Deuteron spectrum measurements under radiation belt with PAMELA instrument

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Abstract

In this work the results of data analysis of the deuteron albedo radiation obtained in the PAMELA experiment are presented. PAMELA is an international space experiment carried out on board of the satellite Resurs DK-1. The high precision detectors allow to register and identify cosmic ray particles in a wide energy range. The albedo deuteron spectrum in the energy range 70 – 600 MeV/nucleon has been measured.

Keywords: cosmic ray, PAMELA experiment, deuteron, albedo, radiation belt

1. Introduction

Albedo radiation is a product of the interaction of particles of primary cosmic rays (PCR) and the nuclei of the residual atmosphere. Secondary particles moving in a magnetic field of the Earth form albedo fluxes of particles under the radiation belt. Study of albedo radiation allows to understand the mechanisms of their generation, namely, for a known content and the particle spec-

trum of the PCR and for a well known nuclear composition of the nuclei of the residual atmosphere to estimate the contribution of different processes of their interactions into observed particle flux. In addition, knowing of the albedo particles flux is necessary for evaluating the radiation background at low altitudes.

Earth radiation belt and albedo radiation were discovered in 1957 [1, 2]. It has been found that particles of albedo are predominantly protons [3, 4]. Events, corresponding to heavier nuclei and electrons were detected as well. In [5] it was mentioned the registration of deuteron albedo radiation for the first time, in [6] the results of the unique attempt to measure the spectrum of deuterons under radiation belt in the AMS-01 experiment was presented. This result was compared with the calculated models described in [7, 8].

Results of the experiment AMS-01 [6] do not coincide with the computational model, which is based on the predominance of deuteron generation by means of nuclear reactions of the incident cosmic ray particles with the nucleons of the atmospheric nuclei. In view of the paucity of data on the measurement of deuteron fluxes under radiation belt this it is undoubtedly required new measurement, verification and refinement of the results. In addition, these measurements are needed to refine estimates of the radiation environment in near Earth orbits.

In this paper we present the first results of data analysis for measuring the albedo deuteron fluxes. Data from the PAMELA experiment from 2006 to 2008 were used.

2. PAMELA experiment

PAMELA experiment [9] is a magnetic spectrometer (MS) equipped with a time-of-flight system (TOF) and the calorimeter. It also includes a tail shower scintillation detector and neutron detector. The magnet is surrounded by scintillation counters operating in the anticoincidence mode (AC) used to select events with particles entering the spectrometer in its filed of view.

Detailed description of scientific equipment PAMELA detectors can be found in [9, 10, 11, 12].

3. Particle identification

For the definition of detected particle nature, as well as the recovery of its energy the multivariate correlation analysis of the signals from the PAMELA detectors was used. At the first stage the selection of "good" events was carried out. For this purpose, the analysis of the characteristics of events was used to identify isotopes in the energy range from 60 MeV/nucleon to 2

GeV/nucleon, a special set of criteria for implementing the so-called "basic" selection has been developed. Events passed "basic" selection have no signals from anticoincidence detectors, corresponding to one particle arriving inside the aperture of apparatus, which has not multiple interactions with the detector material, having well approximated trajectory in tracker.

In order to check the correctness of selection and to determine its efficiency mentioned selection criteria were applied as to the data from the orbit and to the data of Monte Carlo simulation of crossing of different particles through the detector system, implemented using the software package GEANT [13]. At the second stage of the analysis the procedure of event identification was applied using values of particle rigidity R, measured by tracker, its velocity β, measured by TOF and multiple measurements of the energy losses of TOF and tracker detectors [12].

