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Relativistic electron fluxes and dose rate variations observed on the international space station

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ABSTRACT

The paper presents observations of relativistic electron precipitations (REP) on the International Space Station (ISS) obtained by three Bulgarian-built instruments flown in 2001 and 2008–2010. The first data are from the Liulin-E094 instrument flown in May–August 2001 inside the US laboratory module of the ISS. Next the time profiles of the REP-generated daily fluences and the absorbed doses at the orbit of ISS during the period February 2008–August 2010 are analyzed in dependence of the daily Ap index and compared with the daily relativistic electron fluence with energies of more than 2 MeV measured by the GOES. The REP in April 2010 being the second largest in GOES history (with a >2 MeV electron fluence event) is specially studied.

1. Introduction

Relativistic electron precipitations (REP) have been observed for many years. First reports are by Brown and Stone (1972), Imhof et al. (1986, 1991). The most comprehensive study of long-term observations of REP was made by Zheng et al. (2006), using the 2–6 MeV electron data from the SAMPEX satellite during 1992–2004.

Relativistic electrons enhancements in the outer radiation belt are one of the major manifestations of space weather (Zheng et al., 2006; Wrenn, 2009) near the Earth's orbit. Their understanding is of significant importance from both a practical and a space radiation physics point of view. Electrons with energies of a few MeV can penetrate the spacecraft shielding and can deposit significant charge in the dielectric materials, which after electrostatic breakdown can damage sensitive electronic preamplifiers and whole systems of the spacecraft. A similar event happened with the Galaxy 15 spacecraft (Green et al., 2010), which stopped responding to ground commands at the beginning of the period studied by us on 5th of April 2010 at 09:48 UTC.

The total dose of an astronaut, who is spending 6 h on Extra Vehicular Activity (EVA) inside the REP, has been estimated in the United States report of the Committee on Solar and Space Physics and Committee on Solar-Terrestrial Research (2000). The conclusion is that the dose will be large enough to exceed the astronaut's short-term limits for both skin and eyes. One of the recommendations (3b on page 37) is: "As soon as possible, JSC should install an electron dosimeter and an ion dosimeter outside the ISS that can return data in real time to the Space Radiation Analysis Group (SRAG) at the Johnson Space Center". To our knowledge such dosimeters are still not installed outside the ISS. There is an another more disturbing fact that there is no active control of the doses accumulated by the American astronauts and Russian cosmonauts during EVA.

In 2001 we observed for the first time relativistic electrons in the US laboratory module of the ISS in the data of the mobile dosimetry unit no. 2 (MDU#2), which was a part of the Liulin-E094 instrument (Dachev et al., 2002a; Reitz et al., 2005). Because of the relatively small dose rates the effect was not fully understood. It was part of a presentation (Dachev et al., 2002b) but was not published. In this paper we present more comprehensive study of the whole dynamics of the latitudinal distribution of the ISS radiation environment parameters, which are affected by middle-term leaving belt centered at $L=1.6$, outer radiation belt signatures at $3<L<5$ and solar proton event (SPE) at $L>5$. L is

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the McIlwain's parameter (McIlwain, 1961; Heynderickx et al., 1996).

Relativistic electrons were observed by us outside the Foton-M2/M3 spacecraft in the periods 31 May–16 June 2005 and 14–29 September 2007 and outside the European Columbus module of the ISS in 2008 (Dachev et al., 2009). The relativistic electrons observed on ISS in 2008 were connected with the geomagnetic field disturbances in the period from 27 February to 7 May 2008.

Here we present the full range of data obtained by two independent Liulin type instruments in the period between February 2008 and August 2010. The main idea of the analysis of more than 750 daily fluences on ISS in this period by the R3DE/R instruments, which were part of ESA EXPOSE-E/R facilities (Horneck et al., 1998; Rabbow et al., 2009, in press) is to underline that the REP events are common on ISS. Although the obtained doses do not pose extreme risks for the astronauts being on EVA they have to be considered as permanently observed source, which requires additional comprehensive investigations.

2. Material and methods

Three different Liulin type instruments (Dachev et al., 2011a) were used in this study:

(a) The Liulin-E094 instrument contains four Mobile Dosimetry Units (MDU) (Dachev et al., 2002a, 2006). It was a part of the experiment Dosimetric Mapping-E094 (Reitz et al., 2005) placed in the US Laboratory module of the ISS as a part of the Human Research Facility in May–August, 2001. The main purpose of this experiment was to understand the dose rate distribution inside the ISS; the obtained data were used for statistical validation of the high-charge and energy (HZE) transport computer (HZETRN) model (Wilson et al., 2007; Nealy et al., 2007; Slaba et al., 2011).
(b) The R3DE instrument, which was part of the EXPOSE-E facility on the EuTEF platform outside the Columbus module of ISS in the period March 2008-September 2009 (Horneck et al., 1998; Dachev, 2009; Dachev et al., in press).
(c) The R3DR instrument, which was part of the EXPOSE-R facility outside the Russian Zvezda module of ISS in the period March 2009–August 2010 (Dachev et al., 2012b).

