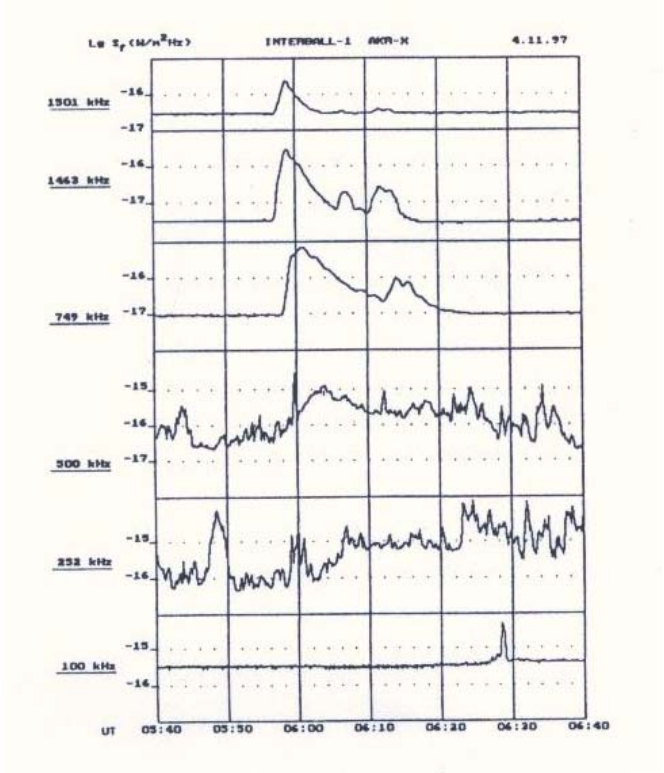
From the list of events of radio bursts we selected only the bursts of III type, identified with solar flares. As a rule, the flares were localized at geoeffective longitudes, i.e., at the western hemisphere of the Sun. The radio emission of magnetosheric origin, type of AKR, we don't consider here. The detail description of similar bursts are given at [4].

Further we studied the events with energetic electrons from DOK-2, which coincided with long-wave solar radio bursts, and analyzed the temporal profiles electron fluxes at channels e1, e2, e3. It is possible to notice several types of electron flux's profiles. The events with sharp increases of fluxes and determined onset are of the especial interest, because this mean , we suppose, the arrival of electrons to the Earth. In many cases the intensification of the fluxes coincided with strong fluctuations and oscillations, with maximum and decreases, but sometimes exist the regular and equal background. The similar classification of electron events from ACE/EPAM were discussed at [3] and there were picked the types of spikes, pulse, ramp and continuum at temporal profiles. For our purpose we consider only the events with onset and increase of flux. The cases with the large fluctuations we don't describe because of its complex connection with magnetospheric and solar wind disturbances.

The typical temporal profiles of analyzed events are given at Fig.2 - 7. From these and similar profiles we may determine the onset of increase of flux (UTonset), i.e. the moment of arrival of electrons to the Earth. If we know the beginning of generation for solar hectometric radio burst during the flare, we may evaluate the delay of arrival of energetic electrons to the Earth.

The Table 1 contains the data with the estimations of the time delay for some solar flares. At the Table are given the data about flares (Importance, coordinates, No. AR, microwave emission 15,4 GHz (Fmax, UT max), radio bursts of III, II, IV types, UT onset and Pmax of radio bursts at frequency f=1463 kHz, the beginning of increase of the

electron flux (UTe) and the time delay of electron's arrival (Δt)).



