MEASUREMENTS OF LIGHT ISOTOPES OVER THE SOLAR MIMIMUM IN THE PAMELA EXPERIMENT

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INTRODUCTION

Deuterons of galactic cosmic rays (GCRs) are produced alongside other light nuclei in the interactions between primary cosmic rays (mostly protons and alpha particles) and interstellar matter. They propagate and diffuse within the interstellar medium, reach the heliosphere, and enter near-Earth space where these particles can be registered by cosmic ray experiments. **The differential energy spectrum of deuterons** reconstructed in the vicinity of the Earth **varies over time**. It is strongly affected by solar activity, which alters the parameters of particle transfer in the heliosphere. This alteration is induced by changes in the corresponding solar parameters (e.g., the solar wind velocity or the tilt angle of the heliospheric current sheet [Potgieter, M.S. Living Rev. Sol. Phys. (2013) 10: 3. doi:10.12942/lrsp-2013-3]) and makes the GCR spectrum sensitive to solar phenomena. None of the existing models provides an unambiguous and complete description of the processes of solar modulation of galactic cosmic rays. Since GCR modulation is believed to depend on the charge sign, mass, and type of particles, it is crucial to measure the CR particle spectra at different times (i.e., at different solar parameters) and to obtain spectra of different GCR components. Such measurements should help to determine the details of solar GCR modulation and possibly develop a theory characterizing the entire body of GCR-related processes occurring within the heliosphere. In the last twenty years, several research groups (e.g., the BESS, AMS and PAMELA collaborations) have measured the spectrum of galactic deuterons in the energy interval of ~0.1–1.0 GeV/nucleon. Since the periods of observations differed, however, the absolute values of these spectra were often contradictory. The BESS group, which used a balloon-borne magnetic spectrometer with several additional detectors, was the first to make longterm measurements of the deuteron spectrum in the interval from 1992 to 2000. The first results from measuring the GCR deuteron spectra in the interval from the middle of 2006 to the end of 2009 (solar minimum period) are reported here.

THE PAMELA EXPERIMENT

The PAMELA experiment [Adriani, O., Barbarino, G.C., Bazilevskaya, G.A., et al., Phys. Rep., 2014, vol. 544, p. 323] is being conducted by a group of scientists from Russia, Italy, Germany, and Sweden. The "heart" of the PAMELA instrument is the magnetic spectrometer (an arrangement of track semiconductor detectors located within the working volume of a permanent magnet). The unit is also fitted with a time-of-flight system that contains three double- layer scintillation detectors, an electromagnetic calorimeter, a scintillation shower detector, and a neutron detector. The working volume of the magnetic spectrometer is surrounded with scintillation counters operating in the anticoincidence (AC) mode. The AC system is used to reject events in which particles enter the spectrometer outside of its aperture.

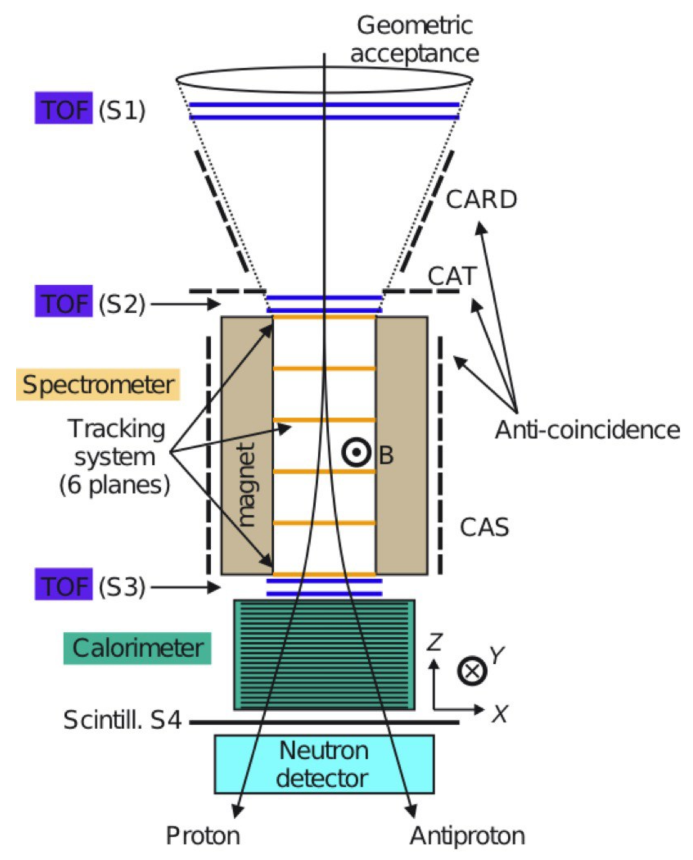

Fig. 1. Scheme of PAMELA instrument.

DEUTERON SPECTRUM RECONSTRUCTION

In reconstructing the differential energy spectrum of deuterons, the latter are identified in narrow energy intervals, and the efficiency of their detection and selection is determined. The identification procedure is based on a multiparameter correlation analysis of the signals from different PAMELA detectors, when the simultaneous analysis of a great number of event parameters allows us to identify deuterons reliably in the hardness range of 0.5–2.5 GV. The efficiencies of the detection and selection of particles, which depend on their energy and type, were calculated using cross calibrations (i.e., the efficiency of a certain detector was determined using other detectors) and were checked against the data from Monte Carlo modeling with the GEANT software package. The resulting efficiencies for deuterons and protons differed (but were fairly close).

SOLAR MODULATION OF DEUTERONS

The preliminary results from reconstructing differential energy spectra of GCR deuterons in the rigidity range of 0.6–2.5 GV in the interval from July 2006 to December 2009 in the figures below.

