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Geomagnetically trapped, albedo and solar energetic particles: Trajectory analysis and flux reconstruction with PAMELA

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Abstract

The PAMELA satellite experiment is providing comprehensive observations of the interplanetary and magnetospheric radiation in the near-Earth environment. Thanks to its identification capabilities and the semi-polar orbit, PAMELA is able to precisely measure the energetic spectra and the angular distributions of the different cosmic-ray populations over a wide latitude region, including geomagnetically trapped and albedo particles. Its observations comprise the solar energetic particle events between solar cycles 23 and 24, and the geomagnetic cutoff variations during magnetospheric storms. PAMELA's measurements are supported by an accurate analysis of particle trajectories in the Earth's magnetosphere based on a realistic geomagnetic field modeling, which allows the classification of particle populations of different origin and the investigation of the asymptotic directions of arrival.

Keywords: Cosmic-rays; Radiation belts; Albedo particles; Geomagnetic cutoff; Solar energetic particles

1. Introduction

PAMELA (a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) is a space-based experiment designed for a precise measurement of charged Cosmic-Rays (CR) – protons, electrons, their antiparticles and light nuclei – in the kinetic energy interval from several tens of MeV up to several hundreds of GeV (Adriani et al., 2014). The Resurs-DK1 satellite, which hosts the apparatus, was launched into a semi-polar (70° inclination) and elliptical (350–610 km altitude) orbit on 15 June 2006; in 2010 it was changed to an approximately circular orbit at an altitude of ~580 km. The instrument consists of a magnetic spectrometer equipped with a silicon tracking system, a time-of-flight system shielded by an anticoincidence system, an electromagnetic calorimeter and a neutron detector. Details about apparatus performance, proton selection, detector efficiencies and experimental uncertainties can be found elsewhere (see e.g. Adriani et al. (2013)).

PAMELA is providing comprehensive observations of the interplanetary (Adriani et al., 2013, 2015d) and magnetospheric (Adriani et al., 2011a, 2015a,c, 2016) radiation in the near-Earth environment. In particular, PAMELA is able to precisely measure the solar energetic particle (SEP) events during solar cycles 23 and 24 (Adriani et al., 2011b, 2015b). This work reviews PAMELA's main magnetospheric results, with the focus on the analysis methods developed to support the observations, based on an accurate reconstruction of particle trajectories in the Earth's magnetosphere.

2. Geomagnetically trapped and re-entrant albedo protons

The Van Allen belts constitute a major radiation source in the Earth's vicinity. Specifically, the inner belt is mainly populated by energetic protons, mostly originated by the decay of albedo neutrons according to the CRAND mechanism (Farley and Walt, 1971), experiencing long-term magnetic trapping. Despite the significant improvement made in the latest decades, the description of the trapped environment is still incomplete, with largest uncertainties affecting the high energy fluxes in the inner zone and the South Atlantic Anomaly (SAA), where the inner belt makes its closest approach to the Earth.

In addition, the magnetospheric radiation includes populations of albedo protons originated by the collisions of interplanetary CRs on the atmosphere. A quasi-trapped component concentrates in equatorial regions and presents features similar to those of radiation belt protons, but with limited lifetimes and much less intense fluxes. An untrapped component spreads over all latitudes including the "penumbra" region near the geomagnetic cutoff, where particles of both interplanetary and atmospheric origin are present.

In this Section we discuss the new accurate measurements of the magnetospheric radiation made by the PAMELA experiment (Adriani et al., 2015a,c). Results are based on data collected between July 2006 and September 2009.

2.1. Particle classification

Trajectories of all selected down-going protons were reconstructed in the Earth's magnetosphere using a tracing program based on numerical integration methods (Smart and Shea, 2000, 2005), and implementing the IGRF11 (Finlay et al., 2010) and the TS05 (Tsyganenko and Sitnov, 2005) as internal and external geomagnetic field models, respectively (Bruno et al., 2015a). Solar wind and Interplanetay Magnetic Field (IMF) parameters were obtained from the high resolution (5-min) Omniweb database (http://omniweb.gsfc.nasa.gov/). Trajectories were propagated back and forth from the measurement location and traced until: back-traced trajectories reached the model magnetosphere boundaries (*galactic* protons); or they intersected the absorbing atmosphere limit, which was

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