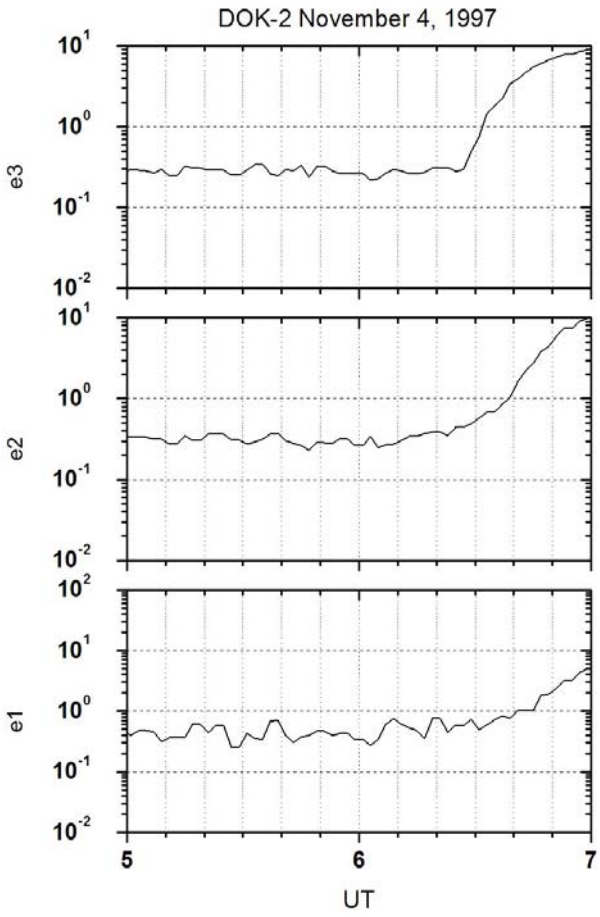
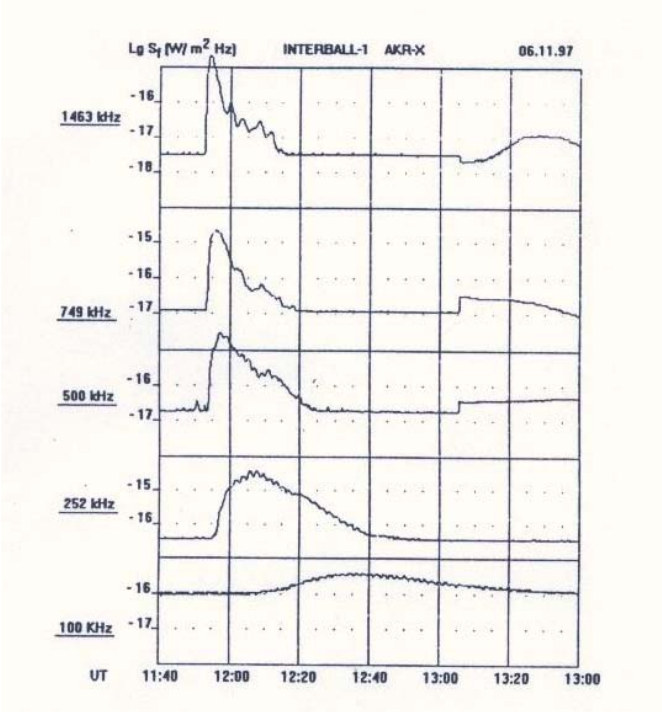


Figure 1. The temporal profiles of radio bursts in the frequency range 1500-100 kHz, registered by AKR-X (up) and energetic electron fluxes registered by DOK-2 at three energy ranges (e1:21-34 keV,e2:39-46keV and e3:76-96 keV) (down) on Interball-1 for November 4, 1997 solar flare.



