Proceedings of ICRC 2001: 4144 © Copernicus Gesellschaft 2001

ICRC 2001

Origin of high-energy charged particle bursts in the near-Earth space

S. Aleksandrin[1], F. Forzan[1], A. Galper[1], L. Grishantzeva[1], S. Koldashov[1], L. Maslennilov[1], A. Murashov[1], P. Picozza[2], and S. Voronov[1]

[1]Moscow State Engineering Physics Institute, Russia
[2]University of Roma "Tor Vergata", Italy

Abstract. For the first time high-energy charged particle bursts in the near-Earth space were discovered in the MARIYA experiment on orbital station SALYUT-7, continued on Mir orbital station later on. In this work processing of experimental data obtained on the various space vehicles: orbital station MIR, METEOR-3, GAMMA and SAMPEX satellites with instruments, registering high-energy charged particles, was carried out for purpose of looking for particle bursts. In each considered experiment the bursts of the high-energy electrons were selected. Spatial and temporal distributions of the particle bursts were studied. It was shown that strong bursts of electrons have peculiarity in local time distributions of their appearances and can be caused by geomagnetic pulsations. Whereas the significant part of weak and moderate particle bursts is correlated with seismic activity, and at that the particle bursts were observed several hours before strong earthquakes. This result is in accordance with conclusion made earlier on the basis of analysis of MARIYA experimental data. Some features of physical model of seismic disturbance of radiation belt particles were considered.

1. Introduction

For the first time high-energy charged particle bursts (with energies about several tens of MeV) were observed in MARIYA experiment on board the SALYUT-7 orbital station (Voronov et al, 1987). At the same time the existence of correlation between short-term variations (bursts) of high-energy charged particle fluxes in the near-Earth space and the seismic activity was pointed out (Voronov et al, 1987; Voronov et al, 1989). This conclusion was made on the basis of results obtained in MARIYA experiment on board SALYUT–7 station. This experiment has been carried out in 1985. Then, the detailed study of electron and proton flux variations under the radiation belt was continued by MARIYA–2 magnetic spectrometer on board MIR orbital station, and by the instruments ELECTRON on board INTERCOSMOS–BULGARIA–1300 and METEOR–3 satellites (Galper et al, 1989; Voronov et al, 1990). The results of these experiments confirmed the conclusion for correlation between short-term sharp increases of particle intensities and seismic processes. Moreover, it was found that the particle flux variations appeared 2–4 hours before the main shock of strong earthquakes (Aleshina et al, 1992; Galper, Koldashov & Voronov, 1995). This means that the earthquake precursors in the near-Earth space were experimentally observed.

Using analysis of spatial distributions of particle bursts and strong earthquakes with magnitude more than 4, it was also shown that the forthcoming earthquake and its precursor (burst) are situated at the same drift shell.

The explanation of this phenomenon is connected with local disturbance of the particle flux in radiation belt caused by ultra low frequency (ULF) electromagnetic emission (EME), generated in forthcoming earthquake epicenter and propagated upwards into near-Earth space. It should be mentioned that frequencies of the ULF EME practically coincide with frequencies of bounce oscillations of high-energy particles trapped by geomagnetic field.

This emission, as it was shown in some of ground-based experimental observations, was created in the earthquake epicenter several hours before the main shock (Fraser-Smith, Bernard & McGill, 1990) and could propagate into magnetosphere (Molchanov & Majaeva, 1994). There it interacts with particles trapped by geomagnetic field and results in particle precipitation from radiation belt. These precipitated particles drift around the Earth along L shell, which corresponds to the earthquake epicenter position (Galper et al, 1997). The wave of precipitated particles is created by this process, and can make one or more revolutions around the Earth (Galper, Koldashov & Voronov, 1995).

Here we present the results of analysis of new experimental data on bursts of high-energy charged particle fluxes and comparison of these results with experimental data described above.

Correspondence to: Galper@incos.mephi.ru

2. Instrumentation

The brief description of instruments, used for searching for the seismo-magnetosphere correlations is presented below.

The MARIYA and MARIYA–2 instruments are magnetic time-of-flight scintillator spectrometers (Voronov et al, 1991) installed on board SALYUT–7 and MIR orbital stations (51° inclination, 400 km altitude). These instruments provide detection and identification of protons, electrons and positrons in energy range 20-200 MeV. The measurements were carried out periodically from 1985 to 2000.

The instrument ELECTRON (Galper et al, 1983) was installed on board METEOR–3 satellite (82° inclination, 1250 km altitude). Using stack of scintillator detectors and Cherenkov counter, it registers electrons with energy more than 30 MeV. The measurements were carried out 1985-1986.

