Solar flare activity in 2006 - 2016 according to PAMELA and ARINA spectrometers

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Abstract. From 2006 to 2016 years on the board of RESURS-DK1 satellite PAMELA and ARINA cosmic rays experiments was carried out. The main goal of experiments is measurement of galactic component of cosmic rays; it also registers solar particles accelerated in powerful explosive processes on the sun (solar flares) in wide energy range. The article includes the list of solar events when PAMELA or ARINA spectrometers have registered increasing of proton flux intensities for energies more than 4 MeV.

1. Introduction
Solar cosmic rays (SCR) are forming on the sun by accelerating solar wind plasma particles during solar flares, coronal mass ejections and other energy releasing events. After that they can reach the Earth. Despite a long history of SCR measurements (starting from 1942) there is still a lack of experimental data, especially in relativistic energies (T > 1GeV), where just 71 such events was registered in the recorded history [1].

At the same time accurate measurements of cosmic rays spectra in the wide energy range is necessary for study principles of particles generation and acceleration on the sun, their propagation through the interplanetary space, penetration into the Earth magnetosphere and filling radiation belts.

Low energies SCR could be measured just by simple probes intended for radiation situation and space weather monitoring [2, 3], and high energies SCR indirectly with ground stations [4]. PAMELA and ARINA experimental data fill SCR energy range from dozens of MeV to dozen of GeV [5, 6], which hasn’t been covered before.

Most important task for cosmic research is providing radiation safety for a spaceship crew and electronics during near space orbiting and interplanetary flights. Solar cosmic rays are the most hazardous and the least predictable component of space weather. Their flux can increase by orders of magnitude in several minutes and keep high during from several hours up to several days.

This is the reason to study SCR influence to the Earth radiation belts. For example in the article [7] (the article is about the Forbush decrease associated with solar flare 17 May 2012) the Earth magnetic field disturbance due to the solar flare is studied. An additional filling with protons and electrons of radiation belts can take place during solar flares. β-decay of free neutrons produced in the interaction of high energy SCR with the Earth atmosphere or violation in adiabatic invariants due to magnetic
field disturbance resulting in acceleration of trapped particles and their transit from outer to inner radiation belt.

2. PAMELA and ARINA spectrometers

The satellite RESURS-DK1 with PAMELA and ARINA spectrometers on the board was launched on 15 June 2006 year. Its orbit was semipolar with inclination about 70 degrees, elliptical with apogee 600 km and perigee 350 km until September 2010 when it was changed to almost circular with radius about 600 km.

The PAMELA instrument consist of set of subdetectors: Anticoincidence system is used for exclude particles outside instrument acceptance; Time of Flight system is used for providing trigger signal and to measure velocity; silicon microstrip tracking system surrounded by permanent magnet is used for measure rigidity of particles by deflection in magnetic field; silicon-tungsten calorimeter is used for hadron/lepton separation by shape of shower; neutron detector and shower tail catcher scintillator S4 is to used enhance rejection power for high energies. ARINA spectrometer is simpler device consisted of 10 scintillator plates and is able to register protons end electrons, measuring their energy by measure a number of plates it passes through. Protons energy range available for ARINA is from 45 MeV to 100 MeV. Energy resolution of ARINA and PAMELA spectrometers is about 15% and several percents respectively. A detailed description of the apparatus can be found in [5, 6].

3. Numbers of registered events SCR

Numbers of solar events registered by PAMELA and ARINA spectrometers are in the tables 1 and 2 respectively divided by minimum energy of particles and their type. In the tables one can see that there is a large statistics of particle events to analyze accumulated by spectrometers including four events with protons more than 1 GeV (GLE 70 and 71) and five events with helium nuclei.

| Table 1. SCR event numbers: PAMELA | Table 2. SCR events numbers: ARINA |
|----------------------------------|----------------------------------|
| Proton channels, flares          | Proton channels, flares          |
| > 200 MeV                        | > 45 MeV                        |
| 31                               | 58                              |
| > 500 MeV                        | > 100 MeV                       |
| 18                               | 58                              |
| > 1 GeV                          | > 500 MeV/n                     |
| 4                                | 1                               |

| Table 3. SCR proton event statistics for different years |
|----------------------------------------------------------|
| ARINA | PAMELA |
| > 45 MeV | > 100 MeV | > 200 MeV | > 500 MeV | > 1000 MeV |
| 2006   | 2        | 2        | 2         | 2          |
| 2011   | 2        | 5        | 2         | 0          |
| 2012   | 7        | 14       | 6         | 3          |
| 2013   | 2        | 14       | 6         | 3          |
| 2014   | 3        | 10       | 4         | 1          |
| 2015   | 1        | 2        | 1         | 0          |

The number of solar events registered by the PAMELA and the ARINA apparatuses distributed by years is in the table 3. Two last strong solar flares of 23rd cycle including GLE 70 was registered by the instruments in 2006 year. No solar events were registered in the further years till March 2011. The time level of solar activity was unusually low. The highest number of solar events was observed in 2012 including GLE 71. High Energy particle solar events also were observed in January 2014. There was no strong solar flare in 2015 and 2016. Achieved solar event data allows performing physical analysis of as single flares [7, 8] as their sets.
4. High energy protons during the solar flare on 23th of January in 2012.
In the figures 1-3 at the top panels one can see differential energy spectra of protons accelerated during solar flare with class M8.7 on 23th January 2012 year in the different stage of particles coming. The moments of time when measurements of spectra took place are marked by red dotted line in the bottom panels. In the top panels intensities of proton fluxes measured by PAMELA and ARINA spectrometers are shown with red squares and light blue circles correspondingly. Galactic cosmic rays spectrum is marked with black squares (measured by PAMELA) and white circles (measured by ARINA).
In the bottom panel time profiles (from 22 Jan to 31 Jan 2012) of proton flux intensities if different energies are shown (PAMELA data marked as black squares, ARINA data as white diamond). Green marks correspond to $45 \div 55$ MeV proton flux intensity; black marks – $90 \div 115$ MeV, red marks – $620 \div 670$ MeV.
Results of PAMELA and ARINA instruments are agreed at each separate moment of time, what validate both measurements, performing independent tests of each, and showing opportunity of study of particle arriving dynamics into the near Earth space in the wide energy range. We also want to note that features of the satellite orbit allow studying cosmic rays particle penetration into the Earth magnetosphere.

5. Conclusion
PAMELA and ARINA experiments expand energy range of direct measurements of SCR from dozen of MeV up to the order of GeVs. During the period from June 2006 to January 2016 spectrometers have registered a large number of SCR events reached the Earth's orbit. We plane to conduct their analysis in the future.
Figure 2. SCR flux obtained on 23.01.12 (06:30 ÷ 06:35)

Figure 3. SCR flux obtained on 25.01.12 (11:25 ÷ 11:35)

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