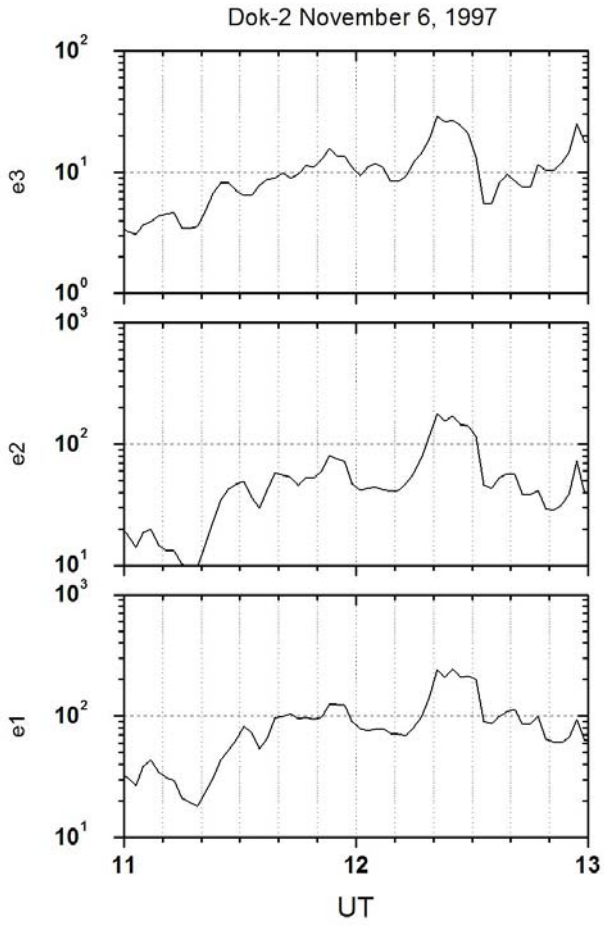
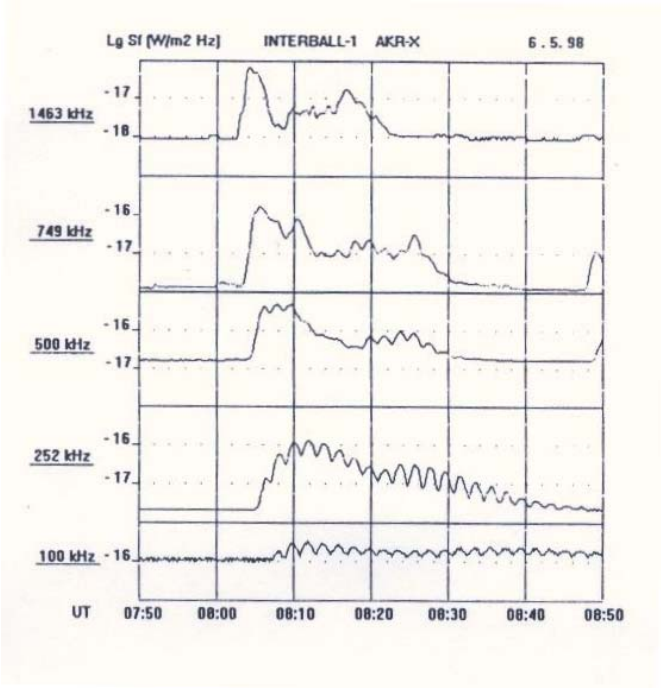
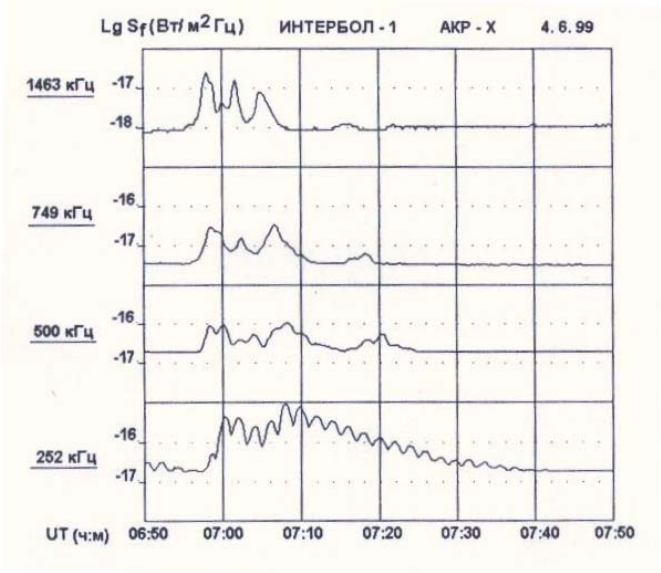


Figure 2. The same like on Fig.1 for November 6, 1997 solar flare.





