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PRESENT STATUS OF THE BELGRADE COSMIC-RAY EXPERIMENT

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Abstract. In the present paper a novel cosmic-ray experiment in the Institute of Physics, Belgrade is described. A couple of plastic scintillator detectors are in continuous operation since December 2001, measuring cosmic muon flux at ground level and at shallow depth underground (25 m of water equivalent). Quasi-periodic variations of muon flux in the period 2002-2004 are studied, and strong correlation with solar activity is found. Sporadically, sudden decreases in CR intensity are detected, mostly as consequences of coronal mass ejections propagating toward the Earth. Small anisotropy in cosmic rays is also detected.

1. Introduction

The cosmic ray group of the Institute of Physics, Belgrade operates two muon detectors: one ground-based and another located in the Belgrade underground laboratory (25 mwe). Position of the laboratory is: geographic latitude 44°51'N; geographic longitude 20°23'E, altitude 78m above sea level. Geomagnetic latitude of the laboratory is 39°32′N and vertical geomagnetic rigidity cut-off is 5.3GV.

Muon observations provide information about primary cosmic radiation and its hadronic interactions in the atmosphere, its modulation in the heliosphere, and about atmospheric and geomagnetic effects of cosmic rays.

2. Experimental setup

Detector system consist from two identical plastic scintillator detectors (50cm × 23cm × 5cm). Each detector lies horizontally on its largest side and single 5 cm photomultiplier watches its long side (50cm × 5cm) via a correspondingly shaped light guide. When a muon (or other charged particle) passes through the detector, the scintillator is excited and it emits a fluorescent light. Signal reaches photomultiplier where it is converted into a week electric signal, which is further pre-amplified and subjected to pulse treatment in the amplifier.

The analog output signal from detector is linked to laboratory made A/D converter and digital signal is then linked to a computer PCI card. The data is automatically recorded every $5min$, with $270sec$ dedicated to measurements, and $30sec$ being allowed for recording on local hard disc, some quick interventions on a system and data transmission to second local network computer. The setup enables off-line data analysis without interrupting measurements.

The recorded spectrum is mainly the spectrum of muon energy deposit ΔE. The spectrum stretches to about 200 MeV and have a well defined single particle peak corresponding to an energy loss of some 11 MeV. Monte Carlo simulation of this ΔE spectrum, based on GEANT4 package, agrees with the experimental spectrum within statistical error. With the given geometry, detector response to cosmic and ambient radiation are well separated (as confirmed by MC simulation) and unambiguous selection criteria of muon events can be applied.

3. Quasi-periodic variations of muon flux

The data from Belgrade muon detectors for the period 2002-2004 (descending phase of solar cycle 23) are spectrally analyzed. Lomb-Scargle periodogram (Lomb 1976, Scargle 1982) analysis method has been used in spectral analysis of cosmic muon time series. This particular method is preferred since it can successfully treat unevenly sampled and gapped time series. Another advantage of Lomb-Scargle method is well known statistical interpretation of periodogram.

Beside statistical, periodogram analysis faces also spectral problems (spectral leakage and aliasing). Thus, statistical criterion alone, based on false alarm probability is not sufficient for discrimination between true and false periodicities in the time series. Yet another problem might plague the result - the pattern in missing data could cause the presence of false peaks and in the case of noisy data could shift position of true peaks.

Above mentioned problems are addressed by CLEAN deconvolution algorithm (Roberts et al. 1987). The true, undistorted spectrum is obtained by deconvolution of "dirty" spectrum from spectral window function. The spectrum reffered to as "dirty" is computed in our case as Schuster periodogram and it turns out to be almost identical to Lomb-Scargle periodogram. Deconvolution procedure is started from highest amplitude component in "dirty" spectrum. A fraction of its amplitude (named gain: $0 < g < 1$) is convoluted and removed from "dirty" spectrum, resulting also in removal of its sidelobs in residual spectrum. In our calculations value $g = 0.1$ is used, but results are not sensitive to change of this value. Residual spectrum is processed in the same manner until the stopping condition is met. We have chosen stopping condition that residual spectrum is not significantly different from pure noise.

The statistically significant peaks identified in the spectra are listed in Table 1 and Table 2. The ΔT is estimated error.

T	1	8.7	13.6	20.5	25.4	26.5	34.5	37	77	90	162	194	236	350
ΔT	-	0.1	0.1	0.2	0.3	0.3	0.5	0.5	2.5	4	10	20	23	45

Table 1: Periodicities present in the underground data set. Periods are given in days.

High-altitude neutron monitor (NM) data (as reported by Cabalero & Valdés-Galicia 2003), exhibit common features with Belgrade muon data. In the analyzed

T	5.3	8.4	13.6	20.5	27	34.6	37	57	90	194	237	350
ΔT	-	0.1	0.1	0.2	0.5	0.5	0.6	2.5	4	15	18	43

Table 2: Periodicities present in the ground data set. Periods are given in days.

period (1990-1999), 27 day periodicity is present in Climax, Lomnický Štit, Tsumeb and Huancayo-Haleakala data. The 35 day signal (similar to ours 34.5 day) is detected only in Climax data. On the other hand, 37 day signal is found in all NM data, except Huancayo. Lomnický Štit, Mexico and Tsumeb NM have 58 day signal, corresponding to 57 day signal in our GD data. The 78 day wave is present in Mexico and Huancayo NM (77 day in our UD). In all NM 89 day periodicity is also found in all NM data (90 day in our muon data). Interestingly, this periodicity appears in Climax data in descending phase of solar cycle 22 (1992-1994), but not in the solar maximum period. The 115 day variation, otherwise common in NM data, is missing from Climax in the same period (1992-1994). This signal is not detected in Belgrade muon data.

