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Method Of Solar Neutron Search With PAMELA Neutron Detector

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Abstract. This research is devoted to solar neutron search in the flux of the particles emitted by the Sun during solar flare by means of the neutron detector of the magnetic spectrometer PAMELA. The main objectives of our research were to study the background conditions in the Resurs-DK1 satellite orbit during the periods of quiet Sun and to develop the methods of solar neutron search in the flux of high-energy solar particles. The tasks of study were as the analysis of the neutron detector count rate during solar flares with possible generation of neutrons and the attempt to detect the stationary neutron flux from the Sun in weak flares. The analysis was carried out for 28 solar events when neutrons could be produced during the period from December 2006 till October 2015.

1. Introduction

The Sun is a unique space source whose neutron fluxes can be detected near Earth. During periods of active processes on the Sun (in particular, solar flares), there are accelerations of charged particles up to high energies. Charged particles interacting with the solar atmosphere can generate high-energy neutrons. Part of generated neutrons leaves the Sun. Detections of these neutron fluxes serve for studying and understanding of acceleration processes during solar flares, give information about acceleration time and total flux of the accelerated particles [1]. As neutrons don't possess any electric charge their trajectories in space aren't influenced by magnetic fields. They travel from the area of generation to the place of registration in the vicinity of Earth along a straight lines, unlike of charged particles which have curved trajectory, "wrapping" over power lines of the Sun magnetic field, passing longer way in comparisons with neutron one [2]. Observations of solar neutrons can be implemented by means of the ground facilities conducting continuous monitoring of space radiation. However in this case solar neutron flux will be noticeably reduced because of absorption in the Earth atmosphere. Therefore it is more preferable to conduct measurements of solar neutron flux high in mountains or on board spacecraft.

2. Experiment

The experiment PAMELA [3] was started on board Resurs-DK1 satellite in June 2006. The satellite was launched into a polar elliptic orbit of 350 - 610 km height and experiment have been continued till March 2016. The experiment main goal was precise measurement of charged particle and antiparticle fluxes in cosmic rays. The PAMELA was equipped with magnetic spectrometer, imaging electromagnetic calorimeter, time of flight system, anticoincidence system, bottom shower scintillator detector and in addition with neutron detector (ND). ND served for identification of detected electrons and positrons on proton background. The detector consists of two layers of 18 cylindrical proportional counters of 18 mm diameter and 209 mm length filled with gas ^{3}He gas under 7 atmospheres pressure and surrounded by a polyethylene moderator 9 cm thick. As well it provides the detection of neutron background flux at the same time (so-called the background channel). Background neutrons were registered during time intervals between registrations of charged particle detections. This background channel was used to search for solar neutrons as it provides continuous monitoring of neutron flux.

3. Data analysis and results

Analysis of the neutron detector counting rate during solar flares from 2006 to 2016 was carried out to search for solar nature neutrons. There were considered only solar flares with X-ray emission when the neutrons production was possible [4]. The list of flares was taken from [4] and supplemented using the data of a magnetic spectrometer PAMELA as results of solar proton event observation. Characteristics of these events (flare class and the start time of the flare) were taken according to GOES (http://goes.gsfc.nasa.gov/) and shown in the table 1. Measured count rates of the neutron detector during the period of solar flares were compared with expected background. The expected count rate of solar quiet period was estimated by using the ND data taken from the satellite orbits preceding the flare starting time under identical geomagnetic conditions. Observations of a solar neutron signal are possible during time intervals between the onsets of X-ray flash until emergences of solar energetic protons near the Earth. In the same time it has to be checked that the satellite was on sunlit side of the Earth. Time intervals of possible solar neutron detection are presented in table 1.

Table 1.

Date	Flare class	The start time of the flare	The start time of possible observation
06 December 2006	X9.0	10:35	11:14
13 December 2006	X3.4	02:40	03:07
14 December 2006	X1.5	22:15	22:23
06 September 2011	X2.1	22:20	22:28
08 September 2011	M6.7	15:46	16:08
03 November 2011	X1.9	20:27	20:35
07 March 2011	M3.7	20:12	20:20
07 June 2011	M2.5	06:16	06:24
23 January 2012	M8.7	03:38	03:46
27 January 2012	X1.7	17:37	17:59
05 March 2012	X1.1	04:05	04:13
07 March 2012	X5.4	00:24	00:32
09 March 2012	M6.3	03:45	03:53
13 March 2012	M7.8	17:25	17:47
17 May 2012	M5.1	01:47	01:55

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06 July 2012	X1.1	23:01	23:17
19 July 2012	M7.7	04:17	04:30
11 April 2013	M6.5	06:55	07:06
12 April 2013	M3.3	20:38	20:46
22 May 2013	M5.0	13:08	13:16
06 January 2014	–	08:00	08:08
07 January 2014	X1.2	18:04	18:12
01 September 2014	C1.6	18:03	18:11
20 February 2014	M3.0	07:56	08:04
08 July 2014	M6.5	16:20	16:28
29 March 2014	X1.0	17:48	17:56
18 April 2014	M7.3	13:03	13:11
29 October 2015	<C1.0	02:15	02:23

Figure 1 shows the average daily dependence of the count rate on the rigidity of geomagnetic cutoff Region of South Atlantic Anomaly (SAA) was excluded. This dependence can be used to obtain the expected count rate for nearest orbits.