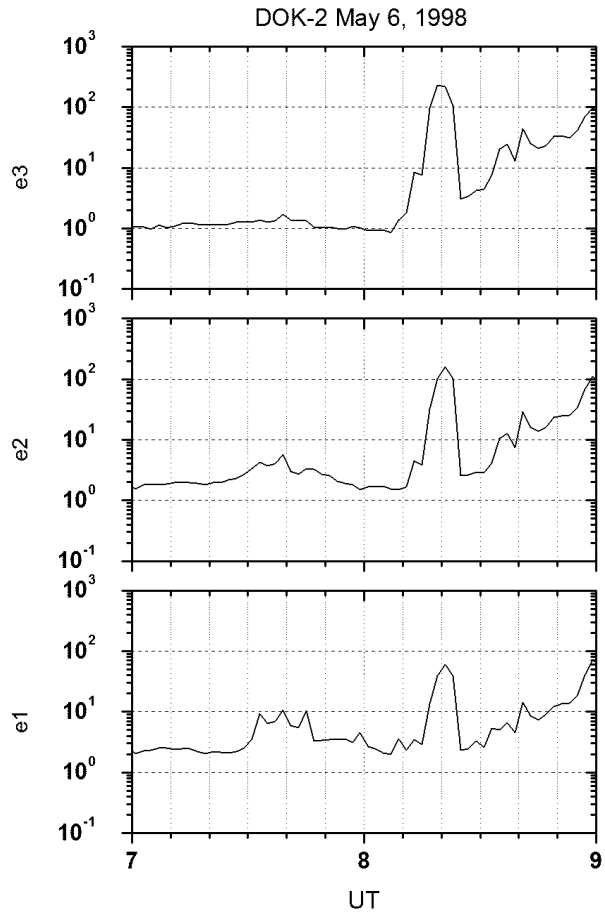


Figure 3. The same like on Fig.1 for May 6, 1998 solar flare.

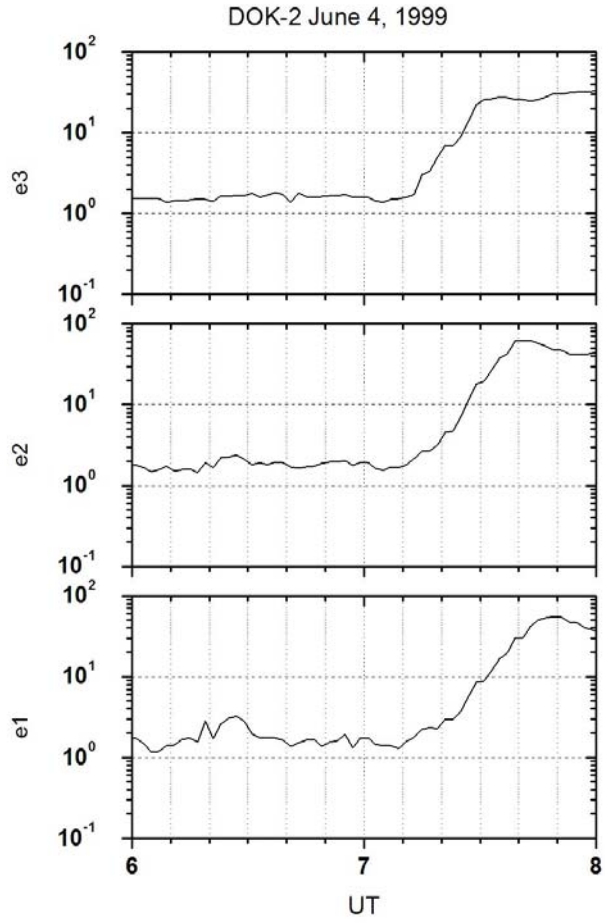
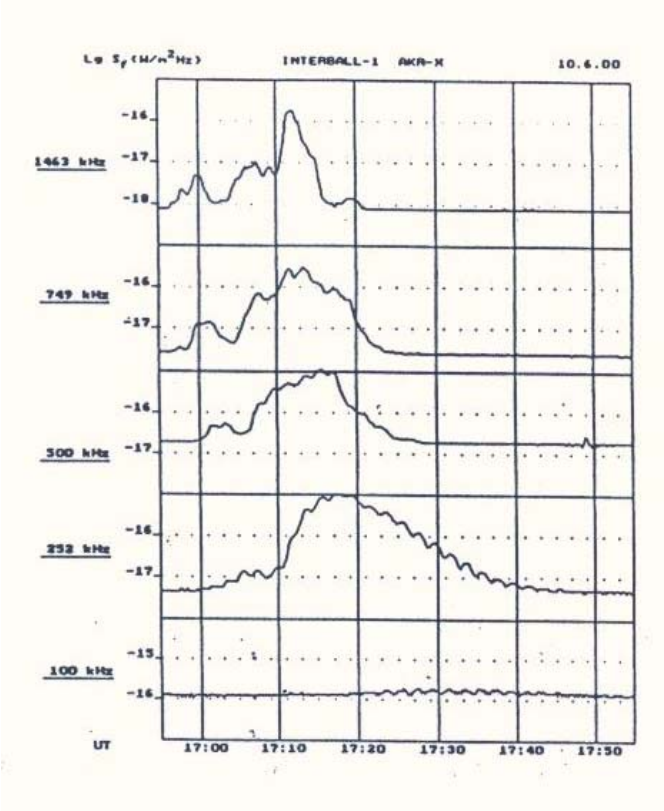
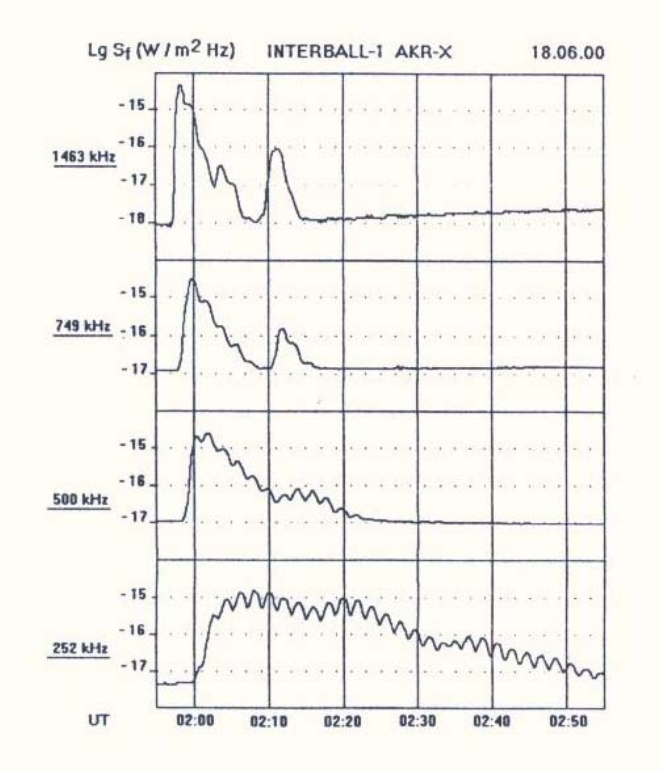