The experiments with R3DE/R spectrometers were performed after successful participation in the ESA announcements of opportunities, led by the German colleagues Dr. Gerda Horneck and Prof. Donat-P. Häder (Horneck et al., 1998). The R3DE/R spectrometers were jointly developed with the colleagues from the University of Erlangen, Germany (Streb et al., 2002; Häder et al., 2009).

Liulin-E094 and R3DE/R instruments are low mass ($\sim$100 g), small-dimensioned ($76 \times 76 \times 34$ mm) automatic devices which measure solar radiation in 4 channels and ionizing radiation in 256 channels. They are Liulin type energy deposition spectrometers (Dachev et al., 2011a). They are all mounted in small size aluminum boxes and the ionizing radiation is monitored using a semiconductor PIN diode detector (2 cm^2 in area, 0.3 mm thick).

The main measurement unit in the spectrometers is the amplitude of the pulse after the preamplifier generated by particles or quanta hitting the detector (Dachev et al., 2002a). The amplitude of the pulse is proportional by a factor of 240 mV MeV^{-1} to the energy loss in the detector and to the dose, respectively. By 12 bit ADC, using only the oldest 8 bit, these amplitudes are digitized and organized in a 256-channel spectrum. The dose D [Gy] by definition is 1 J deposited in 1 kg of matter. We calculate the absorbed dose by dividing the integrated energy deposition in the spectrum in Joules to the mass of the detector in kilograms.

$$D = K \sum_{i=1}^{255} i k_i A_i MD^{-1} \quad (1)$$

where MD is the mass of the detector in kg, k_i is the number of pulses in channel "i", A_i is the amplitude in volts of pulses in channel "i", $K.i.k_i.A_i$ is the deposited energy (energy loss) in Joules in channel "i". K is a coefficient. All 255 deposited dose values, depending on the deposited energy for one exposure time, form the deposited energy spectrum. The energy channel number 256 accumulates all pulses with amplitudes higher than the maximal level of the spectrometer of 20.83 MeV. The methods for characterization of the type of incoming space radiation are described by Dachev (2009).

The construction of the Liulin-E094 and R3DE/R boxes consists of 1.0 mm thick aluminum shielding before the detector. The total shielding of the detector is formed by additional internal constructive shielding of 0.1 mm copper and 0.2 mm plastic material. The total external and internal shielding before the detector of the devices is less than 0.41 g cm^{-2}. The calculated stopping energy of normally incident particles to the detector is 0.78 MeV for electrons and 15.8 MeV for protons (Berger et al., 2012). This means that only protons and electrons with energies higher than the above mentioned values can reach the detector. The Liulin-E094 MDUs was situated at different places inside the American laboratory module and Node-1 of the ISS (Nealy et al., 2007), while the R3DE/R instruments were outside the Columbus and Russian Zvezda modules, respectively. The amplitudes of the fluxes and doses with the Liulin-E094 MDUs are smaller than the R3DE/R amplitudes because of the additional shielding by the walls of the ISS, but all radiation sources are clearly seen in both the locations.

3. Overview of the solar and particle data for the periods of Liulin observations on the ISS

Fig. 1 presents the variations of the daily particle fluences and daily F10.7 solar radio flux obtained from DPD.txt and DSD.txt files, prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center http://www.swpc.noaa.gov/ftpmenu/index.html. The analysis of the proton daily fluence with more than 100 MeV in Fig. 1 shows a relatively good correlation with the solar activity. Because

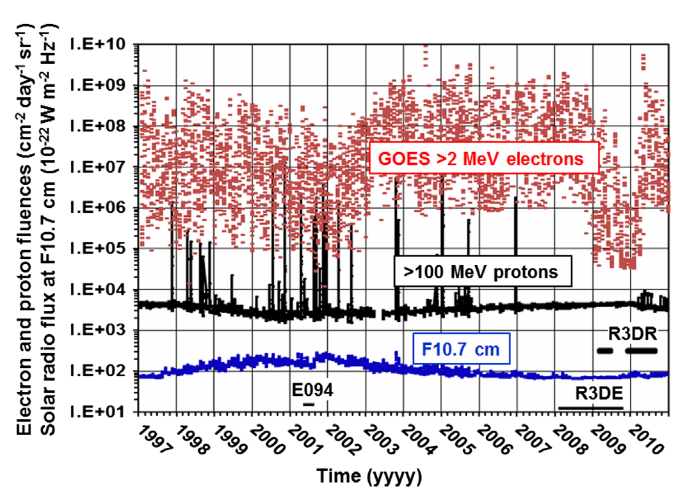

Fig. 1. Variations of the measured data by GOES satellites for the (>2 MeV electrons fluence), >100 MeV protons fluence and solar radio flux (F10.7 cm) for the period 1997–2010.