Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 43 (2009) 582–588
ADVANCES IN SPACE RESEARCH
(a COSPAR publication)
www.elsevier.com/locate/asr

The unusual cosmic ray variations in July 2005 resulted from western and behind the limb solar activity

A. Papaioannou [a], A. Belov [b], H. Mavromichalaki [a,*], E. Eroshenko [b], V. Oleneva [b]

[a] Nuclear and Particle Physics Section, Physics Department, Athens University, Panlpolis15771 Athens, Greece
[b] Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation by Pushkov, Russian Academy of Sciences, IZMIRAN, Russia

Received 11 January 2008; received in revised form 15 July 2008; accepted 5 September 2008

Abstract

One of the most interesting and unusual periods of the recent solar activity was July 2005. Despite the fact that it was a late declining phase of the 23rd solar cycle, generally a time of solar quiescence, that period was marked by extreme activity. The main events occurred at the invisible side of the Sun and did not reveal significant consequences in the Earth or near the Earth. However, cosmic ray variations testify to the high power of these events. A rather unusual Forbush effect was observed starting from July 16, 2005. It was characterized by very large cosmic ray anisotropy, the magnitude and direction of which are in accordance with a western powerful source. Usually in such a case when the main interplanetary disturbance is far in the west, the Forbush effect is absent or it is very small and short lasting. In July 2005 a rare exclusion was observed which may testify to the giant decrease of 10 GV cosmic ray density (quite possible >=30%, indicating an unusually high cosmic ray gradient) to the west from the Sun–Earth line. In this work, a description of the July 2005 situation as well as the results of the convection- diffusion treatment with space cosmic ray gradients is presented. Some general remarks concerning extreme western solar events and their impact on cosmic rays are also discussed.

Keywords: Convection-diffusion model; Forbush effects; Coronal mass ejections; Solar flares

1. Introduction

At the declining phase of the 23rd solar cycle, a number of extreme events characterized by rather peculiar properties have taken place, such as those of October–November 2003, January 2005, August–September 2005 and the recent ones of December 2006 (Eroshenko et al., 2004; Plainaki et al., 2007; Belov et al., 2005). Dynamic phenomena related to solar flares (SF) and coronal mass ejections (CMEs) dominated the heliosphere in a most profound way and resulted in large variations in cosmic ray (CR) intensity up to energies of at least tens GeV. A number of attempts have been made in order to explore the relation between solar extreme phenomena and their impact on cosmic rays (Harrison, 1995; Hundhausen, 1999; Cane, 2000; Kudela and Brenkus, 2004; Belov et al., 2005; Mavromichalaki et al., 2007). It is commonly pointed out that solar extreme events influence cosmic rays in a dynamic way and different correlations can possibly be established between the cosmic ray variations and various characteristics of solar wind and interplanetary space (Belov et al., 2001).

On July 16, 2005 a deep decrease of the cosmic ray density (of about 8% for 10 GV particles) with a complicated shape and an intermediate large increase was recorded by neutron monitors during a non significant disturbance of the solar wind (Papaioannou et al., 2005). Right after the main phase of this Forbush effect (FE), a sharp enhancement of cosmic ray intensity starting from July 17, was registered only to be followed by a second decrease within less than 12 h. The enhancement on July 17 was related neither

* Corresponding author.
E-mail addresses: atpapaio@phys.uoa.gr (A. Papaioannou), abelov@izmiran.ru (A. Belov), emavromi@phys.uoa.gr (H. Mavromichalaki), erosh@izmiran.ru (E. Eroshenko).

0273-1177/$34.00 © 2008 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2008.09.003

to a ground level enhancement (GLE) nor to a geomagnetic effect. The analysis of this peculiar event shows that it could be connected with an internal structure of the disturbance similar to the event of March 1991 described by Hofer and Flueckiger (2000), but in our case it is not confirmed by solar wind data. Usually short-term cosmic ray variations are well correlated with solar wind changes near the Earth. During the events of July 2005 unusual CR variations were recorded and the most unusual fact was that these variations are not related to changes in the solar wind.

In this work an extended analysis of these cosmic ray variations during the extreme events of July 2005 based mainly on the terms of anisotropy and space gradients of cosmic rays, is performed. The possibility to provide explanations on this kind of cosmic ray events is also being discussed.

2. Data selection

In this analysis the used data taken from the following web sites: http://sec.ts.astro.it/sec_ui.php on the solar and space conditions; http://www.ngdc.noaa.gov for solar flare data from and http://lasco-www.nrl.navy.mil for CME data.

