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Spectral characteristics of electron fluxes at L<2 under the Radiation Belts.

O.R. Grigoryan, M.I. Panasyuk, V.L. Petrov, V.N. Sheveleva, A.N. Petrov

Skobeltsyn Institute of Nuclear Physics, Moscow State University, Vorobyevy gory, Moscow, 119991, Russia, e-mail: orgri@srd.sinp.msu.ru, fax: +7(495)9395034

Abstract

The paper presents the analysis of experimental data on electron fluxes with energies 10 keV – 10 MeV. Data were obtained during 1978-2005 years in different space experiments (COSMOS-900, MIR Space Station, ACTIVE, SAMPEX, CORONAS-I, CORONAS-F, NOAA POES-17, TATYANA and others). Two areas of electron flux enhancements are studied in the paper: the near-equatorial (L<1.2) zone and the middle-latitude (1.2<L<1.9) zone. It is shown that electron flux enhancements are regularly registered at L < 2 and the observed formations have some typical features. Electron peaks at L<1.2 appear sporadically while peaks at 1.2<L<1.9 are observed regularly. The approximations of spectra by several functions including kappa-function are presented.

1. Introduction

Electron flux enhancements under the Radiation belts at L<2 have been observed since early 1978 in different space experiments (Nagata et. al., 1988). Nevertheless many questions concerning the structure, dynamics and sources of these electron flux formations still remain open. This paper systematizes experimental data on electron flux enhancements at L<2 obtained in different space missions.

Regions of electron flux enhancements registration at the 1000 km altitude are shown on Fig.1 (two zones: I and II). It is seen that observed formations are not uniform and have longitudinal gaps. There are three latitude zones of electron flux registration (I – near equatorial zone, II – middle latitude zone, III – zone at L~2.0). Electron flux formations are concentrated mainly at near-equatorial region and at low and middle latitudes.

The zones of electron peaks registration are marked at the map by dashed lines. The observed formations are not uniform and located at different longitudes. We have also marked at the picture a region of electron peaks registration near L~2.0 where enhancements of electron fluxes are observed as well but we don’t concentrate our attention on this phenomenon in this paper.

We distinguish two zones. The electron peaks at L<1.2 are observed sporadically while enhancements at 1.2<L<2.0 are regularly registered both in southern and northern hemispheres. The intensity of middle-latitudinal peaks is higher. We don’t investigate the SAA (South Atlantic Anomaly) region and the charged particle fluxes at L>2, so we exclude these regions from the data sets processing.

First time similar figure appeared in (Voss and Smith, 1980). They collected different observations data and showed areas of registration of charged particle flux enhancements. We constructed similar map using data obtained in several space experiments, described in Table 1, and mostly in the TATYANA experiment. Beside previous figure our one shows distribution of electrons fluxes at different altitude – 1000 km; we also show different shapes of registration areas. Total statistics is great; it includes different years and different altitudes from 320 km up to 1100 km, so we can say that zone borders in Figure 1 are defined experimentally.