Figure 4. The same like on Fig.1 for June 4, 1999 solar flare.





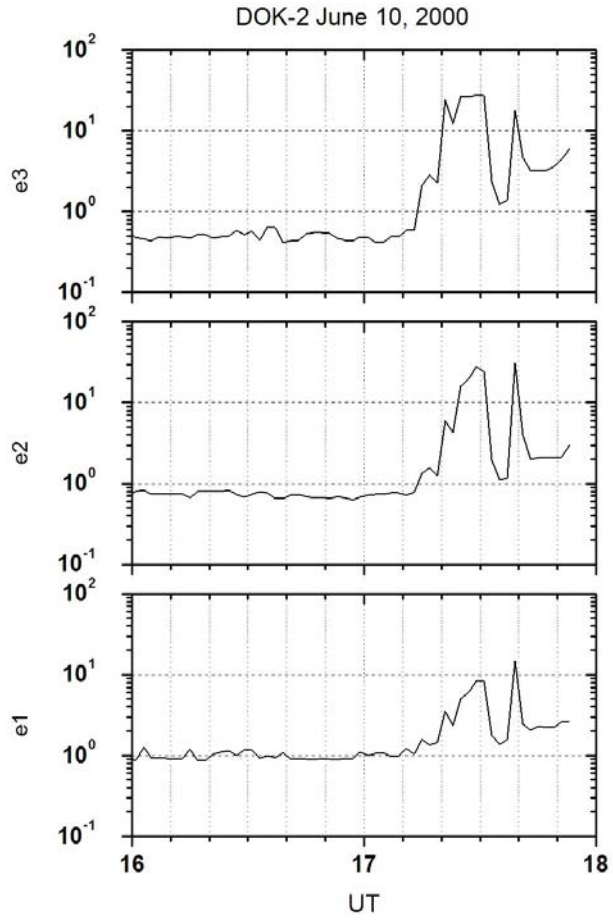


Figure 5. The same like on Fig.1 for June 10, 2000 solar flare.