Some rare periodicities also coincide in muon and NM data: 25 day in Alma Ata and Mexico (1992-1994) and 25.4 day in Belgrade UD; 20 day in Mexico 1992-1994, Lomnický Štit 1990-1999 and 20.5 day Belgrade UD+GD;

Most of the signals identified in Belgrade muon data coincide with periodicities of some parameters of solar activity: solar coronal mass ejections and X-ray solar flares (Lou et al. 2003); sunspot blocking function, 10.7cm radio flux and sunspot number (Lean & Brueckner 1989) etc.

4. Transient variations

The most important types of transient variations of cosmic-ray intensity observed at Earth are ground level enhancement and Forbush decrease. Forbush decreases are sudden rapid decrease in cosmic ray intensity (1-2 days) followed by slow recovery (4-6 days) to the pre-decrease level. They are often associated with solar flares accompanied by coronal mass ejection (CME). The strongest Forbush effect observed by Belgrade cosmic-ray station took place in October 2003. A substantial decrease in the counting rate of both detectors is a consequence of the X17.2 flare on October 28^{th}, located almost at the center of the visible solar disc (16^oS, 8^oE). The conditions were favorable for charged particles emitted by subsequent CME to propagate toward the Earth. The relative counting rate of both detectors is plotted on figure bellow.

Directional anisotropy of CR (seen as daily variation) in the recovery phase is evident on surface detector data plot.

5. Diurnal anisotropy

Daily variation in cosmic-ray intensity is expected from the so called Compton-Getting effect due to the Earth's orbital motion around the Sun. Superposed to this variation is anisotropy caused by solar modulation of galactic CR in the heliosphere. After three years of data collecting, sufficient number of muons is detected for identification of both diurnal and semi-diurnal variation (Fig. 2).

Amplitude of diurnal variation in the ground detector data is $1.96(7) \times 10^{-3}$ and semi-diurnal $7.4(7) \times 10^{-4}$. At the same time amplitude of diurnal variation in the

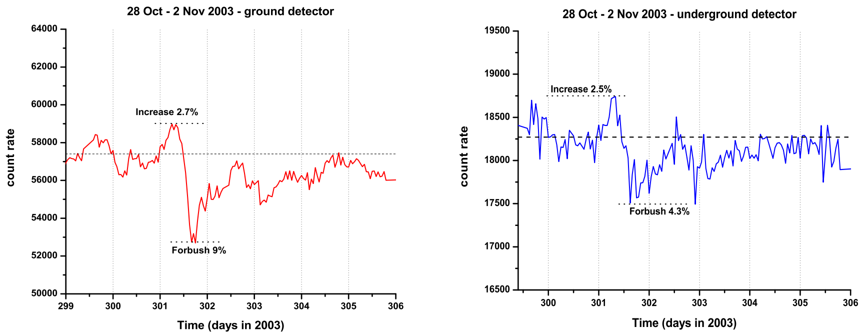

Figure 1: Forbush decrease on October 29 2003 recorded as sudden drop of counting rates of GD (left) and UD (right).

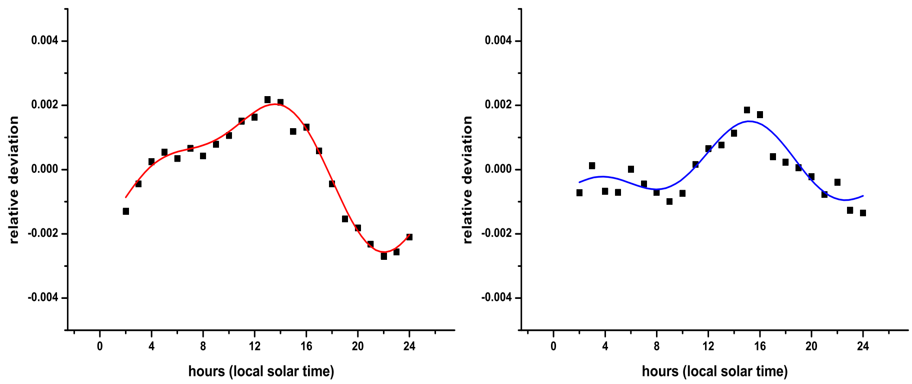

Figure 2: Diurnal and semi-diurnal anisotropy of surface (left) and underground (right) muons.

underground detector data is $9(1) \times 10^{-4}$ and semi-diurnal $6(1) \times 10^{-4}$. The two also differ in phase.

Latest results are available online at: http:\\ www.phy.bg.ac.yu\~cosmic.

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