National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)

2. The results of scientific research on completed space missions obtained by Russian scientists in 2014-2015

ARINA and VSPLESK satellite experiments for study of variations of high-energy proton and electron fluxes in the near-Earth space. Report for 2014 - 2015 (main results)

1. Description of ARINA and VSPLESK satellite experiments.

The stationary radiation environment in the near-Earth space is formed by the superposition of galactic cosmic rays, atmospheric albedo particle fluxes, and charged particles trapped by the geomagnetic field (radiation belt). Today it is important to study the changes of radiation conditions in the near-Earth space including the radiation belt, which appear as variations of charged particle fluxes in a wide energy range.

Satellite experiment ARINA was carried out since 2006 till 2016 (Russian spacecraft Resurs-DK1), and VSPLESK experiment on board the International Space Station was fulfilled since 2008 till 2013 [1, 2]. Scintillation spectrometers ARINA and VSPLESK, developed by MEPhI, are identical in physics scheme and have the same performances like acceptance, energy range, energy and angle resolution, field of view, etc. Multilayer scintillation detector (MSD) is main part of the spectrometers. Charged particles (electrons, protons) moving forward and arriving in the instrument aperture sequentially pass through scintillation layers C1, C2, C3, etc. up to C10, lose energy, and are absorbed in the MSD. Backward particles and particles passed through the entire instrument are cut by detector C10 operating in the anticoincidence mode. Thus, particles stopped in the MSD are electrons with energies of 3 - 30 MeV and protons with energies of 30 - 100 MeV. They are identified by the energy release in each layer under when passing through the instrument (MSD) and by the range in it. The electron and proton energy is measured by their range in MSD layers. The physics scheme and performances of the instrument are described in detail in [3]. Spectrometers allow to study the energy spectra and temporal profiles of particle fluxes.

High statistics of particles, accumulated during 2006-2015 years in ARINA and VSPLESK experiments, allowed to make the detail map of particle fluxes in the near-Earth space. For that a 4-th dimensional space (L and B coordinates, longitude and pitch-angle) was used. Additionally time (date) of observation was used as a fifth coordinate for taking into account the dependence of particle fluxes on phase of 11-year solar cycle and changing the global geomagnetic field. Such a detail approach allows to study various species of particle flux variations. Among them there are bursts of particles with duration about several seconds, caused by local disturbances of the radiation belt (lightning, earthquakes etc.), resulting in particle precipitation from it, several-hour (day) variations, interrelated with solar flares and geomagnetic storms, year scale changes, induced by 11-year solar cycle and global drift of geomagnetic field.

Main experimental results, obtained in 2014 – 2015, are presented here.

2. Dynamics of high-energy electron flux in the outer radiation belt.

Obtained results are presented in [4].

The ARINA and VSPLESK instruments carried out continuous measurements of high-energy electron flux and its energy spectrum in low-Earth orbits in the range 3-30 MeV with 10 – 15 % energy resolution. A time profile of electron flux in different L - shells has been studied since 2006. Detail analysis of experimental data on ultra relativistic (greater than 3 MeV) electrons in the outer radiation belt zone (L~3 – 8) is fulfilled. It was shown a large variability of flux of such electrons there. The sharp effects in electron flux (as rise and as drop) in magnetosphere interrelated with solar flares and coronal mass ejections have been observed.

Typical behavior of ultra relativistic electrons in outer radiation belt is shown in Figure 1. This figure presents the variation of 4 6 MeV electron flux at L=3 - 3.5 during 2012. The periods of significant (greater than some hundreds times) changing the flux of electrons were analyzed. Series of powerful solar flares and CME in the March 2012 gave rise to strong disturbance of the magnetosphere of the Earth (Dst about - 100 nT).

