16th European Space Weather Week, Liege, (18-22 November,2019)

Athens Neutron Monitor Station (A.Ne.Mo.S)

neutron monitor database

Cosmic ray spectral index by two coupling functions using data from the neutron monitor network

L. Xaplanteris, M. Livada, H. Mavromichalaki

Nuclear and Particle Physics Department, Faculty of Physics, National and Kapodistrian University of Athens, Zografos, 15784 Athens, Greece

(email:ksaplant@phys.uoa.gr; mairiliv@phys.uoa.gr; emavromi@phys.uoa.gr)

S3-P20

Abstract The derivation of the coupling function between the primary and the secondary cosmic ray particles through a completely theoretical way, using Quantum Field Theory (QFT) is attempted for first time. More specifically, cosmic rays are an interesting and promising field of physics with a wide variety of phenomena and applications that require technical as well as theoretical understanding. In this work, after a short study of the solar and geomagnetic background of the Forbush decreases of March 2012, the cosmic ray spectral index values based on daily cosmic ray data of the neutron monitor network were calculated. Applying to these data two different coupling functions of the secondary to the primary cosmic rays, the spectral index values during these Forbush decreases were calculated following the technique of Wawrzynczak and Alania (2010). The first coupling function is based on the Yield function of Mishev et al. (2013) and the second is a new one theoretically determined using Quantum Field Theory calculations. It was pointed out that the estimated values of the spectral index of these events follow in both cases the structure of the Forbush decrease. The study and the calculation of the cosmic ray spectral behavior during such events are important for Space Weather and Space Climate applications.

1.- Introduction

Fast decreases of galactic cosmic ray (GCR) intensity during one-two days followed by its gradual recovery in 5–7 days are called as Forbush decreases (FDs) of the cosmic ray intensity (Forbush, 1954). They are observed after large flares on the Sun and solar coronal mass ejecta (CME) (Cane, 2000). The Fds are of three basic types: (1) caused by a shock and ejecta, (2) caused by a shock only, and (3) caused by an ejecta only (Cane, 2000).

In this work we will focus on the Fd that took place on 7-21 March 2012. We will attempt to determine the spectral index values during this period using the technique of Warwrzynczak and Alania (2010) applying two different coupling functions for our computations. The first one is based on the yield function of Mishev et al. (2013) which has been used till now only for the spectral analysis of Ground Level Enhancement events (GLE's).It is the first time applied in the case of a FD event. The second used function is a newly computed coupling function determined theoretically using QFT calculations. QFT is by definition the correct framework for the study of high energy particle interactions in which the number and type of particles is not constant. It will be the first time a function determined solely by theoretical QFT mathematical tools (such as counter terms, Feynman integrals etc.) is applied in an actual cosmic ray variation event and the results are bound to be interesting and educational for future research.

2.- Data and Method

Daily values of the cosmic ray intensity *obtained from the High resolution neutron monitor database -NMDB (www.nmdb.eu)* for seven polar and middle latitude neutron monitor stations (Table 1) during the period 7-21 March 2012 have been used (Figure 1).

Table 1: Characteristics of Neutron Monitor stations

NMDB Stations	Rigidity cutoff (GV)	Altitude (m)
APATITY (APTY)	0.65	181
FORTSMITH (FSMT)	0.30	180
MCMURDO (MCMU)	0.30	48
ATHENS (ATHN)	8.53	260
ROME (ROME)	6.27	Sea level
BAKSAN (BKSN)	5.70	1700
JUNGFRAJOCH (JUNG)	4.49	3475