Gamma-ray telescope GAMMA–1 (Akimov et al, 1988) was installed on board astrophysical satellite GAMMA (51° inclination, 350 km. altitude). In addition the main science information on gamma radiation, charged particle counting rates were registered, in particular, counting rate of electrons with energy more than 50 MeV. For this purpose the scintillator counters, time-of-flight system and gas Cherenkov detector were used in combination with lead scintillator calorimeter (Akimov et al, 1988). The measurements in orbit were carried out within 1990 - 1992.

SAMPEX (Backer et al, 1993) satellite was launched into 82° inclination 600 km altitude orbit in 1992. It consists of a stack of lithium-drifted-silicon detectors and carries out continuos studies of proton and electron fluxes. We used SAMPEX Level 2 30 Second Counting Rate data of PET electron channel (4–15 MeV) for search of seismo-magnetosphere correlations.

3. Data processing and analysis

In order to select charged particle bursts we used the counting rate data of instruments mentioned above. This information was attached to UT and this allows to know the spacecraft orbit parameters, to execute binding of particle counting rates to geographical and L, B coordinates.

For the analysis we select sites of spacecraft orbits, which correspond to regions of the near-Earth space with L less than 2. Moreover, events inside South Atlantic Anomaly region were excluded, in order to decrease background flux and to increase the reliability of particle bursts selection, we choose B coordinate exceeding B_0 value, corresponding to the geomagnetic field boundary of stable radiation belt.

Sharp, short-term increases of particle counting rates from tens of seconds to few minutes were selected as particle bursts if the counting rate exceeds 4 standard deviations from mean value of background flux. Figure 1 presents typical example of observation of particle burst with onboard instrument.

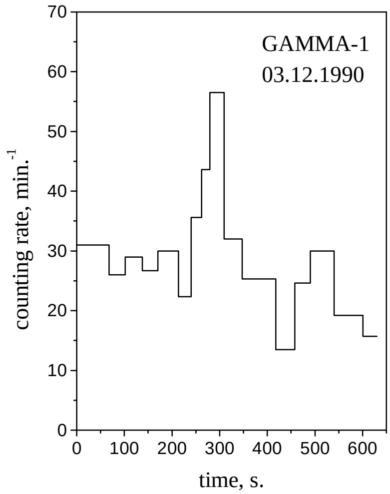

Fig.1. Counting rate of electrons along the GAMMA spacecraft orbit during observation of particle burst.

One of the important characteristics of particle bursts is their relative intensity R (ratio of maximum counting rate to background counting rate). It is possible to consider two opposite cases: relatively strong particle bursts (R>3.5) and weak particle bursts (R<2.5).

4. Local time distributions of high-energy charged particle bursts

Analysis of local time of observation of high-energy charged particle bursts was carried out. It was discovered that strong particle bursts have nonuniform distribution in local time. At that strong particle bursts most often occurs in two local time sectors: late morning – noon (6-12 hours) and evening – midnight (18-24 hours). As for weak particle bursts it was found that their local time appearance distribution has practically uniform shape.

5. High-energy charged particle bursts of seismic origin

Analysis of time correlation between particle bursts and strong earthquakes was carried out using the same procedure for all experiments. The strong earthquakes with magnitudes more than 4 from CNSS Catalog were selected in time range ±12 hours around the time of particle burst observation. The value of time difference between earthquake beginning and particle burst $\Delta T=T_{eq}-T_{pb}$ was calculated for every earthquake. We applied this procedure for all particle bursts. After the processing of all events, the distributions of ΔT values were built for every experiment. As an additional parameter, (value could be varied), we used the difference between L shells of earthquake and particle burst $\Delta L=L_{eq}-L_{pb}$. As the L coordinate of the earthquake we take the L value at point above epicenter. The altitude of this point corresponds to geomagnetic field line on which seismic electromagnetic wave captured during the propagation through the ionosphere. Such determination results from physical model described briefly above (Aleshina et al, 1992). Altitudes of captured as it was estimated in (Molchanov et al, 1992) are about 300 km.

Using it we could take into account only earthquakes, which situated closely to particle burst in L space (used value were ΔL<0.2, or 0.1, or 0.05). It should be underlined that this cut is in correspondence with physical hypothesis of phenomenon. As it was mentioned above, the development of local magnetosphere disturbances caused by earthquakes occurs on L shell, which corresponds to earthquake epicenter.

The distributions of ΔT values, obtained using experimental data of MARIYA–2, ELECTRON, GAMMA–1 and PET, are shown in figure 2.