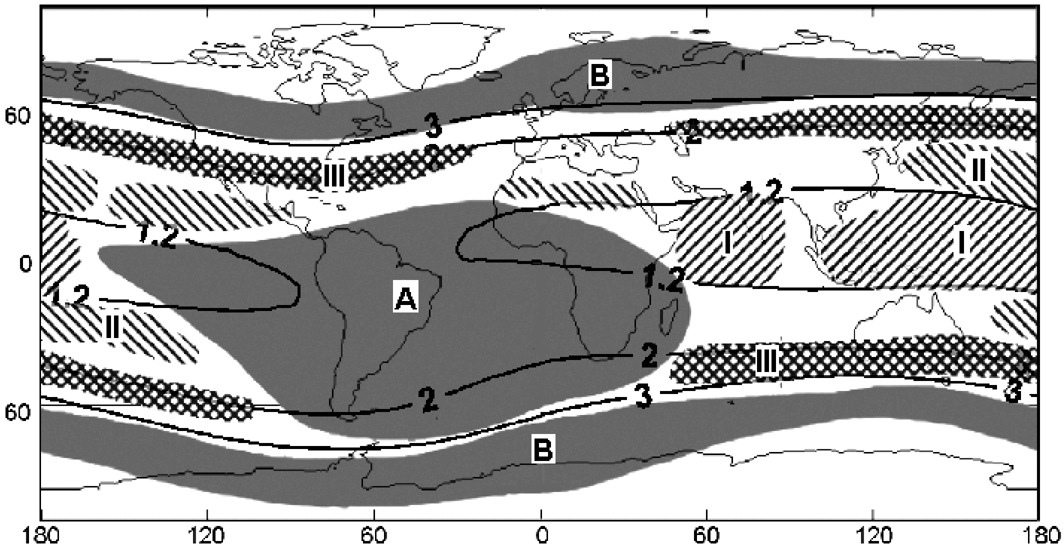


Fig. 1.

2. Observation

The enhancements of electron flux with energies from tens of keV up to several MeV are observed at L-values < 2 in wide altitude range up to 1100 km. We delimit near-equatorial zone and middle latitude zone because the peaks at L<1.2 are registered sporadically. Longitudinal dependence is one of the main feature of electron formations at L<1.2 (Grachev et al., 2005). The formations at 1.2<L<1.9 consist of two peaks: a broad weak peak around L~1.3 and a relatively narrower peak near L~1.7.
These enhancements are stable in time.

Table 1. Some parameters of experiments used. SSD – solid state detector

Space vehicle	**Year**	**Altitude, km**	**Orbit inclination**	**Instrumen-tation**	**Energies of charged particles**
COSMOS 900	1977-1979	500	83°	ssd-500µm	E_e = 30-210 keV
NOAA TIROS-N	1978	850	98.9°	ssd-700µm	E_e>30, >100, >300 keV
ACTIVE	1989-1992	500-2500	81.3°	ssd-300µm	E_e = 30-500 keV
MIR station	1991	400	51.6°	scintillator	E_e > 100, >500, >1500 keV
				Geiger counters	E_e > 75, >300, >600 keV
CORONAS-I	1994	500	83°	scintillator	E_e > 0.5 MeV

SAMPEX	1992-1998	520-670	82°	ssd-telescope	E_e > 150 keV
MIR station	1999	350	51.6°	ssd-300μm	E_e = 0.3-1.5 MeV
CORONAS-F	2001-2005	500	82.5°	ssd-telescope	E_e = 0.3-12 MeV
NOAA POES-17	2005	850	98.9°	ssd-700μm	E_e>30, >100, >300 keV
TATYANA	2005-2007	920-980	83°	ssd-300μm, 1 mm	E_e > 0.3 MeV E_e>70, 300-600, 700-900 keV

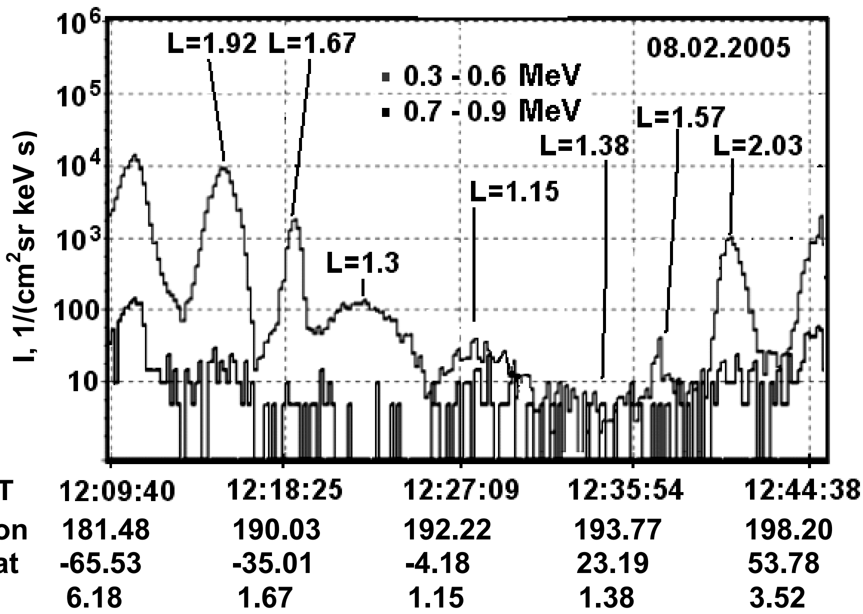


Fig. 2.

