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Features of re-entrant albedo deuteron trajectories in near Earth orbit with PAMELA experiment

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Abstract. The results of trajectory reconstruction for re-entrant albedo deuteron fluxes obtained in the PAMELA experiment are presented in this work. PAMELA is an international experiment aimed on measurements of cosmic ray particle fluxes in wide energy range. In particular, analysis of PAMELA data gives possibility to identify deuterons. Classification of re-entrant albedo deuterons with energies from 70 to 400 MeV/nucleon depending on their reconstructed lifetimes and generation zones is presented here at first time.

1. Introduction

The particles registered in near Earth orbit can be attributed to galactic cosmic ray (GCR) particles generated in astrophysical sources, albedo particles originated in interactions of high energy GCR with the nuclei of the residual atmosphere and radiation belt particles trapped by Earth's magnetic field. For the first time the registration of deuteron albedo radiation was mentioned in [1, 2]. The results of the unique attempt to measure the spectrum of deuterons under radiation belt in the AMS-01 experiment were presented in [3]. The last and the most accurate measurements were implemented in PAMELA experiment [4]. PAMELA instrument was installed on board Resurs DK-1 satellite, which was launched on June 15, 2006. Detailed description of the PAMELA experiment can be found in [5, 6, 7, 8]. Here we present the original and unique study of albedo deuteron generation zones.

2. Particle identification

For the identification of detected particle nature, as well as the recovery of its energy the multivariate correlation analysis of the signals from different detectors was used [4, 8, 9]. This identification method was updated because trajectory reconstruction in Earth's magnetic field requires reliable determination of each deuteron event. If the type of particle will be determined wrong, the trajectory will be reconstructed wrong as well. So only deuterons with kinetic energy from 70 to 400 MeV/nucleon were selected from full data sample. Nevertheless it is impossible to reject secondary deuterons born in the spectrometer material by nuclear interactions with incoming CR protons or helium so from 3% to 10% of selected events are protons.

Measured magnetic rigidities were corrected for the energy losses in ToF and MC, evaluated with Monte-Carlo GEANT4 [10] simulations of the particle interaction with instrument material.

3. Deuteron trajectory reconstruction routine

Trajectory reconstruction was performed solving equations of particle motion in Earth's magnetic field with numerical integration methods [11], using the geomagnetic field model International Geomagnetic Reference Field (IGRF) [12]. Maximum value of drift time was chosen to be 10 seconds.

Deuteron trajectories were reconstructed back from the registration point until they intersected the boundaries of "dense" atmosphere, which was assumed at an altitude of 30 km. These particles were classified as re-entrant albedo deuterons.

4. Trajectory reconstruction results

Data sample from July 2006 to January 2008 was used and more than 20.000 re-entrant deuteron events with energies from 100 to 400 MeV/nucleon were selected.

In the figure 1 the calculated lifetimes for albedo deuterons are presented. It's clear that about 90% of them have lifetimes less than 2 seconds before their registration, it's "splash" albedo particles. Let's name that these particles are short-lived. In contrary, long-lived deuterons with lifetimes more than 2 seconds constitute about 10% of albedo deuteron population.

In the figure 2 the coordinates of re-entrant albedo deuteron generation zones depending from their reconstructed lifetime and measured energies are given. Only number of registered particles is shown, because it's not possible to calculate spectra due to low statistics for different pitch-angles energies. It is shown that re-entrant albedo deuterons are localized in different geomagnetic zones depending from their measured and reconstructed attributes. Short-lived particles are generated uniformly almost in broad longitude and latitude intervals excluding zone of South Atlantic Magnetic Anomaly (SAA) and polar regions.

But if we consider populations of particles with bigger lifetimes then we will find that these particles were not born uniformly. Instead there are two zones of their generation: Zone I in the East of SAA and Zone II near the polar regions.

Another interesting fact is that these particles belong to different sub-populations of re-entrant albedo deuterons, just like for protons registered in PAMELA experiment [13].