In order to obtain variations in the flux and the first harmonic of anisotropy for 10 GV cosmic rays, data from as many stations as possible from the entire global network of neutron monitors (40–45 stations operating at present), with their own properties as coupling coefficients and yield functions, have been used. The calculation of the anisotropy components has been performed using the global survey method (GSM) (e.g. Belov et al., 2005).

3. Solar and geomagnetic conditions

Solar activity: In the beginning of July, although several sunspot groups appeared on the face of the Sun, the main active region was the AR 786. It was the return of AR 775, a powerful active region (AR) from the previous rotation that caused long-duration solar flares. Solar activity was dominated by AR 786 in the northern hemisphere, until it rotated over the western limb on July 14. In this period, this AR had produced 12 M-class and one X-class flares.

On July 12 there was a long-duration M1.5 flare starting at 12:47 UT associated with a bright partial halo CME directed to the NW. On the next day, July 13, two bright CMEs occurred in association with two long-duration flares. The second CME was first seen in LASCO C2 images at 14:30 UT and had an estimated speed of 1420 km/s. The event triggered a gradual increase of the proton and electron fluxes, which reached to the value of 134 pfu on July 14 (http://www.ngdc.noaa.gov). On July 14two flares occurred: an M9.1 flare peaking at 07:25 UT and finally an X1.2 flare with long-duration starting at 10:16 UT. The high energy proton fluxes rose above the NOAA event threshold and a full halo CME was first visible in LASCO C2 at 10:54 UT and arrived at the Earth on July 17, as it is shown in Fig. 1.

Geomagnetic activity. A minor geomagnetic storm occurred on July 13, probably due to the arrival of the partial halo CME from July 10 (C1.6 flare in AR 783). The solar wind speed was >600 km/s (shock recorded at 04:24UT) and the Bz component of the interplanetary magnetic field (IMF) sharply turned southward and from 8 to 11 UT it was remained at a level <−5 nT. The geomagnetic activity then returned to the quiet – unsettled level, except for temporary active conditions recorded at several ground-based magnetometers on July 15 and 16. This weak geomagnetic activity may be a consequence of the partial halo CME observed on July 13 (∼ M5.0 flare and the CMEs from early July 14, which erupted before the full halo CME related to the X1.2 flare). None of the blast waves were Earth directed, nevertheless, Earth's magnetic field was impacted by a weak shock that arrived at the Earth on July 17 at 1:23 UT. This caused mostly active conditions during July 17 (Dst = −74, Kp = 5). Around 19:00 UT on July 17, the interplanetary magnetic field

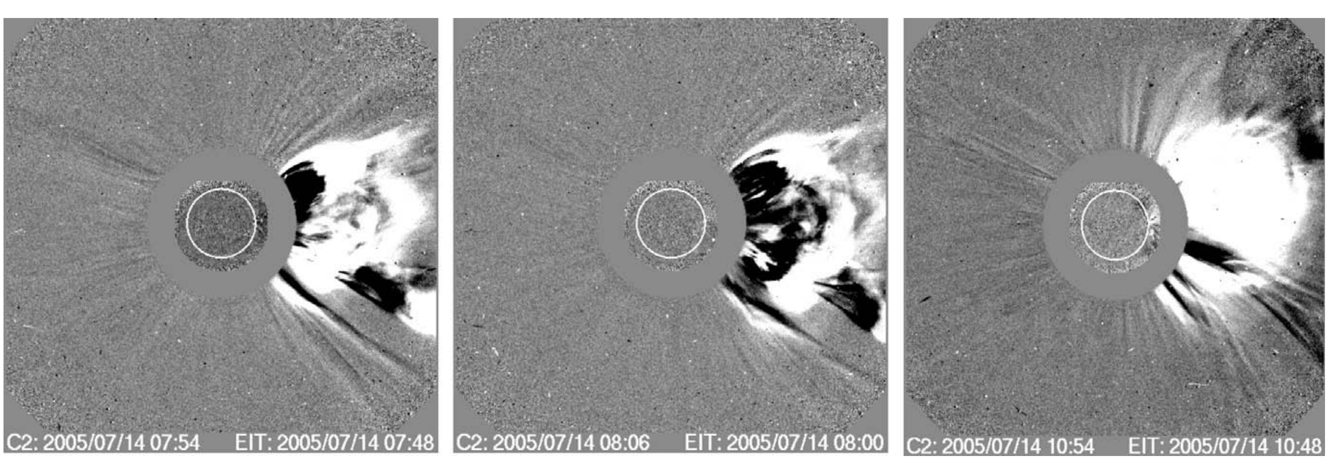

Fig. 1. The most significant CMEs on July 14, 2005 from AR786 as seen by LASCO C2.