Fig. 2 shows examples of electron flux enhancements registration at different L-values according TATYANA satellite observations. Electron fluxes at L ~ 1.6-1.8 usually have less intensity than fluxes in the region of the Radiation Belts. But we observed some events with electron fluxes close to the value of the Radiation Belts electron intensity or even greater. This phenomenon is confirmed by TATYANA and SAMPEX satellite experiments. The same structures we observed in ACTIVE satellite experiment.

We have to point out that we discuss electron fluxes outside the radiation belts. We exclude SAA region for every set of satellite data at every altitude using the same data set. SAA is the only region of inner radiation belt at altitudes < 1000 km and L<2.

On L-shell < 2 outside the SAA there are no populations of electrons and protons of high energies with fluxes maximum placed at this area. Therefore even if there is some addition in count rate due to such particles, their intensity decrease monotonously towards geomagnetic equator so they can not imitate increases of electron intensity at L<2.

In near-equatorial region (L<1.2) only the protons with energies E>50 MeV can make an essential contribution to the background count rate in Geiger counters. However, in

(Bratolyubova, et al., 2001) it is shown that the count rate of < 4 protons*s^{-1} is observed at the near-equatorial latitudes. The background of energetic particles in the scintillation detectors as in the semiconductor detectors may be considered as stable low, since the deposited energy of protons with energy >50 MeV does not increase with particle energy growth, and protons of lower energies can not penetrate into detectors. This statement is supported by the following fact: even if the count rate of a Geiger detector increases at low L, the count rate of a scintillation detector does not change (Bratolyubova, et al., 2001).

At 1.2<L≤2 region proton count rate is less then 10% of electron count rate. We consider it inessential.

The next step of our investigation was to examine electron flux spectra.

It is obvious from Fig. 3 that different experimental data for more than 30 years period obtained by various detecting devices can be approximated with high accuracy. Fig. 3 shows the following features of the obtained spectra: the curves of electron flux spectra at L<1.2 and at 1.2<L<1.9 are similar, the electron flux at 1.2<L<1.9 is ten times higher than the flux at L<1.2. Experimental points in the spectrum at energies from tens of keV – 1 MeV lays along the exponential-like curve. At energies >1 MeV the spectrum shape is approximately linear in log-log scale. We have obtained that electron flux spectrum at L<1.2 slightly depends on altitude so we may not take this dependence into account. The shape of electron spectra at L<1.2 and 1.2<L<2.0 are similar. Both spectra have break at the energy ~1 MeV. At lower energies the intensity of electron flux at 1.2<L<2 is ten times higher than at L<1.2.

We calculated corresponding approximations which are presented on Fig. 4. We used kappa-function (at 1.2<L<1.9) and Maxwell function (at L<1.2) for data points in energy range <1 MeV and power-law function for data with energies >1 MeV. The chosen approximations are the best from the kappa, Maxwell, and exponential function (Grigoryan et al., 2006). The similarity of spectra at L<1.2 and 1.2<L<1.9 allows to suppose that these particles are generated by similar mechanisms. Also it's seemed that there is an "additional source" of electrons with energies >1 MeV. Observed distributions of charged particles under the Radiation Belts can be explained due to wave-particle interaction which is one of the main processes in Earth magnetosphere (Blake et al., 2001; Bashkirov et al., 1999). The other mechanism that provides electrons with energies > 1 MeV can be so called runaway electrons (Lehtinen et al., 1997).