Long-lived deuterons born in Zone I are an "quasitrapped" particles, these particles have features of their motion in Earth's magnetosphere very close to radiation belt particles. It is clear from figure 2 that there are an longitudinal and energetic dependences for quasitrapped deuterons. If we take bigger lifetimes and bigger energies these particles will be born in zones closer to SAA. Long-lived deuterons born in Zone II are an "pseudotrapped" particles, they are born in zone of geomagnetic penumbra and their magnetic rigidities are close to cutoff ones [14]. These particles have complicated trajectories in Earth's magnetic field.

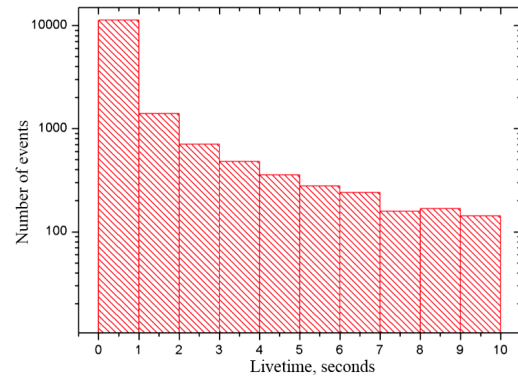


Figure 1. Lifetime distribution for re-entrant albedo deuterons.

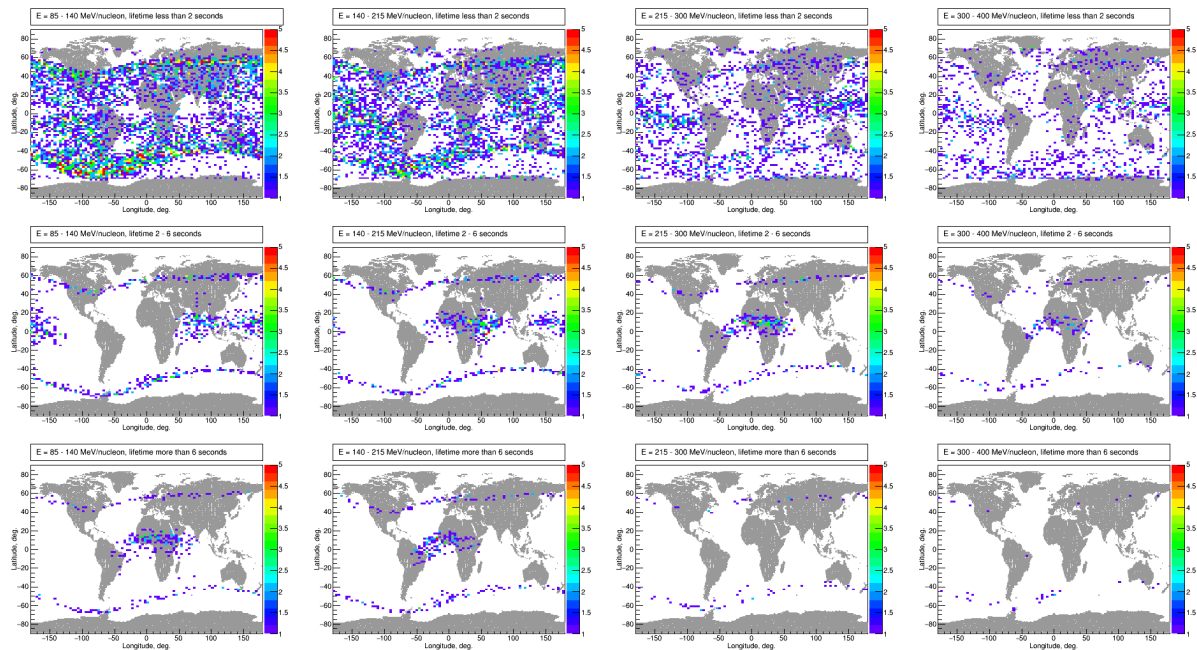


Figure 2. Coordinates of re-entrant albedo deuteron generation zones depending on their reconstructed lifetime and measured energies.

5. Conclusion

As a result of this work the trajectory reconstruction for re-entrant albedo deuterons with kinetic energies from 70 to 400 MeV/nucleon was performed. Three populations of albedo particles with completely different character of motion in Earth's magnetic field were completely distinguished.

Acknowledgments

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