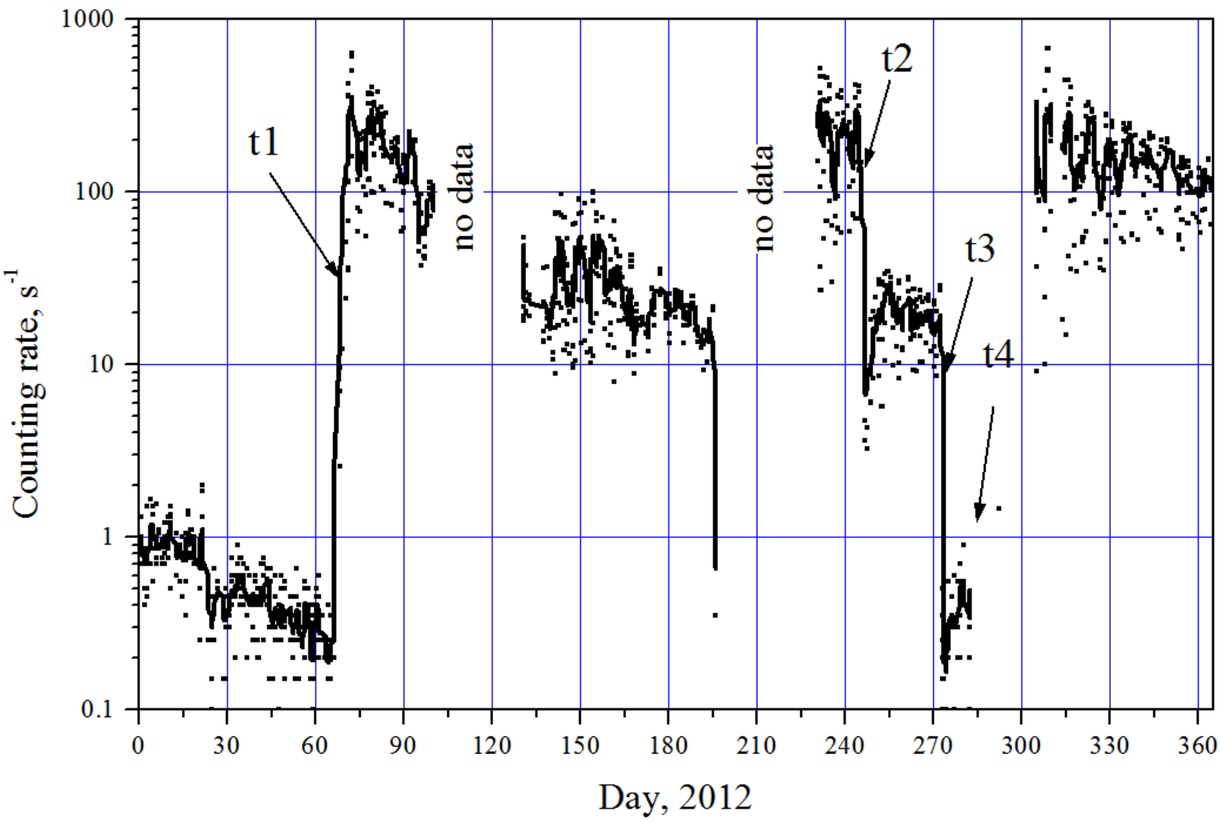

Figure 1. Variation of flux of 4 – 6 MeV electrons at L=3 - 3.5 observed by ARINA in 2012. Points is counting rates of electrons in 20 s intervals. Curve is approximation of experimental data. Arrows (t1, t2, t3, t4) mark sharp changing electron flux.

Arrows (t1, t2, t3, t4) in the figure mark the sharp changing (grows or drop) in 4-6 MeV electron flux. Each of these changing coincides with time of strong magnetospheric disturbances with Dst value about - 100 nT, caused by solar events (flares, CME, etc.). Also it is necessary to mark that ARINA and VSPLESK observations revealed that the strong geomagnetic storm is able to cause as sharp increase as sharp decrease of ultra relativistic electron flux in outer radiation belt.

2. Long-term variation of high-energy proton flux in the inner radiation belt.

Obtained results are presented in [5, 6].

2.1. Drift of South Atlantic Anomaly region in proton flux [5].

A geographical distribution of particle fluxes has been studied on the ARINA and VSPLESK experimental data. It is known that there is a movement of global geomagnetic field, leading to drift of South Atlantic Anomaly (SAA) region. This effect was observed in high-energy proton flux with ARINA and VSPLESK measurements. The analysis of temporal changing the position of proton (about 50 MeV) maximum for each separate L-shell was carried out. The drift of position of particle flux maximum was measured. The speed of the drift is about 0.45º±0.07º longitude/year in west direction (Figure 2). Analysis showed that speeds of this drift for different L-shells are practically the same. The value of the measured speed is in accordance with drift of global magnetic field of the Earth.