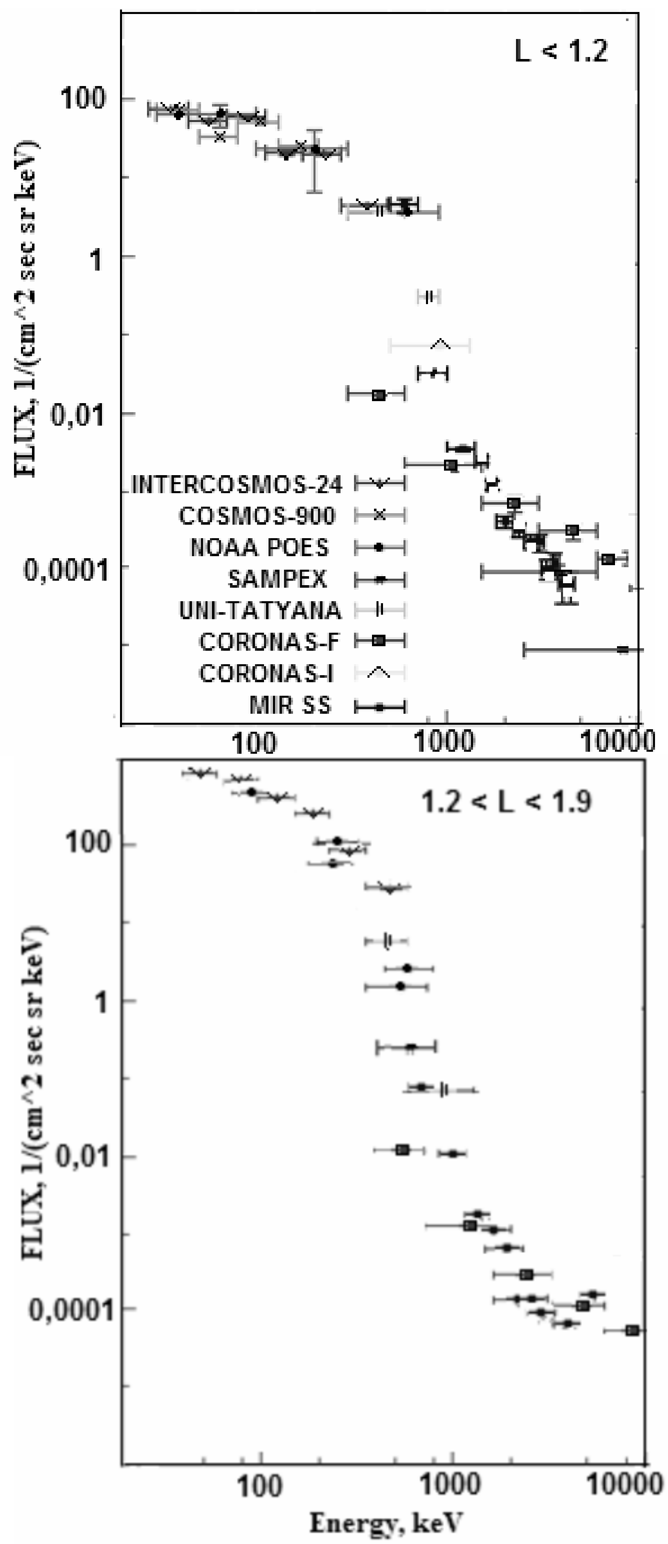

L < 1.2
FLUX, 1/(cm^2 sec sr keV)
100
1
0,01
0,0001
INTERCOSMOS-24
COSMOS-900
NOAA POES
SAMPEX
UNI-TATYANA
CORONAS-F
CORONAS-I
MIR SS
100
1000
10000
1.2 < L < 1.9
FLUX, 1/(cm^2 sec sr keV)
100
1
0,01
0,0001
100
1000
10000
Energy, keV

Fig. 3.