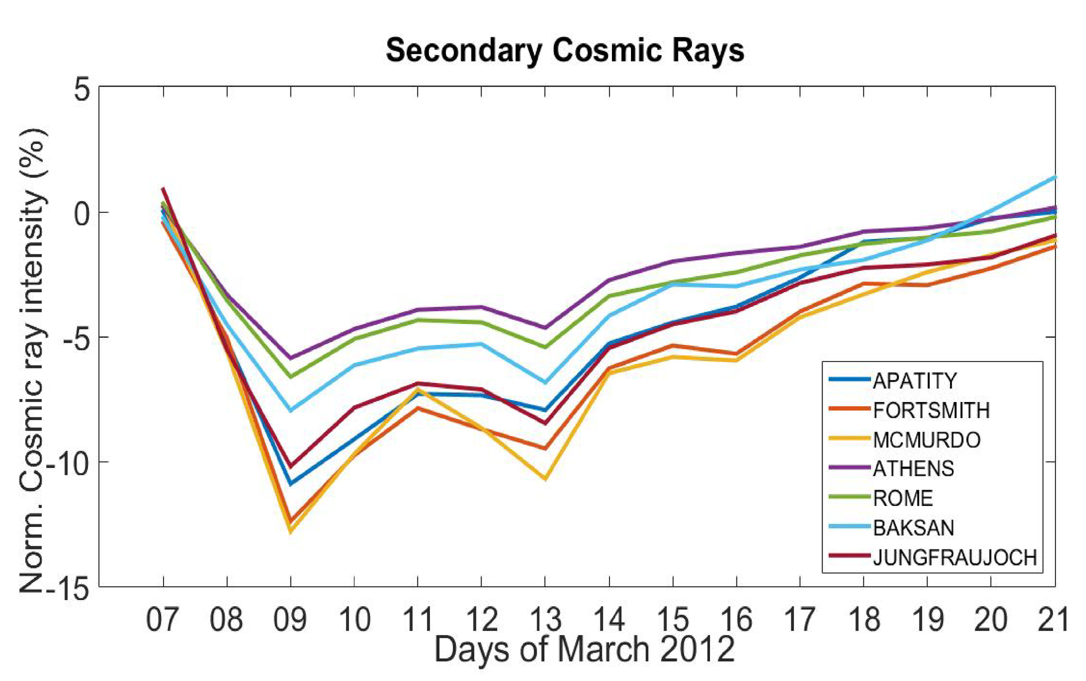

Figure 1: Time profiles of the normalized Cosmic Ray intensity for polar and middle latitude NM stations (<8.53 GV) during the FDs of March 2012.

According to the coupling coefficient method**,** secondary cosmic ray measurements can be linked to the primary incident cosmic ray particles via specific mathematical functions that take into account the acceptance vectors for each detector (neutron monitor), based on its local characteristics (*Dorman, 2004; Wawrzynczak and Alania, 2010*). Temporal intensity variations of GCRs during Forbush decreases can be represented as a power law in rigidity, according to Equation (1), where R_0=10GV and R_{max} is the rigidity beyond which the Forbush effect of the GCRs vanishes. A usual choice for the upper limit is R_{max}=200GV

$$\frac{\delta D(R)}{D(R)} = \begin{cases} A\left(\frac{R}{R_0}\right)^{-\gamma} & R \le R_{max} \\ 0 & R > R_{max} \end{cases} \qquad (1)$$

According to the coupling coefficient method, the average cosmic ray intensity variation that is being recorded by a specific detector 'i' on the k day may be represented by equation (2). Substituting eq. (1) into eq. (2) leads to equation (3) in which the amplitude of the Fd in free space is independent of the local characteristics of the detector.

$$J_i^k = \int_{R_{max}}^{R_i} \left(\frac{\delta D(R)}{D(R)}\right)_k W_i(R,h_i)dR, (2) \longrightarrow A_i^k = J_i^k \Big/ \int_{R_i}^{R_{max}} \left(\frac{R}{R_0}\right)^{-\gamma_k} W_i(R,h_i)dR, (3)$$

In our analysis we have calculated the integral ourselves providing the values of γ ranging from 0.5 to 2 with a step of 0.01. According to our requirement an acceptable γ_0 must correspond to the values of the A_i^k being almost the same for all neutron monitors. In equation (3) we have used two different coupling functions:

===

A) $$Y_i(R,h) = \sum_i \iint A_i(E,\theta)\cdot F_{ij}(R,h,E,\theta)dEd\Omega \qquad (4)$$

where Ai(E,θ) is the geometrical detector area times the registration efficiency,
Fij is the differential flux of secondary particles of type j for the primary particle of type i,
E is the secondary particle's energy, θ is the secondary particles' angle of incidence.For this work the value of the yield function that was used for protons with R = 100 GV was Yp=0.992 in units of m^2sr (Mishev et al. 2013).