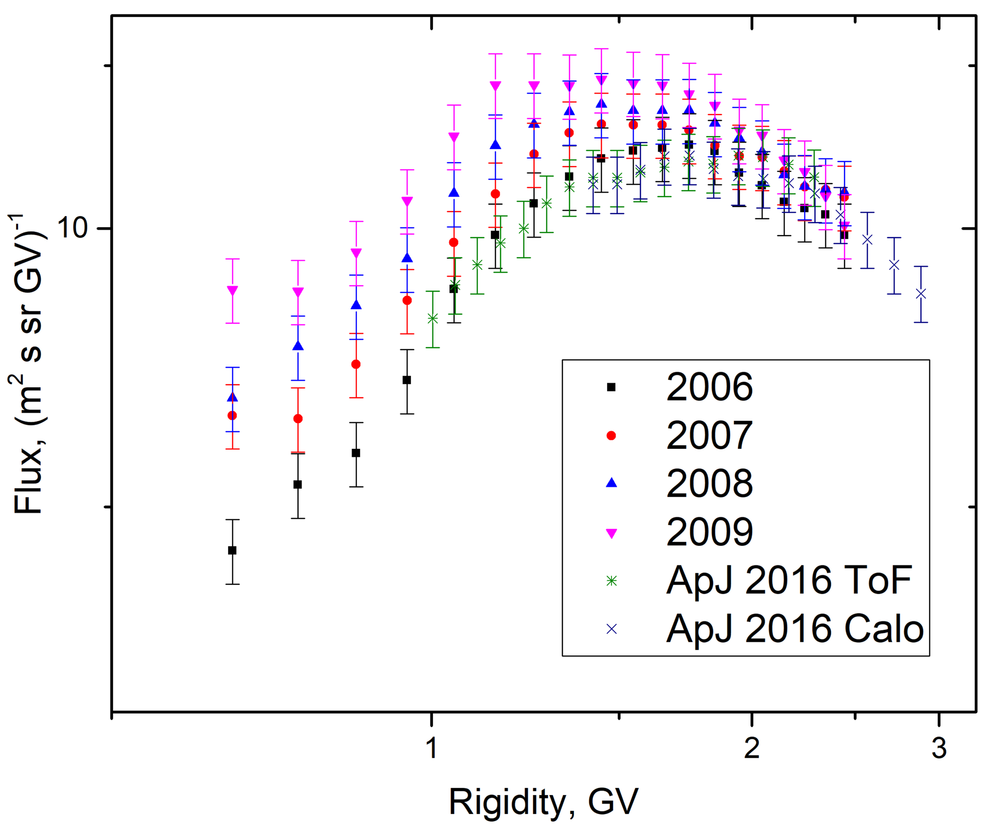

Fig. 2. GCR deuteron spectrum for period from 2006 to 2009 (preliminary).

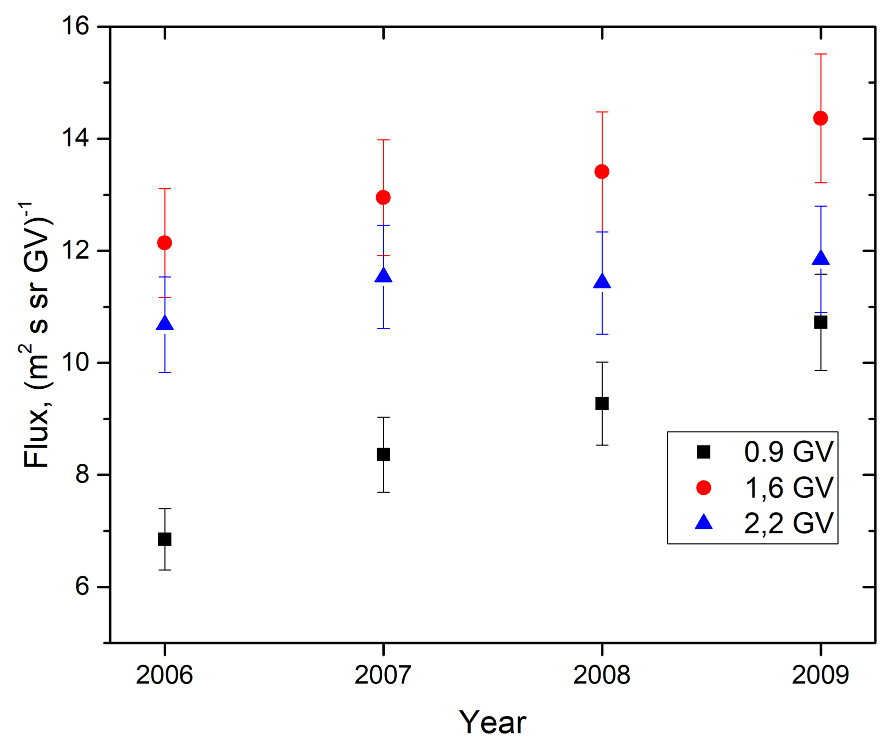

Fig. 3. Consideration of several energy bins of GCR d spectrum over the time from 2006 to 2009 (preliminary).

A gradual increase in the absolute spectrum values, which we attribute to a weakening of the effect of solar modulation of cosmic rays (the modulating influence was at its minimum in 2009), is seen clearly. An understandable weakening of the modulation effect at higher particle energies is also evident.

CONCLUSIONS

The preliminary results from measuring the spectra of GCR deuterons in 2006–2009 were presented. A clear increase in the absolute flux values closer to the solar modulation minimum in 2009 was observed. The PAMELA experiment's data with a uniquely long interval of measurements outside the atmosphere break new ground in investigating the solar modulation of GCR deuterons. The complete data set will be analyzed in future studies, and the results for the solar modulation of GCR deuterons in 2006–2015 will be presented in future.