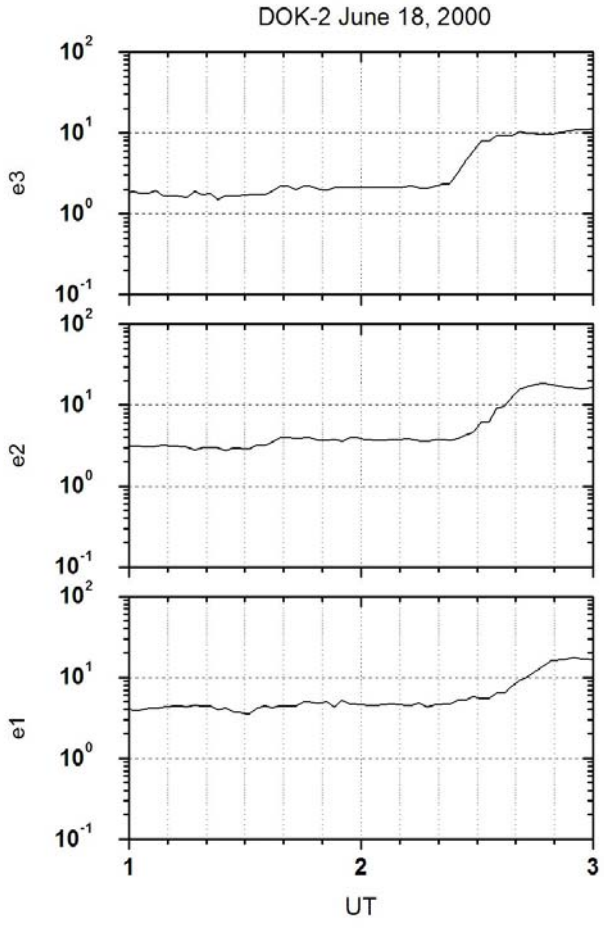
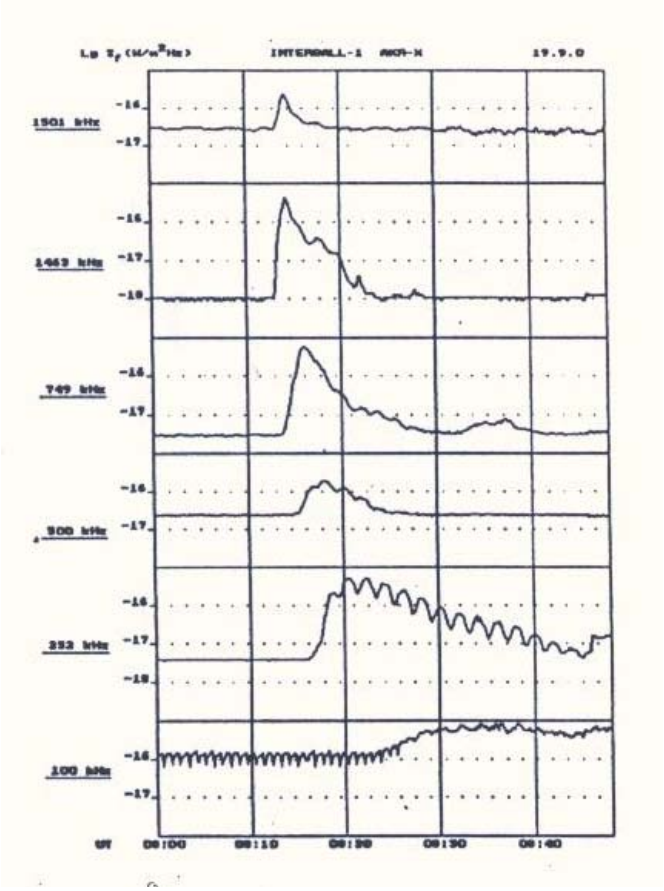


Figure 6. The same like on Fig.1 for June 18, 2000 solar flare.