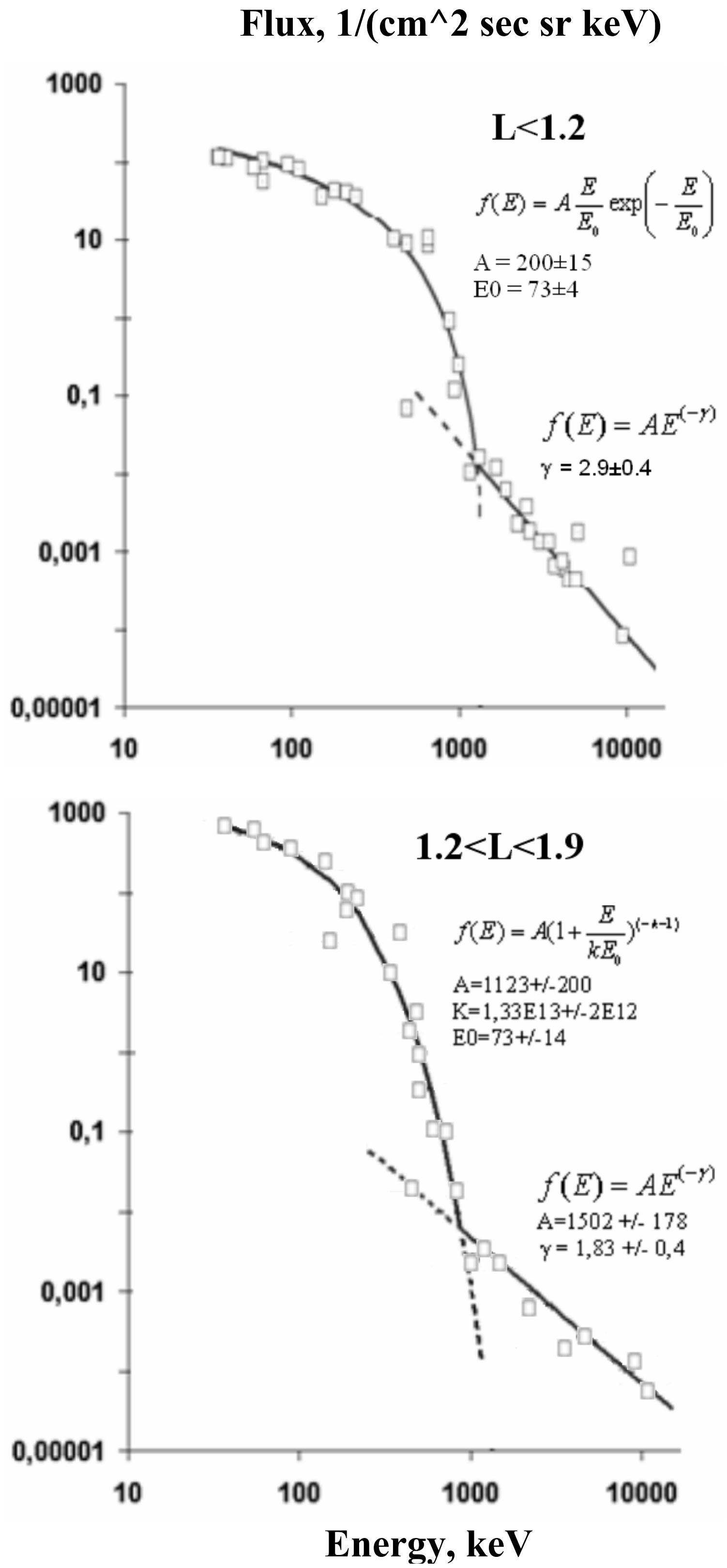

Flux, 1/(cm^2 sec sr keV)
L<1.2
$f(E) = A\frac{E}{E_0}\exp\left(-\frac{E}{E_0}\right)$
A = 200±15
E0 = 73±4
$f(E) = AE^{(-\gamma)}$
γ = 2.9±0.4
1.2<L<1.9
$f(E) = A(1+\frac{E}{kE_0})^{(-k-1)}$
A=1123+/-200
K=1,33E13+/-2E12
E0=73+/-14
$f(E) = AE^{(-\gamma)}$
A=1502 +/- 178
γ = 1,83 +/- 0,4
Energy, keV

Fig. 4.