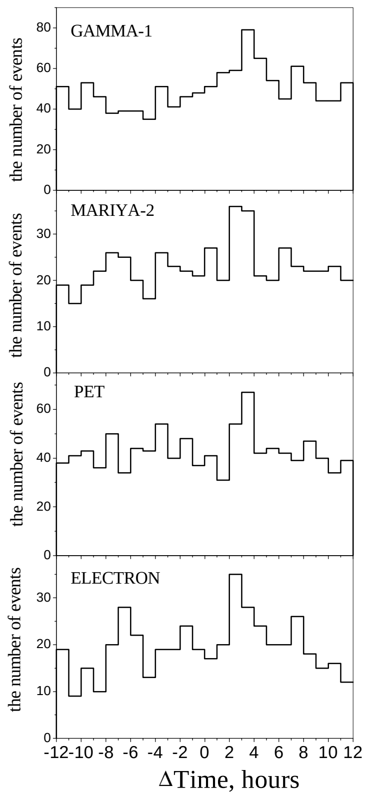

Fig.2. ΔT distributions for particle bursts and earthquakes obtained in different satellite experiments (see text).

One can see that the shapes of all four distributions are practically the same. This expresses in existence of obvious peak with mean position from 2 to 5 hours. The position of this peak in ΔT distributions means that the particle bursts can appear as a short-term earthquake precursor.

It should be underlined that for different earthquake magnitudes (M) and values of ΔL the confidence level of peak can significantly change. The value of this level varies from very high one if M>5, ΔL<±0.05 to low for uniform distribution if ΔL>±0.5. Putting cut on value ΔL>±0.5 means that only earthquakes, those L shells significantly differ from L shells of particle bursts, were taken for analysis. The uniform ΔT distributions were also obtained if only strong particle bursts were taken for analysis.

6. Discussion.

Possible physical reasons for generation of high-energy charged particle bursts were considered in (Aleshina et al, 1992; Galper et al, 1997; Galper, Koldashov & Murashov, 2000). It was shown that some different local disturbances of the radiation belt could cause the particle precipitation with subsequent formation of wave of drift high-energy charged particles. Such wave can propagate around the Earth along drift shell. Where spacecraft crosses this disturbed L-shell, such particle wave can be observed as particle burst by onboard instrument.

Evidently, local disturbances of the radiation belt can be caused by different magnetospheric pulsations, connected with hydromagnetic wave propagations.

Another considered reason of radiation belt disturbances is the electromagnetic emissions of seismic origin, which are generated during earthquake preparation phase (Aleshina et al, 1992; Molchanov & Majaeva, 1994).

Main discovered features of strong particle bursts is nonuniform distribution of local time of their appearance and also the lack of peak in ΔT distribution. These practically exclude seismic origin of strong particle bursts. However there are some types of geomagnetic pulsations with nonuniform distributions of their appearances in local time. In particular, Pi2 occurs predominantly in evening - midnight sector, Pi1 and Pc3 are observed in late morning – noon sector. Therefore most probable reason of strong particle burst generation is connected with different magnetospheric processes resulting in geomagnetic pulsation creation.

As for weak particle bursts, the existence of obvious maximum in ΔT distributions for them point out unambiguously that the significant part of weak bursts are connected with seismomagnetospheric processes.

It is possible to use ΔT distribution with clear peak as indicator of the presence of seismomagnetospheric interrelation. Such approach allows to analyze some features of physics mechanism of this correlation. In introduction we mentioned about seismo-electromagnetic emission which disturbs the radiation belt in the end. It was shown that this emission is formed in epicenter of forthcoming earthquake, then propagate to ionosphere, where it can be captured by geomagnetic field and further propagates as Alfven wave along geomagnetic force line. Reaching the radiation belt boundary, this electromagnetic wave begins to interact with trapped particles, causing particle precipitation as a result of pitch-angle redistribution. Thus, particle burst, as a final result of precipitation, and electromagnetic wave should to have the same L-shell. The value of altitude where electromagnetic emission captured in geomagnetic force line tube can be estimated from our experimental data on particle burst observation. If to consider the value of capture altitude as a free parameter and to change it, then L coordinates of earthquakes will also change. In this case the part of real correlated events (pairs of burst and earthquake) in total statistics will change because of varying the relation between real events and background events.