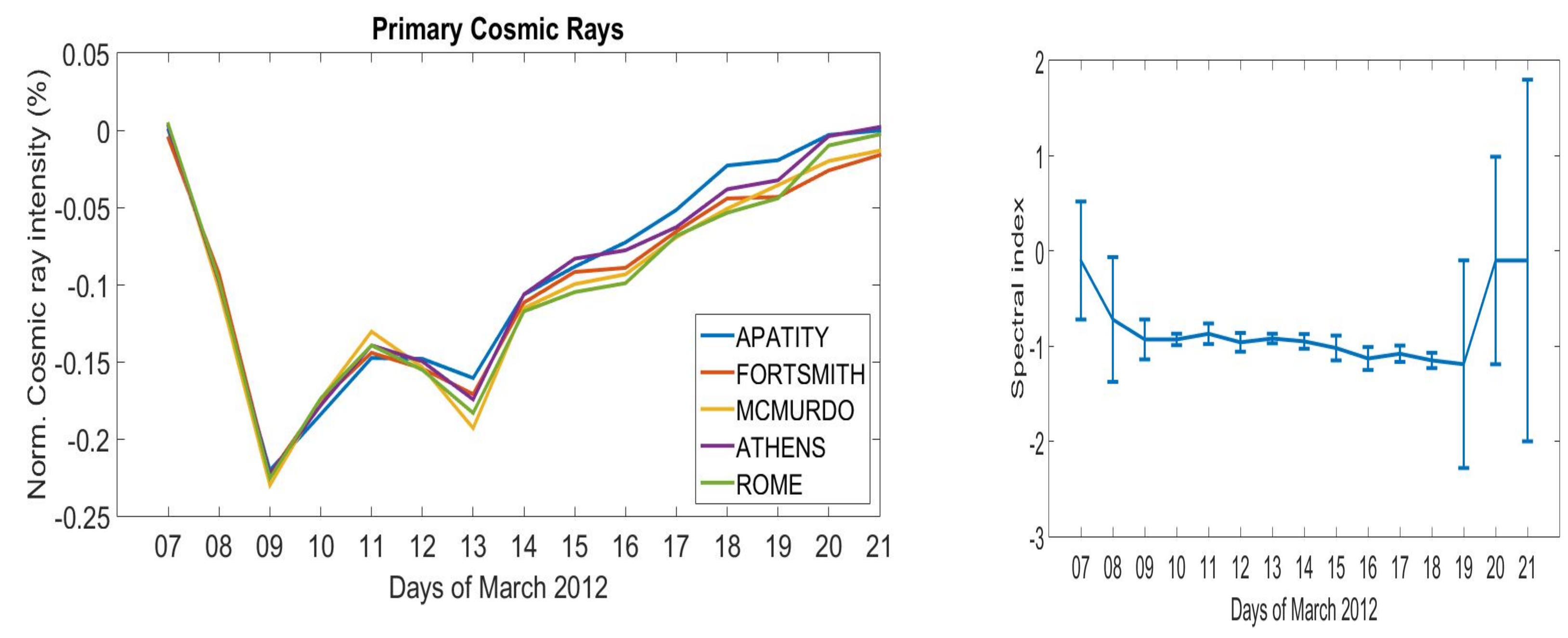

Figure 2: Time profiles of the primary cosmic ray variations (left panel) and the spectral index (right panel) as computed by the yield function of Mishev et al. (2013).

It is noted that this yield function has also been considered for the analysis of the Forbush decreases of 21 December 2014 and 10 September 2017 as well in another work (Livada et al., 2018) and as we can see it produces accurate values of the spectral index.

B) $$W(R) = -4.7\cdot 10^8 \frac{1}{R}\log\left(\frac{3}{R}\right)\left[\frac{0.0003}{1-11.9\cdot 10^{-6}\cdot\log\left(\frac{R}{3}\right)}\right]^2 \qquad (5)$$

where R is the rigidity of the primary particle (proton).
This newly computed function has been determined from theoretical QFT calculations based on renormalization phenomena, in which some physical quantities that were perceived as constants are actually functions of the energy e.g. the screening effect of the nucleus' charge (Peskin and Schroeder, 1997). So the use of this newly computed function may describe better the cosmic ray variations especially in the high energy region (E > 100GeV) where normalization phenomena are more evident.