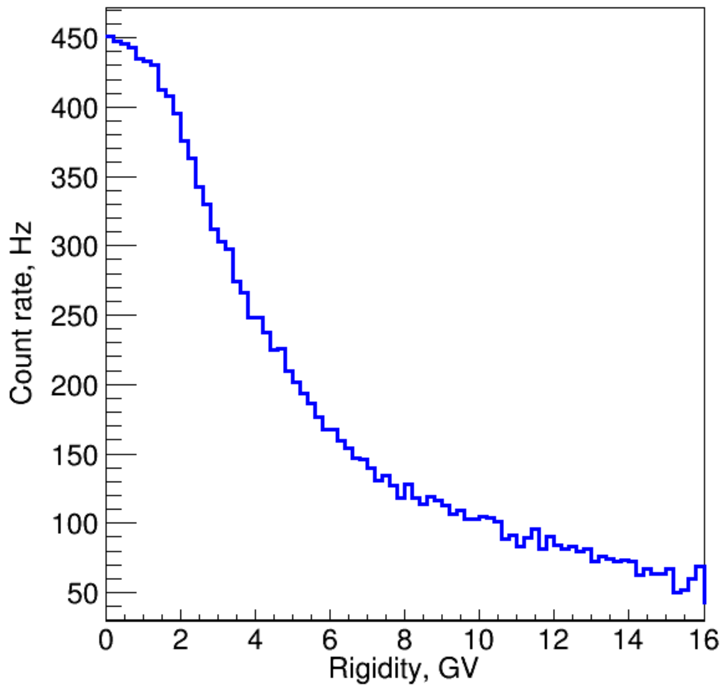

Figure 1. Dependence of the count rate on the rigidity of geomagnetic cutoff.

Figure 2 shows an example of the estimation for solar neutron counting rate 7 January 2014. SF points the time of solar X ray flare (18:04 UT). The blue curve is the expected albedo cosmic ray albedo background count rate according to the data before flare 6 January 2014. The red points are the measured count rate 7 January 2014. The green line is the result after background subtraction. After 20:40 UT it is possible to see increasing of neutron albedo count rate due to solar energetic protons reached the Earth orbit. Interval 18:30-18:50 was excluded from analysis because of passing across of SAA region where used background model does not work properly.

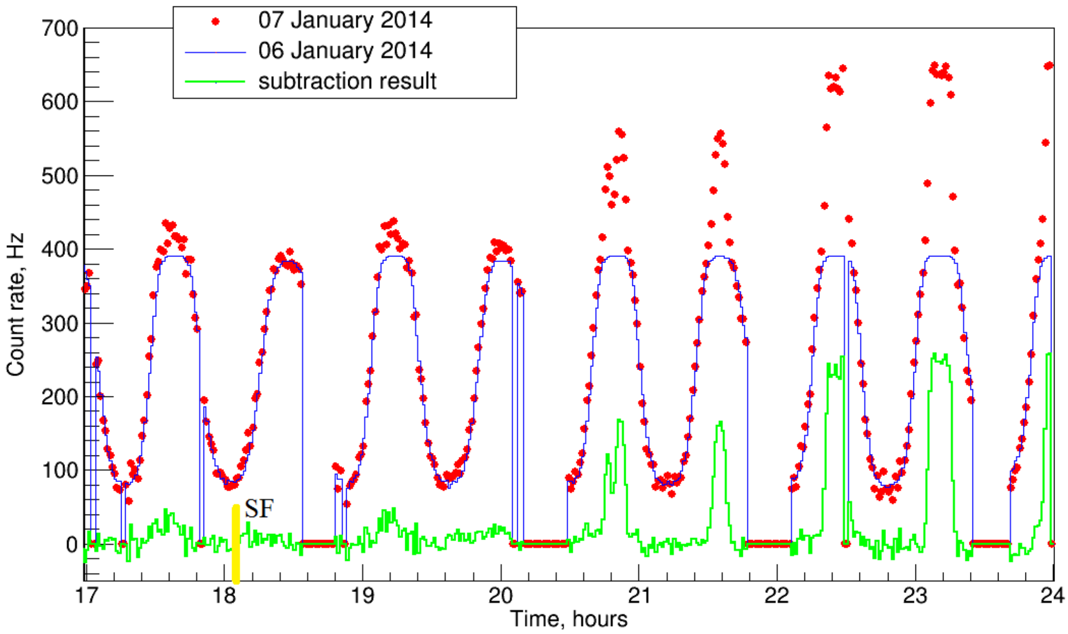

Figure 2. Estimation for solar neutron counting rate 2014 January 7.

4. Conclusion

The analysis of 28 solar events from December 2006 till October 2015 when neutrons could be generated on the Sun was implemented. In a number of events there are some increases of neutron count rates which could be the hints for solar neutron detections from the Sun. The conclusion on the nature of these neutrons requires more careful analysis of background conditions in polar areas that will allow decreasing background fluctuation.

Acknowledgments

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