4. Albedo deuteron spectra

The deuteron spectrum in each narrow energy interval values were calculated as follows:

$$\frac{dJ}{dE} = \frac{N(\Delta E, E)}{\Delta E \times \Gamma(E) \times \varepsilon(E) \times t_{live}},$$

where $N(\Delta E, E)$ – the number of particles with energy E registered in the energy interval ΔE, $\Gamma(E)$ – the geometric factor of the instrument, $\varepsilon(E)$ is the total efficiency of the event selection and t_{live} – "live" time of the spectra measurements. Figure 1 shows the measured spectra of albedo deuterons for different intervals of geomagnetic latitude ϕ_M: $0.2 \div 0.6$; $0.6 \div 0.7$; $0.7 \div 0.8$; $0.8 \div 0.9$, which correspond to the following intervals of L-coordinates $1.04 < L < 1.46$; $1.46 < L < 1.71$; $1.71 < L < 2.06$; $2.06 < L < 2.56$. Simultaneously the results of calculations made in [7] as well as the results of the experiment AMS-01 [6] are shown. As mentioned above, in the area under radiation belt deuterons are born as a result of interaction reaction of cosmic ray particles with the nuclei of the residual atmosphere. In Fig. 1 solid line corresponds to a model where the coalescence is the dominant reaction of albedo deuterons birth [7]. PAMELA experiment data are well agreed with the calculation in the entire energy range. For energy above 200 MeV/nucleon PAMELA data are in good agreement with results of AMS-01 [6]. In the range of L-coordinate $0.8 \div 0.9$ the contribution of galactic deuterons in the obtained spectrum becomes noticeable. This fact can be explained by means of the difference in the geomagnetic cutoff for experiments PAMELA and
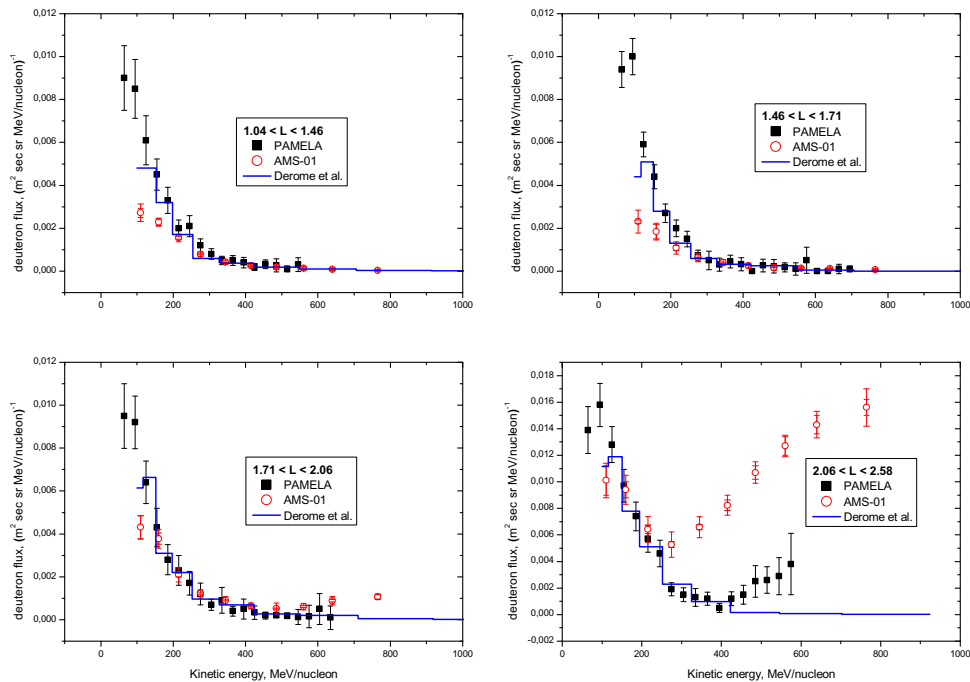
Figure 1: The deuteron albedo spectrum obtained in the PAMELA experiment for different values of *L* geomagnetic coordinate. Black squares are PAMELA data, red circles are AMS-01 data and blue solid lines are theoretical expectations

AMS-01 which is resulting from different angular apertures of the experimental instruments. The radiation belt zone was investigated too and the deuterons were registered in the energy range from 100 MeV/nucleon to 600 MeV/nucleon. It was not possible to calculate the spectrum due to strong angular efficiency dependence and low statistics for different angles.

5. Conclusion

As a result of this work the spectrum of deuterons under radiation belt in the energy range 70 – 600 MeV/nucleon is measured. The measurements are consistent with the theoretical model, where it is assumed that deuterons under radiation belt are generated mainly by nuclear fusion reactions of the incident cosmic ray particles and nucleons of the nuclei of the atmosphere and consequent movement in Earth's magnetic field.

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