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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 the solar activity is found. Sporadically, sudden decreases in CR intensity are detected, mostly as consequences of coronal mass ejections propagating toward the Earth. A 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). The position of the laboratory is: geographic latitude $44^o51'$N; geographic longitude $20^o23'$E, altitude 78m above sea level. The geomagnetic latitude of the laboratory is $39^o32'$N and the vertical geomagnetic rigidity cut-off is 5.3GV.

Muon observations provide information about the 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

The detector system consists of two identical plastic scintillator detectors (50cm × 23cm × 5cm). Each detector lies horizontally on its largest side and a 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. The signal reaches the photomultiplier where it is converted into a weak electric signal, which is further pre-amplified and subjected to pulse treatment in the amplifier.

The analog output signal from the detector is linked to a laboratory made A/D converter and the digital signal is then linked to a PCI card computer. The data are automatically recorded every 5 min, with 270 sec dedicated to measurements, and 30 sec being allowed for recording on a local hard disc, some quick interventions on a system and data transmission to the 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 has a well defined single particle peak corresponding to an energy loss of some 11 MeV. The Monte Carlo simulation of this ΔE spectrum, based on the GEANT4 package, agrees with the experimental spectrum within statistical error. With the given geometry, the detector responses to the 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 the Belgrade muon detectors for the period 2002-2004 (descending phase of solar cycle 23) are spectrally analyzed. The Lomb-Scargle periodogram (Lomb, 1976; Scargle, 1982) analysis method has been used in the 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 the well known statistical interpretation of the periodogram.

Besides, the statistical, periodogram analysis faces also spectral problems (spectral leakage and aliasing). Thus, a statistical criterion alone, based on a 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 the position of the true peaks.

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

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

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

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

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

High-altitude neutron monitor (NM) data (as reported by Cabalero and Valdés-Galicia 2003), exhibit common features with the Belgrade muon data. In the analyzed period (1990-1999), a 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 a 58 day signal, corresponding to the 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 the Climax data in the descending phase of the 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 the 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 the Belgrade muon data coincide with the 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 and Brueckner, 1989) etc.

4. TRANSIENT VARIATIONS

The most important types of transient variations of cosmic-ray intensity observed on Earth are the ground level enhancement and Forbush decrease. The Forbush decreases are sudden rapid decreases in the cosmic ray intensity (1-2 days) followed by a 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 at the 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$^{\text{th}}$, located almost at the center of the visible solar disc (16°S, 8°E). 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 in the figure bellow.

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

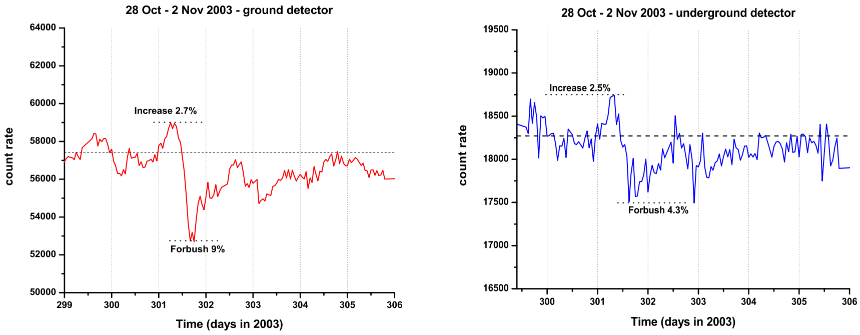

Figure 1: Forbush decrease on October 29 2003 recorded as sudden drop of counting rates of GD (left) and UD (right).

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 the 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 variations (Fig. 2).

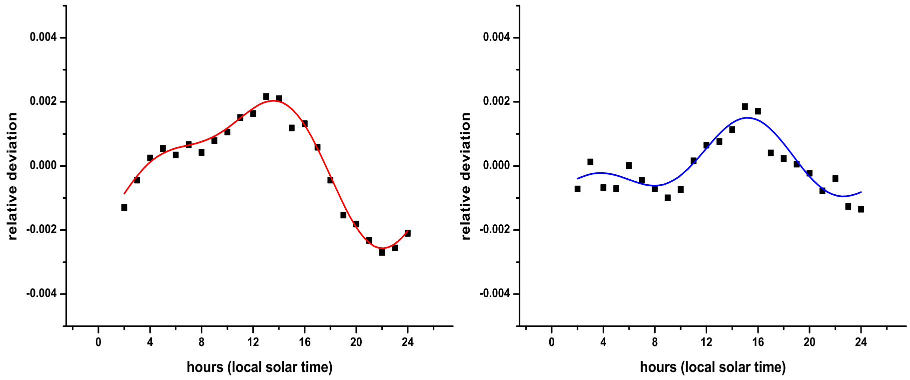

Figure 2: Diurnal and semi-diurnal anisotropy of surface (left) and underground (right) muons.

The 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 the amplitude of diurnal variation in the 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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