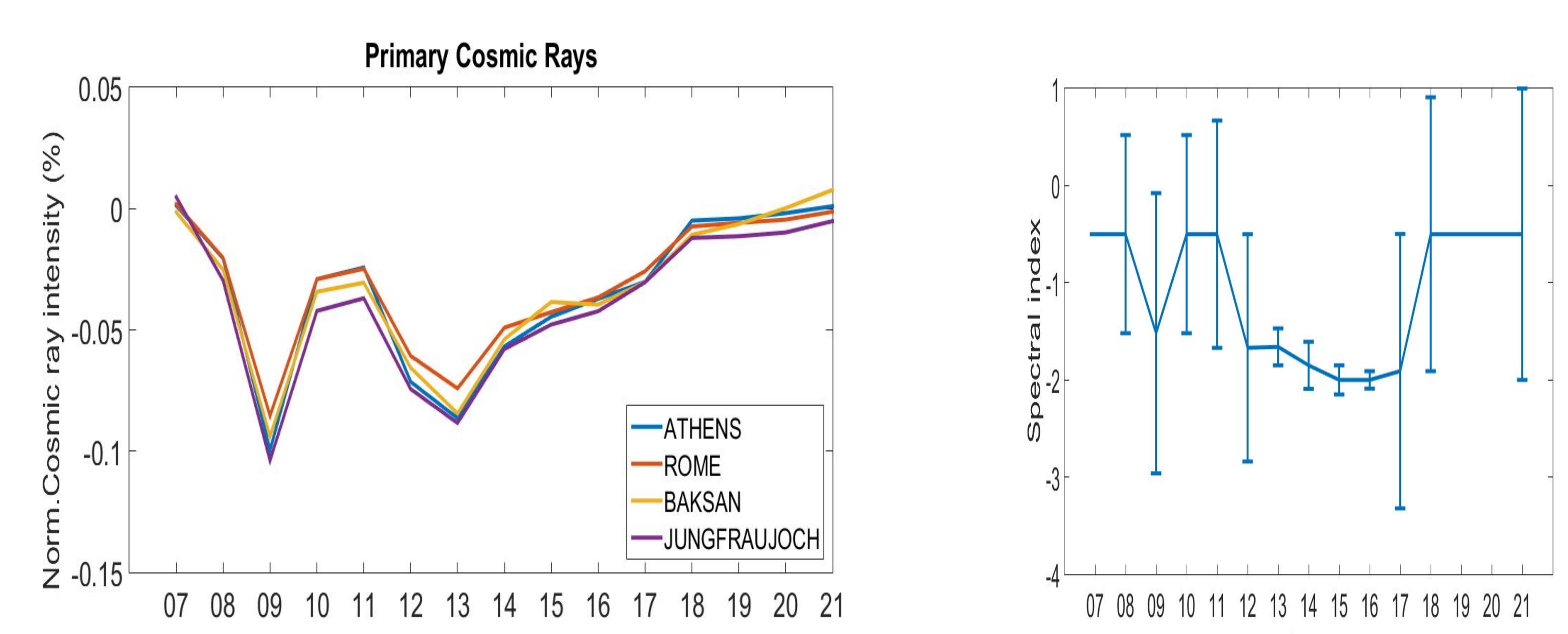

Figure 3: Time profiles of the primary cosmic ray variations (left panel) and the spectral index as computed by the new QFT coupling function (right panel).

In this work the newly computed function was used only for middle latitude stations producing satisfactory values for the primary spectral index following well the behavior of the Forbush decrease. It is interesting to note that the CR variation observed in the days 10-11 March 2012 is also obvious in the spectral index values.

Conclusions

➢Cosmic ray spectral analysis was carried out on the FDs of March 2012 following the technique of Wawrzynczak and Alania 2010, based on the coupling function method.

➢ In order to calculate the spectral index in the heliosphere the yield function proposed for GLE events by Mishev et al (2013) as well as a new coupling function based on the OFT theory were applied to NM data of the NMDB database (Fig. 2).

➢ The first function is used for first time to the case of FD, giving satisfactory values of the spectral index for sea-level polar and mid-latitude stations. The second function applying to middle-latitude stations (3-8 GV) seems to give suitable results (Fig. 3). This study will be extended in the immediate future to both polar and middle latitude NM stations.

Acknowledgements : Special thanks to the colleagues of the NM stations (www.nmdb.eu) for kindly providing the cosmic ray data used in this study in the frame of the High resolution Neutron Monitor database NMDB, funded under the European Union's FP7 Program (contract no. 213007).

References:
Cane, H. V: 2000, Space Sci. Rev., 93, 55.
Dorman, L.I.: 2004, Kluwer Academic.
Forbush, S.: 1954, J.Geophys.Res., 59, 525.
Livada, M. ; Mavromichalaki ; H., Plainaki , C.: 2018, Astrophys. Space Sci., 363, 8.
Mishev et al.: 2013, J.Geophys.Res., 118, 2783.
Peskin and Schroeder : 1997, Westview Press .
Wawrzynczak, A. and Alania, M.:2010, Adv. Space Res., 45, 622.

Contact: ksaplant@phys.uoa.gr