3. Conclusions

Using datasets of different space experiment the averaged flux spectra were obtained for two main types of electron formations at L<2: the near-equatorial electron zone (L<1.2) and middle latitude electron zone (L=1.2-1.9). It was shown that electron formations at 1.2<L<1.9 are regularly registered, but not uniform in space and have two intensity peaks (L ~ 1.2-1.4 and L~1.6-1.8). The intensity of some electron peaks at L~1.6-1.8 is close to the value of Radiation Belts electron flux at L>2.

Spectrum of electron fluxes at L<1.2 is approximated with high accuracy using Maxwell function $f(E) = A\frac{E}{E_0}\exp\left(-\frac{E}{E_0}\right)$ for energy range <1 MeV and power function $f(E) = AE^{(-\gamma)}$ at higher energies.

Spectrum of electron fluxes at 1.2<L<1.9 is approximated with high accuracy using kappa-function $f(E) = A(1+\frac{E}{kE_0})^{(-k-1)}$ for energies < 1 MeV and power function $f(E) = AE^{(-\gamma)}$ for energies > 1 MeV. These spectra are similar to each other and have break at 1 MeV point. At higher energies the electron spectrum at 1.2<L<1.9 is slightly harder.

We assume that observed particles distribution at L<2 is explained by influence of two dominate mechanisms which are wave-particle interaction and so called runaway electrons. The second mechanism mainly provides electrons with energies > 1 MeV.

References

Bashkirov V.F., Denisov Yu.I., Gotseluk Yu.V., Kuznetsov S.N., Myagkova I.N., Sinyakov A.V. Trapped and quasi-trapped radiation observed by CORONAS-I satellite, Radiation Measurements 30, 537.1999.

Blake J.B., Inan U.S., Walt M., Bell T.F., Bortnik J., Chenette D.L., and Christian H.J. Lightning-induces energetic electron flux enhancements in the drift loss cone, J. Geophys. Res. 106, A12, p.733-744, 2001.

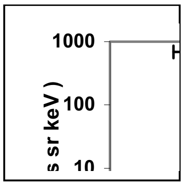
Bratolyubova-Tsulukidze L.S., E.A. Grachev, O.R. Grigoryan, and O.Yu. Nechaev. Near-equatorial electrons as measured onboard the MIR orbital station. Cosmic Research., 39, 6, 564-573, 2001.

Grachev E.A., O.R.Grigorian, S.I.Klimov, K.Kudela, A.N.Petrov, K.Schingenschuh, V.N.Sheveleva, J.Stetiarova. Altitude distribution analysis of electron fluxes at L=1.2-1.8. Adv. Space Res., v.36. pp.1992-1996, 2005.

Grigoryan O.R., L.S.Novikov, V.L.Petrov, V.N.Sheveleva. Electron fluxes with energy < 1 MeV in the surface dose of spacecrafts. Journal of spacecraft and rockets, V.43, No.3, p.530-533, 2006.

Lehtinen, N.G., T.F. Bell, V.P. Pasko, and U.S. Inan. A two-dimensional model of runaway electron beams driven by quasi-electrostatic thundercloud fields, Geophys. Res. Lett., 24, p.2639, 1997.

Nagata K., Kohno T., Murakami H. et al. Electron (0.19–3.2 MeV) and proton (0.58–35 MeV) precipitations observed by OHZORA satellite at low latitude zones L = 1.6–1.8. Planet. Space Sci. V. 36. P. 591–606, 1988.



Figures

Fig. 1. A) The SAA region; B) Electron Radiation Belts; I) electron formations in the near-equatorial region; II) electron formations at low and middle latitudes; III – zone at L~2.0 (example picture for altitude of 1000 km).

Fig. 2. The examples of electron flux enhancements at L< 2 observed onboard TATYANA satellite.

Fig. 3. Electron spectra at L<1.2 (top) and at 1.2<L<1.9 (bottom) due to different experimental data.

Fig. 4. Approximation curves of electron flux spectra at L<1.2 and 1.2<L<1.9.