In figure 3 significance value of maximum $n\sigma$ ($n\sigma$=(Nmax-Nbg)/σ) is plotted depending on altitude of EME capture. Nmax is the number of events in maximum of ΔT distribution, Nbg is the background number of events in ΔT distribution and σ is standard deviation of the number of events in ΔT distribution. Existence of obvious maximum in this plot for all considered experiments confirms the present physical conception of seismomagnetospheric interrelation. Values of altitudes in the range of 300-500 km, corresponding the maximum of this plot, practically coincide with altitudes of the maximum density of ionospheric plasma and agree with altitudes of EME capture obtained independently in direct satellite experiments on study of electromagnetic emission of seismic origin (Molchanov, Majaeva & Protopopov, 1992).

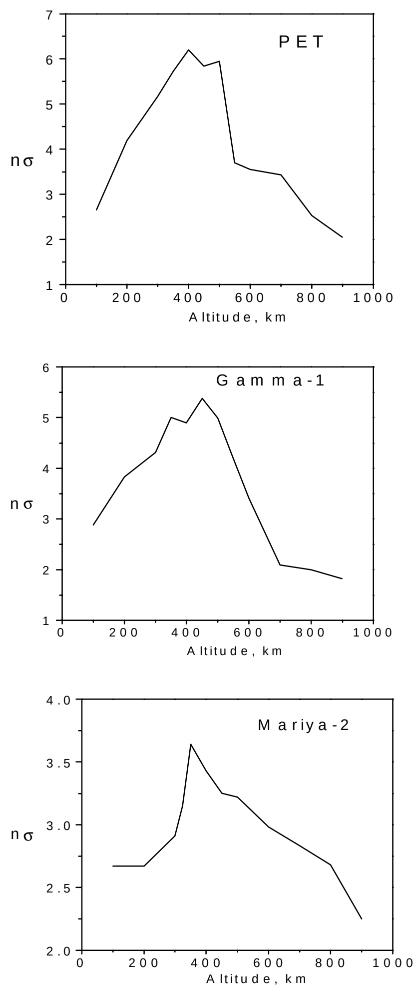

Fig.3. Altitudinal dependence of significance value of peak ($n\sigma$) in ΔT distributions of particle bursts and earthquakes.

7. Conclusion

New experimental results on high-energy charged particle burst observation presented in this report show that there are different types of particle bursts in the magnetosphere and there are different magnetospheric and geophysics processes responding in particle burst generation. Analysis of seismomagnetospheric correlation confirms the conclusion about the connection between significant part of high-energy charged particle bursts and earthquakes. It is necessary to continue further study of details of physical mechanisms of seimomagnetospheric interrelation. It should be noted that this phenomenon could be important for application in development of earthquake forecast methods.

Acknowledgements. We acknowledge Russian Foundation on Base Research, grant 01-02-16442, who partially supported this work.
We acknowledge both the Northern California Earthquake Data Center (NCEDC), the organizations that contributed the data to the Data Center for creation of CNSS earthquake catalog and National Space Science Data Center for providing of SAMPEX Level 2 Data.

References

Akimov, V.V. et al. 1988, Cosmic Science Review, N.49, p.111-124.

Aleshina, M.E. et al. 1992, Cosmic Research, v.30, N.6, p.79-81;

Baker, D.N. et al. 1993, IEEE Trans. Geosciencies and Remote Sensing, 31, 531.

Fraser-Smith, A.S, Bernard, A., & McGill P.R. Geophys. Res. Lett, 1990, v.17, N 9, p.1465-1468.

Galper, A.M. et al. 1983, Cosmic Research, v.21, N.5, p.707-709.

Galper, A.M. et al. 1989, Cosmic Research, V.27, N.5, p.789-792.

Galper, A.M., Koldashov, S.V., & Voronov, S.A. 1995, Adv. Space Research, v.15, p.131-133.

Galper, A.M. et al.1997, Proc. of 25^{th} ICRC, v.2, p.349-350.

Galper, A.M., Koldashov, S.V., & Murashov, A.M. 2000, Cosmic Research, V.38, N.1, p.70-79;

Molchanov, O.A., Majaeva, O.A., & Protopopov, M.L. 1992, Cosmic Research, v.32, N.6, p.128-137.

Molchanov, O.A., & Majaeva O.A. 1994, Cosmic Research, v.32, N.4-5, p.150.

Voronov, S.A. et al. 1987, Proc. of 20^{th} ICRC, v.4, p.451-452;

Voronov, S.A. et al. 1989, Cosmic Research, v.27, N.4, p.629-631;

Voronov, S.A. et al. 1990, Cosmic Research, v.28, N.5, p.789-791;

Voronov, S.A. et al. 1991, Pribori i Tehnika Eksperimenta, N.2, p.59-63;