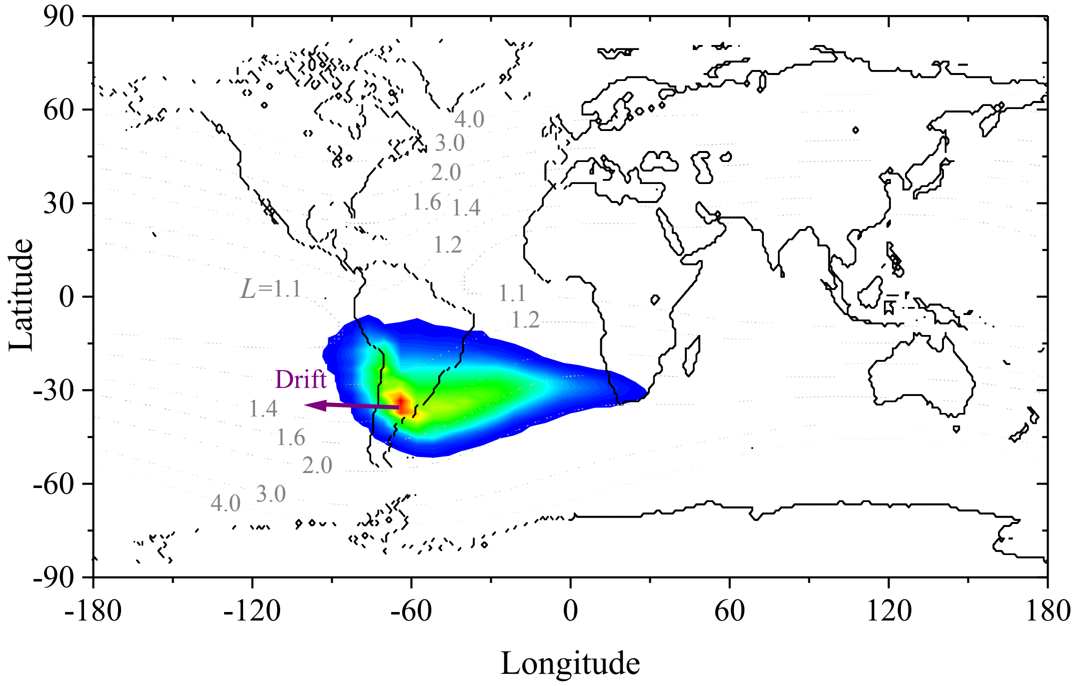

Figure 2. Drift of SAA region on the data of radiation belt proton flux (ARINA experiment, 2014 - 2015).

2.2. Variation of proton flux during the solar cycle [6].

Continuous measurements with ARINA include falling/minimum and rising/maximum phases of 23/24 solar cycles. Variation of proton flux in the inner radiation belt during 2006 - 2014 is presented in Figure 3. Anticorrelation of proton flux with solar activity is clearly visible. The ratio between proton fluxes in solar minimum and solar maximum reaches the value ~ 7.

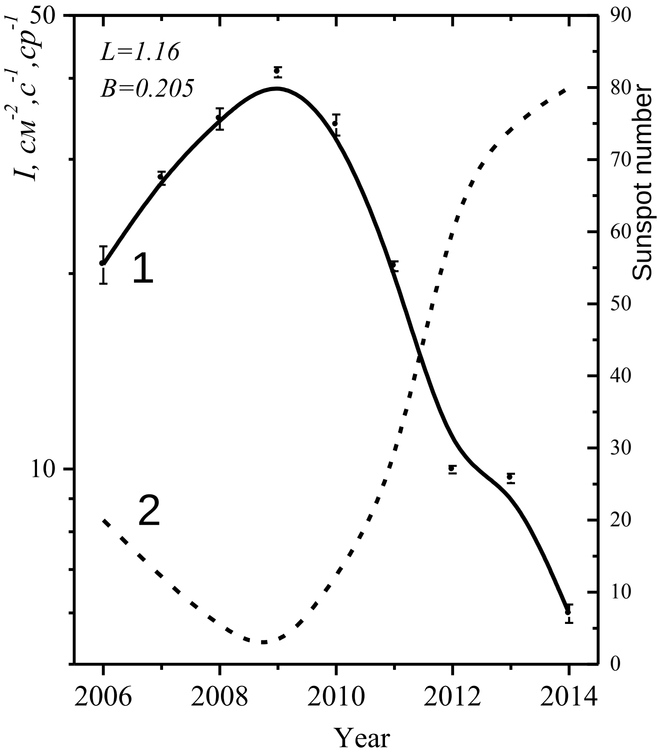

Figure 3. Variation of high-energy proton flux *I* (curve 1) in the inner radiation belt during the solar cycle (curve 2 – mean value of sunspot number).

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