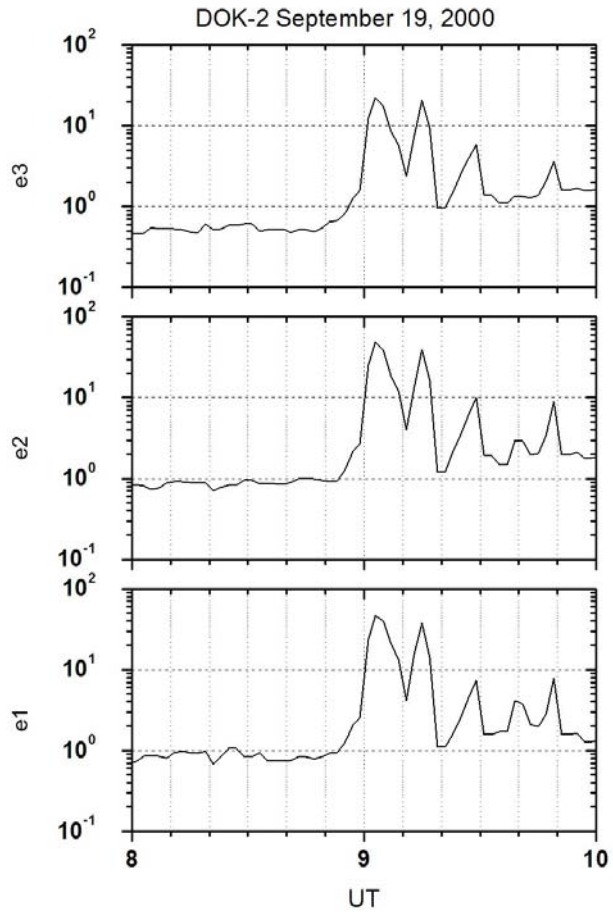


Figure 7 The same like on Fig.1 for September 19, 2000 solar flare.

Table 1.

Data	Radio UT onset Pmax	Electrons UT e	Delay min Δt	Flares Imp, φ,λ, № AR		15,4 GHz UT max/ F max	Radio Types (meters)
4.XI.1997	05.57 8.10^{-17}	06.30	33	X2.1/2B 14S,33W	8100	05.57 1600	II
6.XI.1997	11.53 5.10^{-16}	12.10	17	X9.4/2B 18S,63W	8100	11.53 9800	IV
6.V.1998	08.04 10^{-16}	08.20	16-22	X2.7/1N 11S,65W	8210	08.02 1500	III, V
24.VIII.98	22.05 3.10^{-17}	22.40	35	X1/3B 30N,7E	8307	22.01-22.03 1700	II,III, IV
4.VI.99	06.55 2.10^{-17}	07.20	28	M3.9/ 17N,39W	-	06.51-07.10 1300	III
10.VI.00	16.56 3.10^{-16}	17.30	14-24	M5/3B 22N,38W	9026	16.51=17.08 160	III,II
18.VI.00	01.57 6.10^{-15}	02.20	23	X1/SF 23N, 85W	9033	01.56-01.57 530	III,II II,III
19.IX.00	08.12 4.10^{-16}	0850	38	M5.1/1N 14N,48W	9165	08.09-08.11 1400	II,IV,II

It is noticed, that the onset of hectometric radio burst may be consided with maximum of flare, observed at microwave and HXR ranges [7]. It means, that energetic electrons escape from the region of acceleration at the Sun and are spreading at interplanetary space along IMF structures. The several events with radio bursts and electrons, registered on INTERBALL-1 also were observed on IMP-8 , ACE and WIND, what is important for our future research. The results of the time delay evaluations are presented at the Table 1 (see Δ t). From our data we may conclude that the time delay of arrival of energetic electrons to the Earth relatively to the explosive phase of the solar flare equal to 20-40 min.

3. CONCLUSION

From the study of the observational data we may suppose, that the source of hectometric radio bursts and energetic electrons were the solar flares of X,M Importances, with large microwave emission, coronal radio bursts of III, II, IV types and CME. The flares were developed at active regions with complex magnetic structure, situated at western hemisphere.

The microwave emission is the important parameter for the analysis the events with the energetic electrons. It, as HXR bursts, better determined the process of acceleration at the flare, than the SXR, usually descibed the importance of the flare. Hence for the study of electron events we must use HXR and microwave data.

We obtained the estimation of the time delay of electron arrival by comparison of onset of electron flux increase, registered by DOK-2, with the moment of appearance of hectometric radio burst of III type during the explosive phase, observed by AKR-X on INTERBALL-1. This value was equal to 20 –40 min, the result similar to other reports. The events with considerable fluctuations and oscillations of electron fluxes we don't analyzed because of the different

problems, connected with the acceleration and spreading of energetic particles at disturbed interplanetary space and near magnetosphere.

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